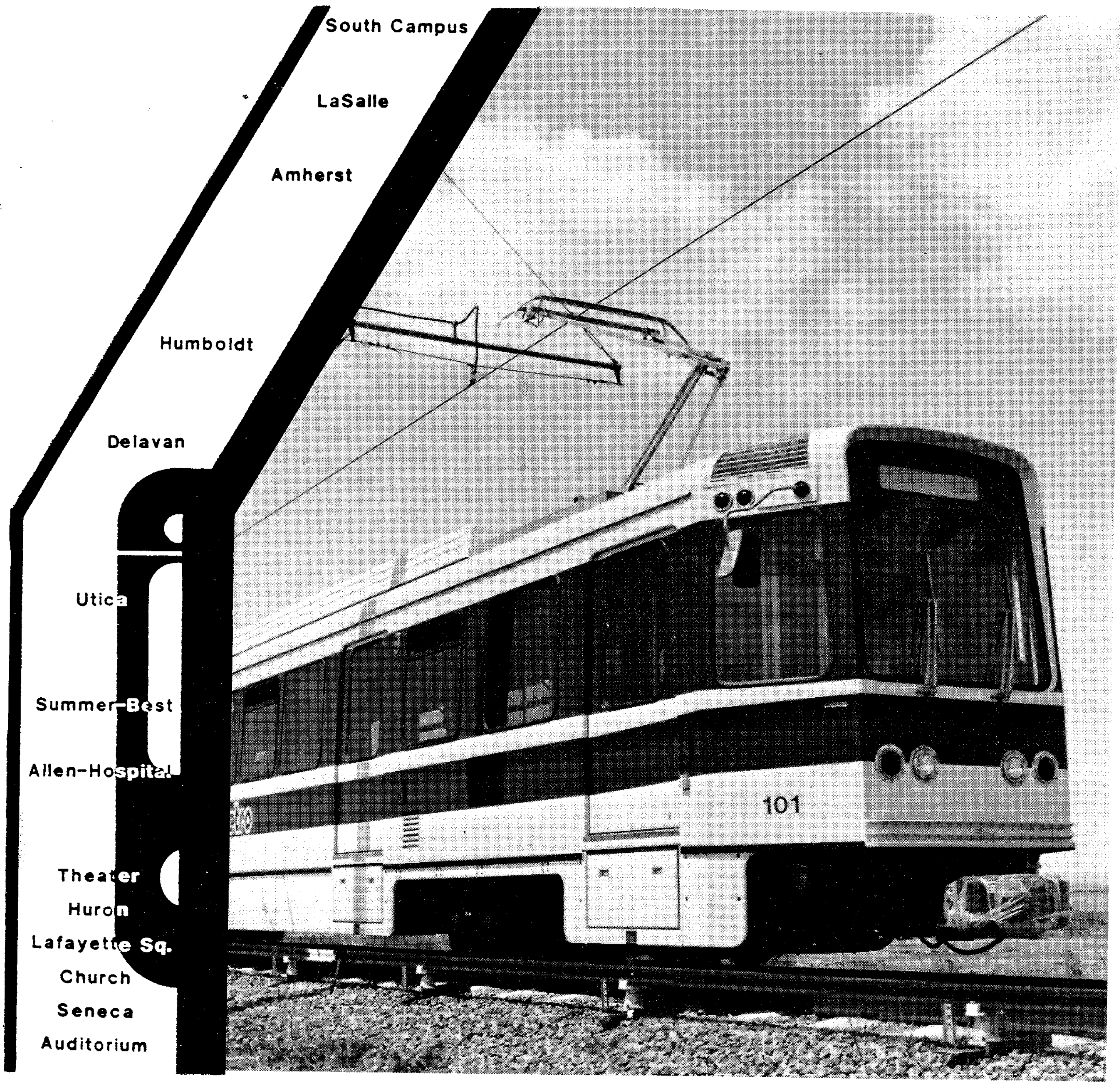
U.S. Department
of Transportation
**Urban Mass
Transportation
Administration**

NIAGARA FRONTIER TRANSPORTATION AUTHORITY VEHICLE TESTS



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16. Abstract

A prototype single car, intended for use on revenue (Niagara Frontier Transportation Authority - NFTA) line in Buffalo, New York, was tested over a twelve-week period by the Association of American Railroads (AAR). Testing at the Transporation Test Center (TTC) in Pueblo, Colorado, was sponsored by the Office of Systems Engineering of the Urban Mass Transportation Administration (UMTA).

The car was manufactured by the Tokyu Car Corporation of Japan, and utilized a Westinghouse propulsion system and Knorr friction brakes. Through the combined efforts of personnel from the Tokyu Car Corporation, the AAR/TTC, and additional subcontractors and consultants, the car was fitted with comprehensive instrumentation and prepared for testing in areas of acceleration/deceleration, power consumption, noise, ride quality, and overall performance under simulated revenue service profiles (duty cycle).

Data reduction was performed by the staff of the TTC resulting in the following conclusions:

Generally, the car satisfied specification criteria outlined in the test requirements - with some minor exceptions. Reliability was excellent for all systems. One instance of propulsion motor flash-over occurred during a duty cycle run, but could not be duplicated subsequently. Friction braking, though criteria were met, evidenced low thermal capacity. Generally, system adjustments and alignments allowed for obtaining optimum performance. However, some settings were observed to be quite critical, thus indicating a need to carefully follow setup and adjustment procedures in preparation for revenue service.

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NIAGARA FRONTIER TRANSPORTATION AUTHORITY VEHICLE TESTS

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

ACRONYMS

AAR	Association of American Railroads
ATP	Automatic Train Protection System
CTA	Chicago Transit Authority
DOT	Department of Transportation
FRA	Federal Railroad Administration
GRS	General Railway Signal Company
LRRT	Light Rail Rapid Transit
NFTA	Niagara Frontier Transportation Authority
PDA	Pueblo Depot Activity
SEPTA	South Eastern Pennsylvania Transit Authority
TTC	Transportation Test Center
TTT	Transit Test Track
UMTA	Urban Mass Transportation Administration
URB	Urban Rail Building

SYMBOLS AND ABBREVIATIONS

α	Acceleration (in g's)
AC	Alternating Current
amp	Ampere
CW	clockwise
CCW	counterclockwise
dB	Decibel
dBA	Decibels, "A" weighted
°C	Degrees Centigrade
°F	Degrees Fahrenheit
Δ	Difference
DC	Direct Current
DCV	Direct Current Volts
ft, '	Feet
FM	Frequency Modulation
g	Gravity x 1 (Also G)
Hz	Hertz (cycles per second)
in, "	Inches
k amp	kiloamps
kph	kilometers per hour
kV	kilovolts
kW	kilowatts
kWh	kilowatt hour
MH	Mega Hertz
MVA	Mega Volt Amps
Hg	Mercury (Atmospheric Pressure)
μ	Micro (unit x 10^{-6})
mph	miles per hour
mphps	miles per hour per second (acceleration)
ma	Milliamperes
mm	millimeters
ms	milliseconds
Pa	Pascal
%	Percent
psig	Pounds per square inch - gauge
Rev	Revolutions
RMS	Root-mean-square
RPM	Revolutions per second
s	Second(s)
V	Volts

EXECUTIVE SUMMARY

A prototype light rail vehicle, built by Tokyu Car Corporation, with Westinghouse propulsion system and Knorr friction brakes, was tested at the Transportation Test Center, Pueblo, Colorado between April and July 1983. The tests, funded by Urban Mass Transportation Administration (UMTA), were designed to evaluate the vehicle performance prior to being introduced into revenue service on the line being constructed in Buffalo, New York.

The vehicle was shipped in finished condition by sea from Japan and then transported by rail to the TTC, where it was fitted with a comprehensive instrumentation package. The tests were based on a standard series of tests: acceleration, deceleration, power consumption, noise, ride quality, revenue service simulation, etc., which were modified to address specific specification requirements.

Representatives from Niagara Frontier Transportation Authority (NFTA), Tokyu Car Corporation (the principle contractor), and subcontractors and consultants were present at significant points in the test and in the periods of adjustments required to bring the vehicle to optimum performance.

The major conclusions of the report are:

- The vehicle satisfied the specification criteria addressed by the TTC tests, except in a few minor areas.
- The reliability of all systems was excellent. The vehicle's high availability contributed to the on schedule completion of the tests.
- Although a propulsion motor flashover was experienced during simulated profile running which caused minimum damage, the condition was not duplicated in any subsequent testing.
- The friction brakes met the design criteria, however, because of the limited thermal capacity of the disc brakes, continuous friction-only operation was not possible.
- During extensive spin/slide operation, in which the blended brake defaults to friction only, there was a possibility of overheating the disc.
- The performance of the vehicle was very dependent on the skill of the personnel setting the many variables of the complex control systems.

1.0 INTRODUCTION

The engineering evaluation testing of the Tokyu Car Corporation Prototype Vehicle No. 101 was initiated at the Transportation Test Center (TTC) in April 1983 as a prerequisite to accepting an order of 27 vehicles by the Niagara Frontier Transportation Authority (NFTA) of Buffalo, New York. The tests were conducted under the auspices of the Urban Mass Transportation Administration (UMTA) and funded through the Federal Railroad Administration (FRA), Washington, D.C. The technical aspects of the testing were monitored by Day & Zimmerman, a consulting firm, representing the NFTA.

1.1 TEST OBJECTIVE

The test program at the TTC was designed to evaluate the performance characteristics of the Light Rail Rapid Transit Vehicle (LRRT) and to determine if its characteristics met the contract requirements. These tests also provided operational time under a simulated environment to ensure good vehicle performance under revenue service.

1.2 BACKGROUND

The Association of American Railroads (AAR) contracted in October 1982 with the FRA for care, custody, and control of the TTC. The NFTA LRRT vehicle evaluation tests were a continuation of the UMTA policy of financing the extensive testing of transit vehicles at the TTC. The technical specifications for the tests were prepared by the TTC with the help of representatives from NFTA, Day & Zimmermann, and the Tokyu Car Corporation. On the Transit Test Track (TTT) the two miles of overhead DC powered catenary used for the tests was reconfigured to represent the variable vertical clearance of the Buffalo city route profile. The test vehicle was shipped from Japan to the west coast of the USA, then transported by rail flat car to the TTC. The vehicle was transported to Buffalo, New York by rail flat car. To facilitate the orderly and successful conduct of the planned testing, a Quality Assurance Plan was prepared and a Quality Assurance Inspector assigned to monitor all aspects of the program.

1.3 TEST PROGRAM SCOPE

The intent of the NFTA test program was to determine if the Prototype Vehicle No. 101 could meet the performance specifications and to correct any anomalies prior to delivery of the remaining vehicles to Buffalo. The tests were conducted up to a maximum speed of 50 mph under the overhead catenary section of the TTT. A special power cart was fabricated utilizing a third rail shoe assembly to power the vehicle to and from the shop to the catenary test section. The power cart attached to the test vehicle was limited to speeds below 30 mph. The vehicle was tested for a total of 1,459 miles and 167 hours. The performance of the test vehicle was evaluated for empty weight (AW0), seated weight plus standby weight (AW2), and crush load weight (AW3) in the following areas:

- Acceleration
- Deceleration
- Spin/Slide
- Train Resistance
- Energy Consumption
- Duty Cycle
- Ride Quality
- Acoustics

Special static tests were performed on the test vehicle as follows:

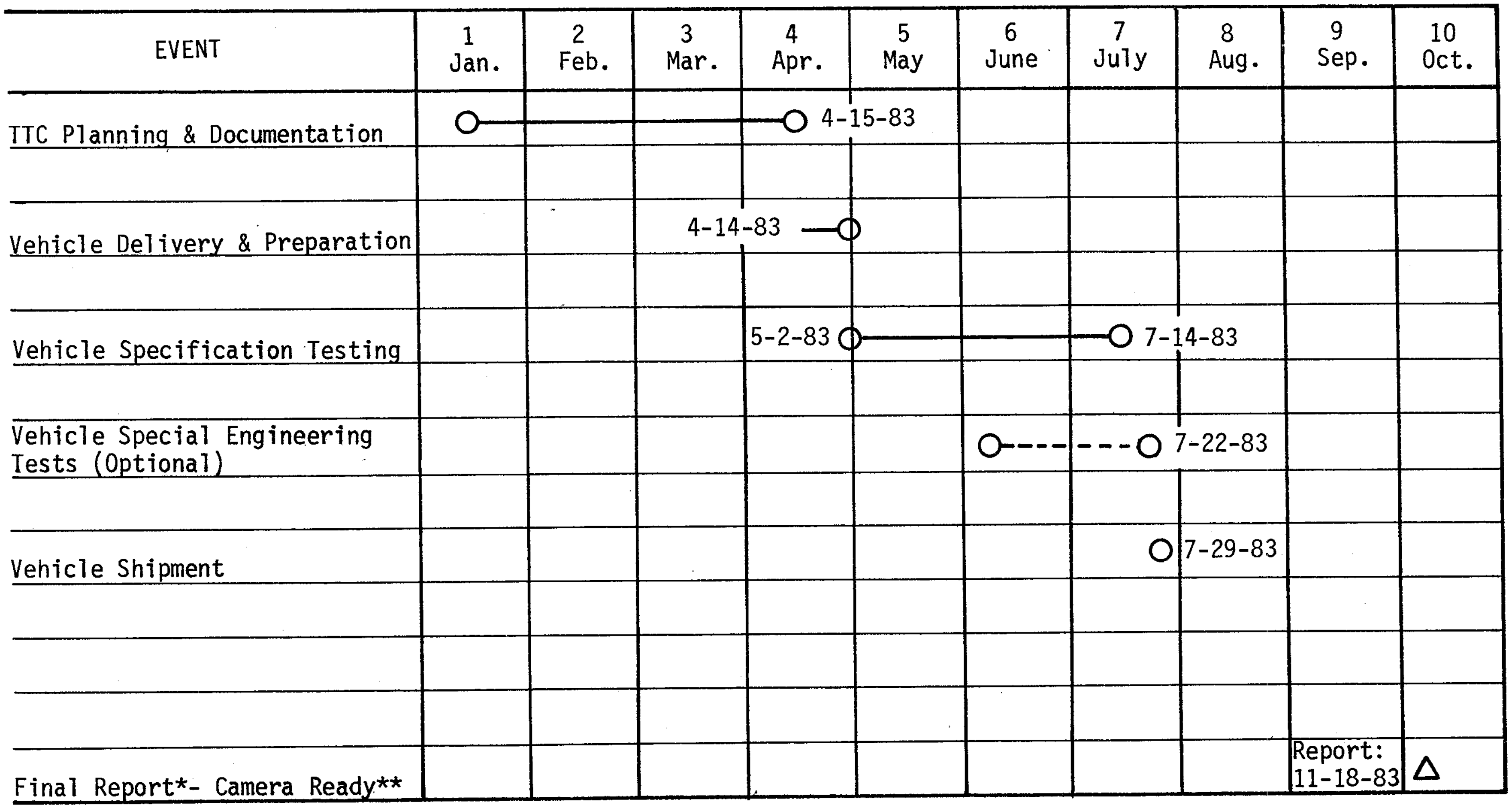
- Truck Characterization
- Vehicle Resonance
- Vehicle Vibration
- Vehicle Roll Angle
- Axle Alignment

A ground vibration study was conducted by Wilson, Ihrig & Associates under separate contract. These tests involved special wayside instrumentation and required special test runs using the transit vehicle.

1.4 CHRONOLOGY

The NFTA test program planning at the TTC was initiated by approval to proceed November 29, 1982. The Task Order No. 8 for the basic AAR/FRA Contract DTFR53-82-C-00282 was issued in April 1983.

The Tokyu Car Prototype No. 101 arrived at the TTC on April 14, 1983 and testing began May 2, 1983. The dynamic and static testing was completed July 22, 1983 and the vehicle was delivered off site for shipment to Buffalo on July 29, 1983. The schedule for the test program is presented as Figure INT1.



* 120 days after completion of testing.

**Actual Camera-Ready Version: Projections subject to preparation, routing, and final acceptance.

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FIGURE INT1. NFTA TEST SCHEDULE.

2.0 DESCRIPTION OF VEHICLE

2.1 DESIGN PARAMETERS

The test vehicle is a Light Rail Vehicle built by Tokyu Car Corporation to NFTA specifications. It is equipped with a Stemmann type BS-80 single arm pantograph, spring up, air power down. Both ends of the vehicle are equipped with operator's controls for single vehicle operation or in a train of up to 4 cars. Passenger boarding steps can be lowered for boarding at street level and raised for boarding at floor level in the subway. Air conditioning is provided for by one underfloor compressor/condensor and two overhead evaporator/blowers with a rating of 13.5 tons at 105°F ambient. Vehicle heating is accomplished by overhead (28 kW) and floor (10 kW) heaters. Automatic Train Protection (ATP) is provided for in the subway by GRS cab signalling equipment. The ATP system includes 5 speed codes, 100 Hz encoded track circuits with overspeed protection. Surface operation is manual with overspeed (28 mph) protection. Seating is provided for 51 passengers with provisions for wheelchairs.

VEHICLE DESCRIPTION

Car Length Over Couplers	66'
Car Length to Anticlimbers	64'
Car Height to Pantograph (Locked Down)	12'4"
Pantograph Working Height	12'9" to 19'
Truck Centers	36.12'
Wheel Base	6'2"
Horizontal Curve Negotiation	75'
Empty Weight AW0	70,400 lbs
Seated Weight AW1	78,460 lbs
Seated and Standee Weight AW2	92,255 lbs
Crush Load Weight AW3	103,105 lbs
Max Speed with Speed Limiting Device	50 mph
Max Speed without Speed Limiting Device	55 mph
Acceleration Rate	3 mph/second
Service Brake Rate	3 mph/second
Emergency Brake Rate	4.0 to 4.7 mph/second

2.2 CARBODY

The carbody is made of low alloy, high tensile strength steel, with rigid monocoque construction. The exterior is finished with polyurethane paint. Interior covering is fiberglass-reinforced plastic and melamine-on-aluminum. The floor is constructed of 3/4" plywood clad with stainless steel and covered with rubber flooring. The step assembly is air-actuated and rotates about a single axis. There are six 45" single-element sliding pocket, overhead air-actuated doors per car. There are nine windows per side, four with transoms. The glass is resiliently mounted bronze tint, single pane safety glass.

2.3 TRUCKS AND SUSPENSION

The trucks are Tokyu Car Corporation trucks of low alloy, high tensile strength steel with welded construction. They are inside-journal trucks with two traction motors mounted on each truck, one motor geared to each axle. Wheels are solid steel and conform to AAR profile and gage. Primary suspension is provided by elastomeric chevron springs mounted between the axle journals and the sideframes. Secondary suspension is provided by two air springs per truck, mounted between the truck bolster and the truck frame. Passenger load is sensed at each truck by load leveling valves which vary the air spring pressure to maintain a constant floor height above the rail. Each truck is equipped with a lateral shock absorber and electric track brakes.

2.4 PROPULSION SYSTEM

The propulsion system is basically the equivalent of the one presently in service in Rio de Janeiro and similar to those designed for South Eastern Pennsylvania Transit Authority (SEPTA) and Miami/Baltimore programs. Power requirements have resulted in some changes in equipment design. A Siemens 3WF32 high speed circuit breaker is supplied by Westinghouse. The 1463D traction motors are force-ventilated by use of a single blower for each traction motor.

The system consists of a four-motor, microprocessor controlled chopper system, with the motors permanently connected two in series and two series groups connected in parallel. Each motor drives a car axle through a parallel drive, double reduction, helical gear unit. Field weakening (50%) is accomplished by connecting two motor fields in parallel. The microprocessor controlled logic provides commands to the chopper and switching equipment after interpreting the operator's trainlined instructions via the P and BRK signals generated by the master controller. The system is designed for manual operation. It has full dynamic brake capability and provides for regeneration to a receptive line during braking for energy conservation.

The system provides performance for voltages ranging from 650 to 750 VDC and reduced performance down to 450 VDC. At 450 VDC the system will shut down. The control voltage is obtained from a 25 cell 189 amperehour Nickel-Cadmium storage battery with charging provided by a TE259B Thyristor Converter. Nominal output of the converter is 37.5 volts with a negative temperature coefficient output up to 41 volts. One hour emergency operation is provided by the battery down to a minimum voltage of 25 volts with a converter malfunction.

The system is spin/slide protected through one digital input from the Knorr spin/slide control unit. This is interpreted by the propulsion logic as a spin or a slide, depending whether the vehicle is in power or brake. In the power mode when a logic "1" is detected, the logic will drop the current down to 50 amps per motor. Then, when a logic "0" is detected, the logic will jerk-limit the current back to the required amount. When a logic "1" is detected in the brake mode, the logic drops the current down to 50 amps per motor. Then, when a logic "0" is detected, the propulsion logic will wait 1 second then jerk-limit the current back to the required amount.

The vehicle's load weight is monitored by an air transducer mounted on the propulsion logic module. The air pressure is converted to a voltage which is proportional to the weight of the vehicle. This voltage is read and stored in memory when the car is at zero speed in brake. Once the vehicle is above zero speed the last load weight read will be used.

The WR-101-3 gear unit is a double reduction, parallel type gear reduction unit with a 7.130 to 1 gear ratio. The motor/gear unit has three points of mechanical interface with the truck structure. These include the solid connection of the gear unit on the axle, the resilient connection of the gear unit to the truck frame, and the resilient support of the end of the motor on the truck frame. The motor/gear coupling has a misalignment capacity of 6° total. The 1463D motor is a 4-pole DC series wound unit with a lap-wound armature. Each armature is cross connected. Each motor is rated at 103 kW at 1944 RPM continuous on NFTA profile and operates on 325 VDC.

2.5 BRAKING SYSTEM

Friction braking is provided by Knorr Brake Corp. using electro-pneumatic, spring applied air release disc brakes, one unit per axle. Normal braking effort is provided by dynamic brakes, with friction brakes blending in at the initial braking effort and again at low speeds when the dynamic brakes fade out. Within the Knorr electronic control unit all brake signals are processed into a demanded brake value adjusted for the actual level of dynamic braking and vehicle weight. The Brake Control Unit then transforms the demanded brake value into a proportional control pressure.

Friction braking is capable of providing full service braking in the event of dynamic brake failure, however, because of the limited size of the brake discs, only 3 consecutive full service friction brake stops from 50 mph are allowed in order to prevent overheating of the discs.

The vehicle is also equipped with track brakes which can be applied manually at will, or automatically along with the friction brakes during emergency braking.

2.6 THIRD RAIL POWER CART

A light weight track cart was modified to provide third rail electrical power to the pantograph equipped test car when not under the overhead catenary power system. The cart shown in Figure DV1 is attached to the test vehicle and uses a power paddle to contact the third rail, thus providing electrical power to the car. The power cart is disconnected from the vehicle during the testing under the catenary.

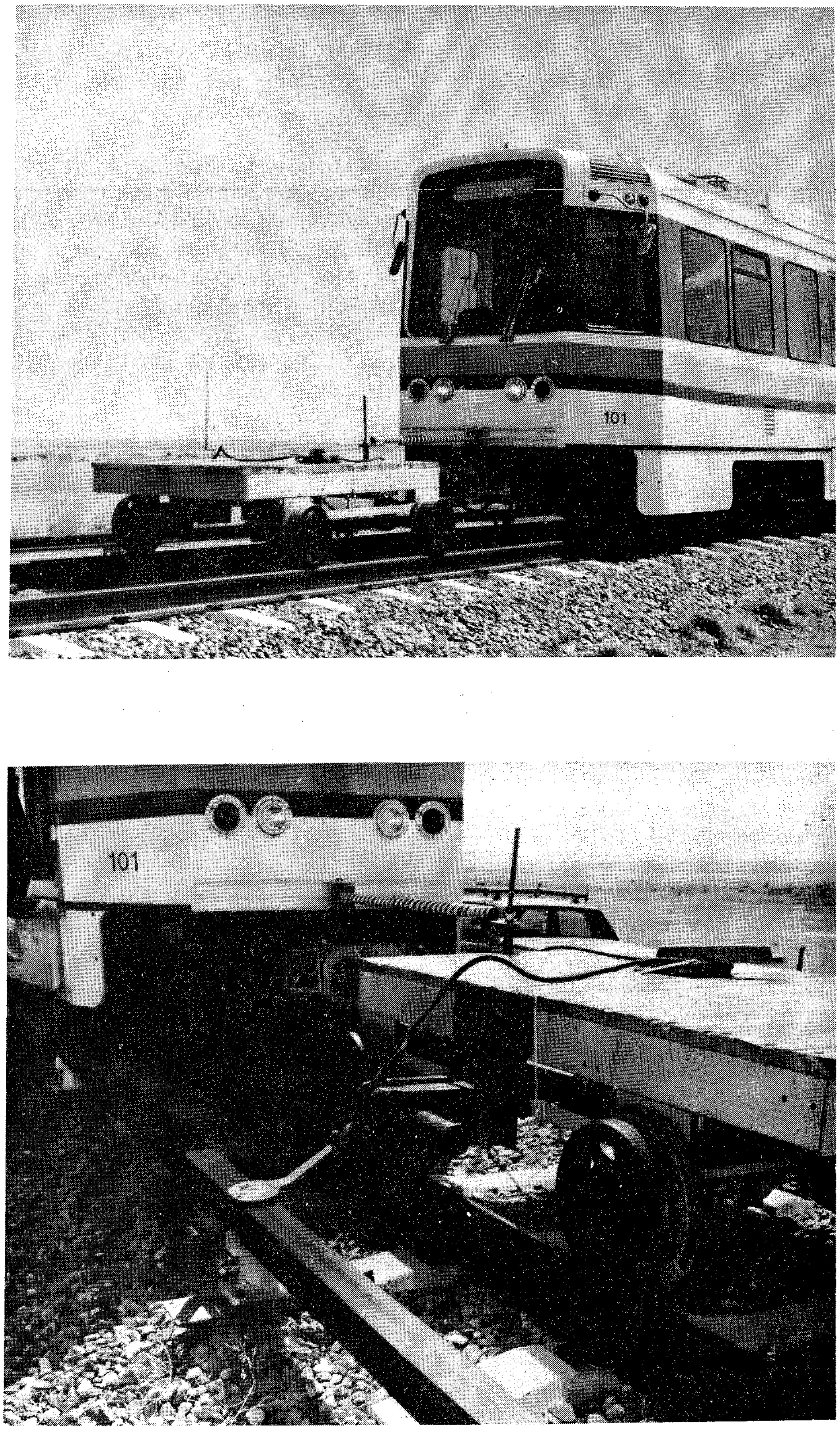


FIGURE DV1. MOTIVE POWER ACQUISITION VIA THIRD RAIL PADDLE CART.

3.0 DESCRIPTION OF FACILITIES

The Transportation Test Center (TTC) is located approximately 30 miles northeast of the city of Pueblo, Colorado. The site consisting of approximately 50 square miles of test area was acquired by the Department of Transportation (DOT) from the State of Colorado by a long-term lease with option to renew. The lease was signed on August 22, 1970. The Federal Railroad Administration (FRA) is the sponsoring administration for the DOT. The Association of American Railroads (AAR) entered into a sub-lease agreement with the FRA on October 1, 1982 to operate and maintain the facilities with option for periodic renewal.

The Test Center layout is shown in Figure DES1. The Center consists of several major permanent buildings as well as a variety of test tracks. The site has rail access through the Pueblo Depot Activity (PDA), two miles southeast, which is linked to the mainline of the Missouri Pacific and Santa Fe railroads at North Avondale, Colorado.

TTC test tracks presently being used are the Facility for Accelerated Service Testing, Railroad Test Track, Train Dynamics Track, Balloon Loop, Tight Turn Loop, and Transit Test Track.

The permanent building complex at the TTC includes management, operations, research, test, maintenance, storage, and security facilities. The major building complex is shown in Figure DES2. Other facilities on site have equipment available for transit use, such as heavy duty cranes, a wheel truing machine, data reduction equipment, and a telefax machine.

3.1 TOPOGRAPHY AND CLIMATE

The Transportation Test Center is located on a gently sloping, semi-arid rangeland along the foot hills of the Colorado Rocky Mountains. The 5,300 feet elevation, low relative humidity with high percentage of bright sunny days provides a dry climate with large daily temperature variations. The sun shines approximately 73 percent of the time, and the average annual precipitation consists of of 12 inches of rain and 32 inches of snow.

3.2 TRANSIT TEST TRACK (TTT)

The Transit Test Track shown in Figure DES3 is a 9.1 mile oval track located in the center of the TTC track complex. The track was constructed in six major segments, each of a different type of track construction, to represent various types of construction that are currently used by transit authorities in the United States.

The TTT consists of three curved and three tangent zones. The curves are 0°-50' (6,876 foot radius) with 2 inch superelevation to 1°-30' (3,820 foot radius) with 4 to 5 inches of superelevation. The curved configurations are balanced for 60 mph operation. The curves can be negotiated at a sustained speed of 80 mph with 2.2 inches of unbalance. The tangent zone located in the western portion of the test track was used for the major part of the performance testing. This tangent is 11,000 feet in length, with 4,000 feet at zero grade 100 lb jointed rail with wood ties and 7,000 feet at 0.69 percent grade 119 lb CWR with concrete ties.

The direct current electrical power for the Transit Test Track is provided through a third rail installation for the entire loop. An overhead catenary positioned above the 11,000 foot tangent test section is used for pantograph vehicle systems.

3.3 POWER SUBSTATIONS

Two nearly identical direct current (DC) power substations, Substations #1 and #2, are located inside the TTT loop. Substation #2, adjacent to the catenary, is shown in Figure DES4. These stations are positioned to allow each station to power a portion of the TTT or power the entire track individually. A tertiary power source is also located inside the loop on the west side. The station is an old unit provided by the Chicago Transit Authority (CTA) and is only used as a "backup" constant voltage source of less than 750 VDC.

Each substation is supplied 115 kV, three phase, alternating current site power through an input transformer rated 115 kV/4160 V at 10 MVA. A dual circuit rectifier transformer supplies two rectifier modulus at 900 V in each substation. The rectifier modulus working in parallel can supply 5 K amps DC current with 7,500 kW memory capacity. Substation #2 is capable of manual control only; however, Substation #1 can operate manually or by computer control.

The computer controlled Substation #1 can provide a selected voltage level at the transit vehicle from zero to 1,150 VDC. The third rail is split and two feeders are used to supply power in each direction from the substation. Eighteen track sensors are located around the track to sense the third rail to track voltages at uniform intervals. The computer calculates the location of the transit vehicle on the track from these readings then adjusts the substation voltage to maintain constant selected voltage at the vehicle. The large ripple voltage on the VDC output, inherent with the design, is reduced to acceptable limits by using a large 2.0 MH reactor and a tuned filter at 360 Hz. These substations have proven to be very reliable and provide good flexibility in operation.

3.4 URBAN RAIL BUILDING

The pre-engineered metal Urban Rail Building (URB) shown in Figure DES5 is located inside the Transit Test Track loop and is connected to the test track by a yard track. The building is used for transit vehicle storage and repair and contains approximately 21,000 square feet of floor space. The facility is completely self-contained with air conditioned office space, restrooms, shop space, and high bay area containing two 190 feet log service tracks (one track has a service pit). The building is equipped with air tables which are utilized in removing heavy equipment from under the car. They can also be used to float one end of the car for evaluating truck suspension systems (Truck Characterization Testing). Floor-mounted supports have been installed to assist in these tests.

URB equipment includes 8 30-ton Whitting jacks for use in loading or off-loading operations, detrucking, etc. Two kinetic rectifiers supply high voltage, variable from 450 to 1000 VDC, to the building and the yard. Other features of the building include customer office space, an electronics lab, and lunch room facilities.

In addition to the normal 120/208 volts AC shop power, two rectifier power units supply 450 to 850 volts DC for transit car service. One of the power units supplies the pit track and the other unit provides power to the wall receptacles and the yard track. The URB is shown in Figure DES5.

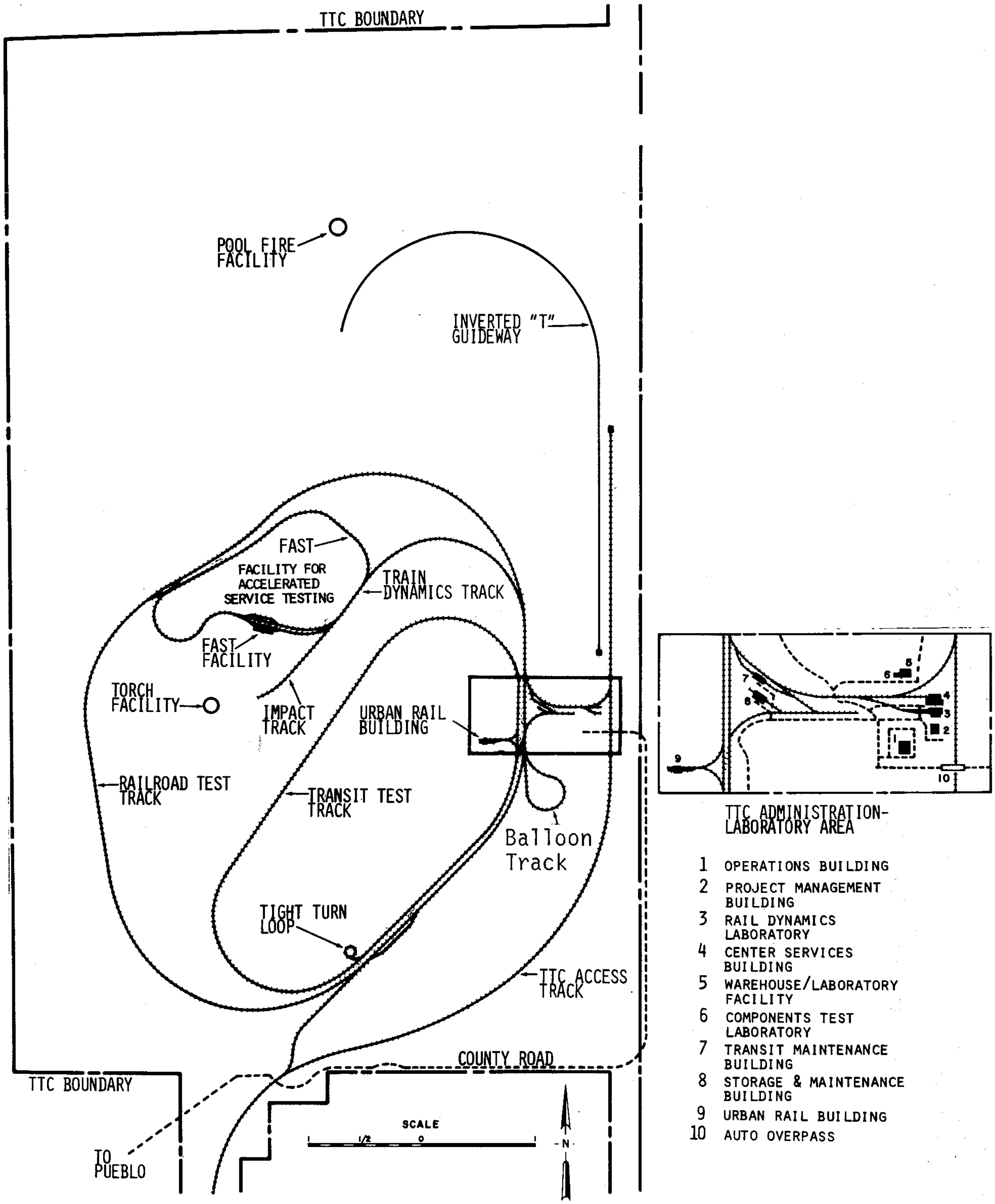


FIGURE DES1. TRANSPORTATION TEST CENTER LAYOUT.

1. Operations Building
2. Project Management Building
3. Rail Dynamics Lab
4. Center Services Building
5. Warehouse/Laboratory Facility
6. Component Test Lab
7. Transit Maintenance Building
8. Storage/Maintenance Facilities
9. Urban Rail Building (See Figure DES5.)

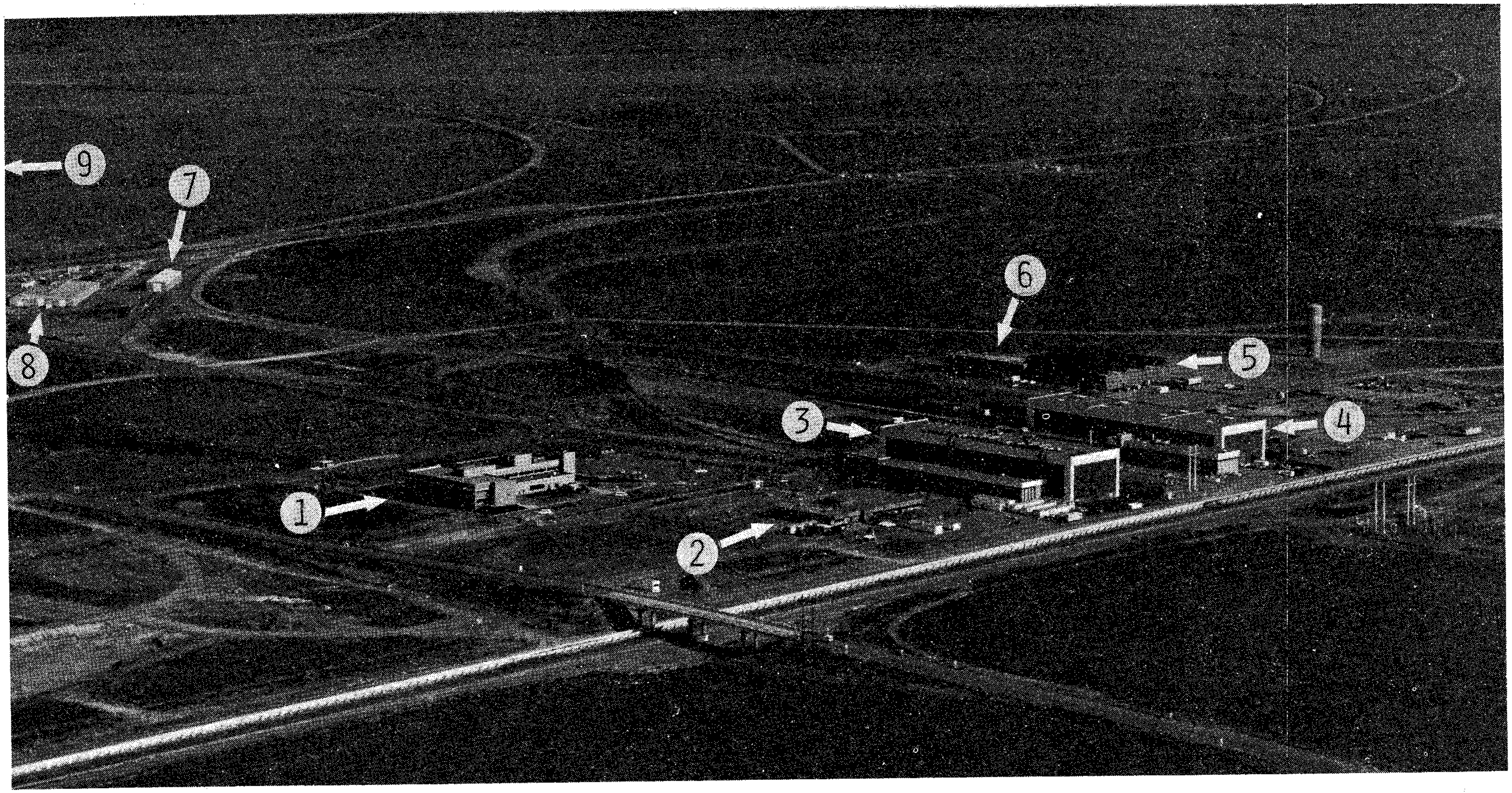


FIGURE DES2. TTC MAJOR BUILDING COMPLEX.

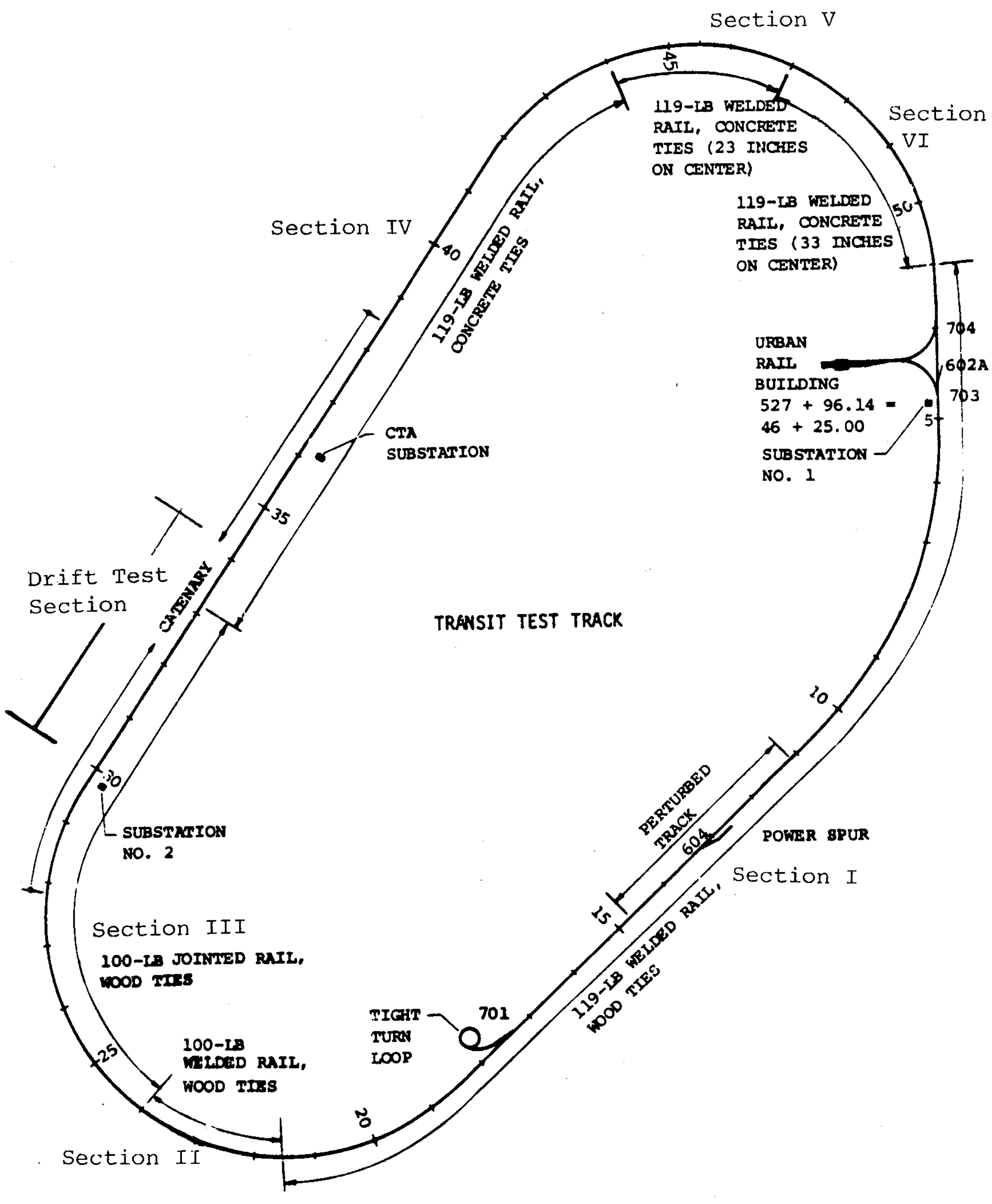


FIGURE DES3. TRANSIT TEST TRACK.

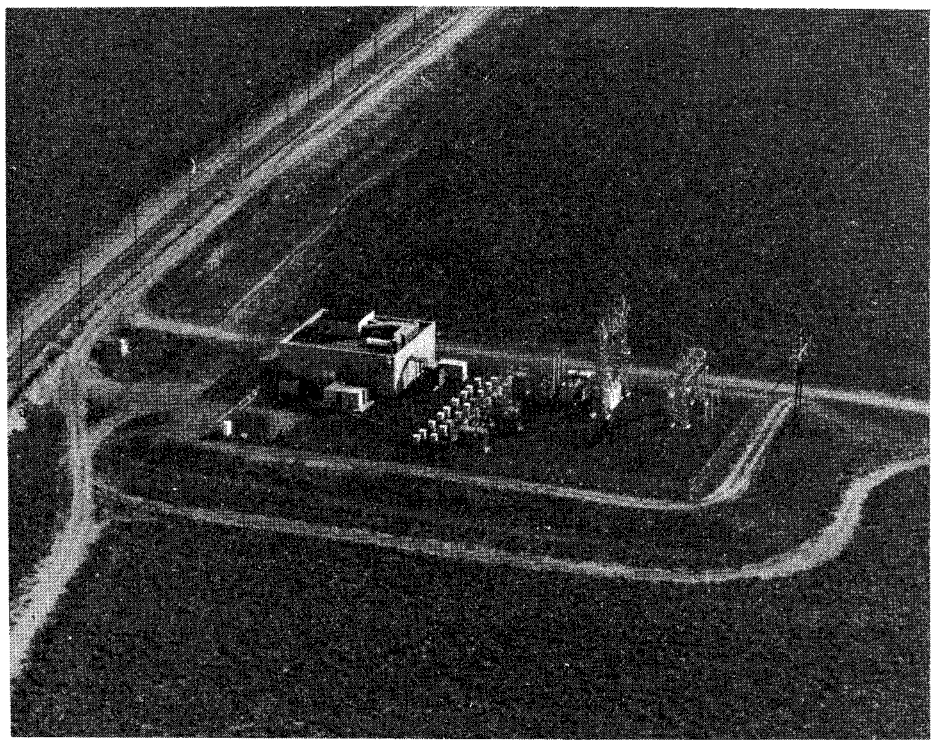


FIGURE DES4. SUBSTATION #2.

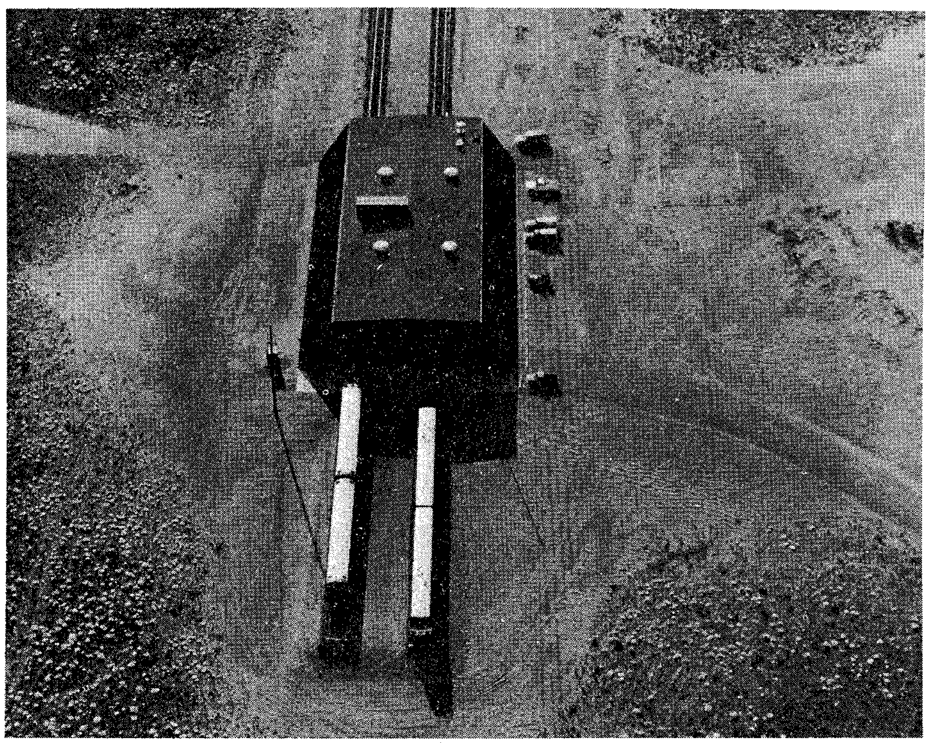


FIGURE DES5. URBAN RAIL BUILDING.

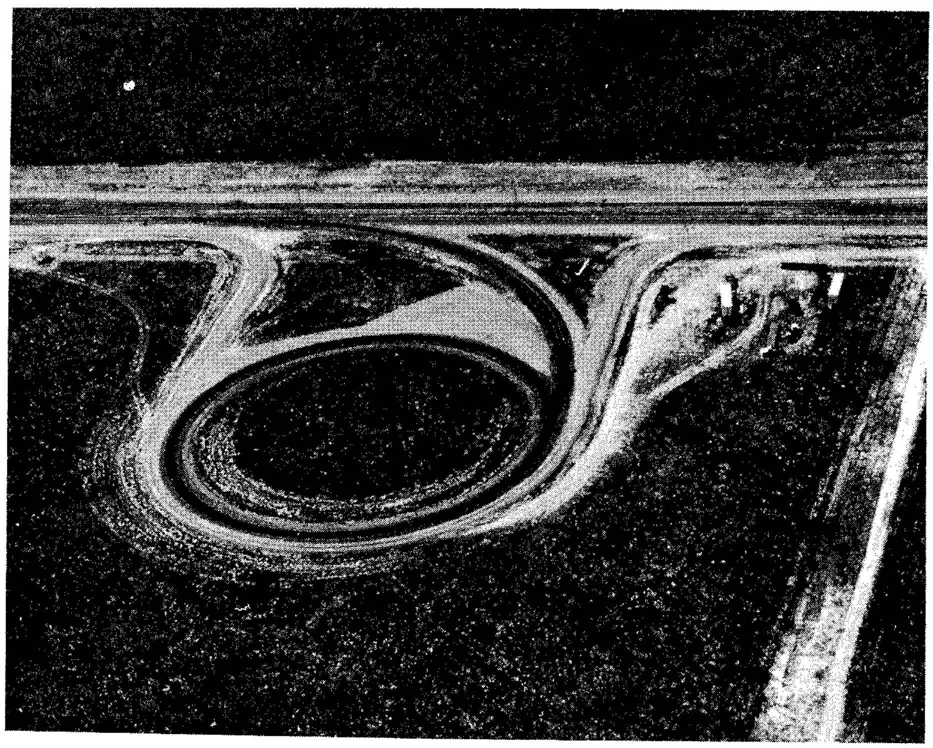


FIGURE DES6. TIGHT TURN LOOP.

4.0 GENERAL DESCRIPTION OF INSTRUMENTATION, DATA ACQUISITION, AND DATA PROCESSING

The single NFTA test vehicle was fitted with a relatively extensive instrumentation package similar to that used in previous transit tests at the TTC. The vehicle's own DC supply powered the package and many of the vehicle owned logic signals were used to assist in the data collection.

A 28 channel FM recorder patched to 'standard' patches with signal conditioners to sensors and signals was used to collect the data. Pen recorder strip charts noted vehicle adjustments, and an X-Y analog plotter was used extensively for speed and acceleration plots.

Calibrations were made either in the URB or at Station 32, both have level track.

An on-board HP 85 desk-top computer, plotter, and other HP-IB controlled analysis equipment give real time data analysis where possible. This was used during train resistance, ride quality, RMS value of motor current, and experimentally during spin/slide tests. This program is also aimed at increasing the portability of the equipment.

For subsequent replay and analysis, the complete signal conditioning frame and recorder was moved to an office at the TTC for playback on the desk-top computer and HP IB controlled instrumentation.

All original charts, plots, tapes, etc., are stored on file at the TTC. An overview of instrumentation used during the NFTA testing is presented in Appendix A.

5.0 PERFORMANCE TESTS

5.1 ACCELERATION AND DECELERATION PERFORMANCE

5.1.1 Objective

The major objective of the test was to compare the vehicle performance against the vehicle specification.

5.1.2 Test Method

When the vehicle was delivered to the TTC, its empty AW0 weight was 70,340 lbs, this was 4,340 lbs over the designed weight of 66,000 lbs. After the vehicle was instrumented and ballast added to give equal truck loads, it weighed 74,080 lbs. Table PER1 gives a summary of the vehicle weights tested at the TTC.

TABLE PER1. SUMMARY OF VEHICLE WEIGHTS.

CODE	WEIGHT (LBS)	DESCRIPTION
Design AW0	66,000	Design weight of empty vehicle
Actual AW0	70,340	Delivered weight of empty vehicle
Test AW0	74,080	Delivered weight plus instrumentation and ballast
Design AW2	87,855	Based on design AW0
Computed AW2	92,195	Based on actual AW0
Test AW2	90,640	Allows for test personnel to bring weight up to computed AW2
Design AW3	98,705	Based on design AW0
Computed AW3	103,045	Based on delivered AW0
Test AW3	101,450	Allows for test personnel to bring weight up to computed AW3

Throughout the testing period the emphasis was on adjusting the vehicle to meet the major performance requirements, rather than on obtaining a complete data matrix at all weights, speeds, directions, notch settings, etc. The presentation of the data in the report follows this approach and, in general, is chronological in nature.

The major test specification requirements which the tests addressed were:

- Equal performance in either direction.
- Acceleration requirements based on AW0 through AW2 at 650 VDC.
- Deceleration requirements based on AW0 through AW3.

- Time to reach 50 mph from standing start shall not exceed 37 seconds.
- Nominal full braking rate shall be 3.0 mph/second plus or minus 10 percent.
- Maximum allowable excursion from nominal full braking rate shall not exceed plus or minus* 0.5 mph/second.
- Friction brake system capable of providing rate of 3.0 mph/second plus or minus 15 percent.
- Emergency brake rate from 50 mph; the gross rate, initial speed/time, shall not be less than 4.0 mph/second. The time range is the time to stop including dead time and build-up time.
- Emergency brake rate from 30 mph; the gross rate shall not be less than 4.7 mph/second.

The concern during the testing was that because the vehicle was above its design weight, speed of 50 mph in less than 37 seconds would not be met. In addition, again because of the vehicle weight and because of the limited size of the disc brakes, the vehicle would be unable to meet the emergency brake rates. However, the vehicle did satisfy the specification requirements when its brake pads, etc., were in optimum condition.

The acceleration/deceleration signal was obtained from the longitudinal accelerometer which provided a DC calibration signal when it was tilted relative to the horizontal. An independent check on the acceleration/speed characteristics obtained on the analog X-Y plotter was made by the use of the HP 85 desk-top computer and pulse computer. Here the acceleration was computed from the 9th wheel speed based on 1/10 second samples, 0.5 seconds apart. This is a method similar to that used to compute the retardation force on the vehicle, see 5.3, Train Resistance. The data were plotted on a digital plotter. Figure PER1 shows a photo copy of Run 37 characteristics produced on the on-board plotter.

Figure PER2 shows the characteristics of Run 37 produced independently by the desk-top computer along with the print-out. It can be seen that the data show excellent consistency, pointing to good calibration accuracy.

5.1.3 Test Results

5.1.3.1 Initial Adjustments and Tests

Acceleration/deceleration testing began by bedding-in the disc brake pads. This is normally done by a series of friction only brake runs, but because of the limited thermal capacity of the discs cooling runs were made between the friction brake stops to prevent overheating.

After several days of adjusting and tuning time to speed, accelerations at AW2 were recorded. Figure PER3 shows the characteristic with initial acceleration of 2.8 mph/second.

It should be noted that the time required to accelerate was started when the traction motor currents started to rise, since the brake release time after the P-Signal increases is 1 second. The time to reach 50 mph was taken as the point at which the propulsion logic cuts back the tractive effort and begins speed maintaining at 50 mph.

Additional adjustments were made to improve the blending characteristics, then full acceleration runs were made CW and CCW (Figure PER4 and PER5). It should be noted that there was a 15 to 20 mph wind during these measurements.

An acceleration run at 750 volts CW (Figure PER6) produced a similar characteristic as at 650 volts in the same direction (Figure PER7). However, the initial acceleration was held longer at the higher voltage and the field curve was higher on the acceleration scale at the higher voltage, therefore, the time to 50 mph was reduced to approximately 30 seconds at the 750 VDC line voltage.

5.1.3.2 Low Voltage Tests

The effect of low voltage on the vehicle systems was investigated. With a static vehicle, as the voltage was lowered, the converter went off line at 459.5 volts. With the converter off, the vehicle would just move forward at a voltage of 454 volts.

5.1.3.3 Further Trial Runs and Adjustments

A further series of deceleration tests showed the blending characteristics did not produce a linear rate with P-wire signal. This was because of excessive friction contribution during blended operation. Figure PER8 shows the overlay blending characteristic and PER9 shows the overlay dynamic only characteristic. These show the need for further adjustments.

Following acoustic and ride quality tests, with the vehicle weight set to AW2 "design", trial runs investigated the load weigh sensors, and the motor output with a failed load weigh signal. The acceleration characteristics for P-wire of 25%, 50%, 75%, and 100% are shown in Figure PER10. There is good linearity. The acceleration characteristic produced with the vehicle in a default load weigh mode are shown in Figure PER11. Here the vehicle was at AW2 weight and since it accelerated at 3.0 mph/second, the default mode is correct.

5.1.3.4 Design AW2 Testing

Westinghouse and Knorr representatives made special runs to characterize performance at design AW2 weight. The 'Knorr' runs addressed friction only decelerations; typical data are shown in Figure PER12 on overlay of decelerations from 40 mph showing 100%, 75%, 50%, and 25% demand.

'West' runs addressed both acceleration and blended and dynamic only deceleration; typical data are shown in Figure PER13 and PER14.

The major testing objective at this point was to bring the two brake systems into tune, both individually and interactively, when in blended brake mode.

5.1.3.5 AW3 Testing - Friction Only and Track Brake

Following the AW2 'design' testing, the vehicle was ballasted up to AW3 weight and a series of friction only runs were made at a combination of entry speeds and brake channels, followed by a few blended runs and then track brake runs.

The friction only characteristics for 100%, 75%, 50%, and 25% are shown in overlay form for each of the 4 entry speeds of 50, 40, 28, and 15 mph in Figures PER15 through PER18.

The blending variation from dynamic to friction was greater than specification (1/2 mph/second), see Figure PER22, from 50 mph. Therefore, runs with various 'fade' speeds were performed as an attempt to overcome the transitional jerk. The series of characteristics shown in Figures PER19 through PER21 for 'fade' speeds of 11.5, 14.75, and 17.2 mph resulted from adjustments made in the speed at which the dynamic brake begins to fade-out.

Track brake only characteristics were obtained at this point for initial speeds of 50 and 30 mph and are shown in Figures PER23 and PER24.

5.1.3.6 AW3 Testing - Emergency Brake, Thermal Capacity of Discs and Spin/Slide

Next, the emergency deceleration was investigated. Figure PER25 shows the friction brake plus track brake characteristic when powered from the vehicle battery. In one run the vehicle took 7.5 seconds from 30.3 mph, a 4.03 mph/second rate. This is below the 4.7 mph/second rate, which was the goal at this point.

A similar emergency run from 50 mph (Figure PER26) produced a 4.06 mph/second rate, exceeding the 4.0 mph per second which was the goal at this point, and a peak deceleration of 6.8 mph/second. (Note: Figures PER25 and PER26 have a different Y scale than on previous figures.)

The thermal behavior of the disc brakes was investigated. The requirement was that the vehicle must be able to stop 3 consecutive times from 50 mph with the dynamic brakes cut out. The characteristics are shown in Figure PER27. They show the vehicle complied with the requirement but with a certain amount of fade as the disc heated. The original disc temperature was 38°C and the final was 390°C (obtained by hand-held temperature probe).

5.1.3.7 AW3 Testing - Emergency

Further testing of the emergency mode showed the vehicle still not meeting the rate, giving 3.95 mph/second and 4.05 mph/second for decels from 30 mph. (Specification requirement is 4.7 mph/second.)

The friction only characteristic was satisfactory, as was the dynamic only characteristic, see Figures PER28 and PER29.

Running for the day concluded with a run to test the property of the 'zero speed relay', which caused the track brake to release at low speed (nominally 3 mph). The characteristic in PER30 shows this effort with dropout at 7 mph.

5.1.3.8 AW3 Testing - Blending Problem Investigation

Testing continued to address the out-of-specification blending variation between dynamic and friction braking. Indications were that the problem lay in the logic of the Knorr equipment and not in the Westinghouse dynamic brake feedback signal.

During the testing, a slide occurred at a deceleration rate of 3.0 mph/second and speed of 21 mph, see Figure PER31. This was unexpected since the weather was dry and sunny. There may have been residue on the rails left from a previous spin/slide test.

5.1.3.9 Final Testing and Adjustments at AW0, AW2, and AW3

A complete data matrix is not available because:

- During AW2 testing, the original brake pads were examined and found to be burned and blistered from overheating. A new set of brake pads of identical composition was installed and carefully bedded-in.
- At all weights, track brake data are not optimum because of an improper rail/brake fit.
- Minor electronic adjustments were made throughout the test sequence.

However, from the data available, the following results are apparent:

Comparison of Friction Only Braking with Original to Replacement Pads

Figures PER32 and PER33 show, in overlay form, the characteristic for friction braking at 100%, 75%, 50%, and 25% demand, at AW2. Neither of the plots show a linear profile, but the new pads do display a higher initial and overall rate of deceleration. The new pads also show a greater fade than the originals at the 100% level.

Unfortunately, the replacement pads interfered with the transition phase between the dynamic and the friction braking, causing the deceleration variation to increase substantially. This is shown in Figures PER34 and PER35.

Transition Between Dynamic and Friction Braking

Throughout all deceleration testing the specification for transition between friction and dynamic braking was satisfied for only the 75%, 50%, and

25% demand level, but at 100%, performance was marginal with the original pads and worse with the replacement pads. Knorr felt the transition problem was caused by a scaling error in the brake electronic control unit. Modifications, however, could not be completed at this time.

Emergency Rate at AW3

The critical emergency braking rate is that of AW3 from 30 mph due to the impact of dead time and delay time. With the replacement pads and the track brake operating properly, the bulk rate (initial velocity/time) was 4.92 mph/ second from 31 mph, against a 4.70 specification required and the bulk rate at 50 mph was 4.35 mph/second. Note: The weather, hot and dry, was optimum for this test. The characteristics are shown in Figures PER36 and PER37. With a worn track brake (closely fitting the rail profile) the rate could be higher.

Load-weigh Failure at AW3

Figures PER38 and PER39 are the load-weigh failure modes for dynamic and friction only braking. With the vehicle at AW3 weight, a 3.0 mph/second rate was obtained in both cases. This is in compliance with the specification that requires default to AW3 characteristic.

Track Brake Performance

The performance of the track brake with the vehicle at its heaviest weight of AW3 is shown in Figure PER40. The characteristic shows rapidly increasing deceleration below 5 mph.

Because the instrumentation system was powered from the vehicle low voltage source, the application of the track brakes caused a lowering of the output voltage, i.e., once the capacity of the converter is exceeded (150 amps) the voltage drops to the battery terminal voltage. For a fully charged battery, this would be 32 volts, i.e., a drop of 5.5 volts. Therefore, preceding all track brake applications for data, all unnecessary loads were switched off to keep the voltage as high as possible. Because the track brake design is such that increased voltage above 32 volts does little to increase the current (saturated) and since attractive force is only affected by current, this was considered a valid approach.

Friction Only at AW3

The characteristic obtained with friction only brake at AW3 is shown in Figure PER41 and represents a satisfactory rate.

Linearity AW0, AW2, and AW3

Good linearity of braking was not achieved at all weights due to insufficient time for further adjustments. Acceptable linearity for AW0 is shown in Figures PER42 and PER43 for blended and friction only, respectively.

Wheel Wear Adjustments - 100% Acceleration at AW0

Three 100% accleration runs were made to produce characteristics at step 0, 10, and step 1 of the wheel wear adjustment. The characteristics are shown in Figures PER44 through PER46. The characteristics show varying but decreasing rates of 3.0, 2.9, and 2.75 mph/second obtained for wheels of constant diameter. This indicates that the wheel wear adjustment system was operating incorrectly, but a software change has since corrected this matter.

Acceleration Characteristics AW0 and AW2

No further testing was performed at AW3. The 100% characteristics at AW0 and AW2 are shown in Figures PER47 and PER48. They show the AW2 rate to be slightly lower. The characteristics were linear with demand.

5.1.3.10 Car Wash Mode

With an AW0 vehicle weight, the Car Wash Push Button gave the vehicle a maximum speed of 3 mph, which is regulated by the propulsion system. In this mode, the chopper and traction motor blowers are shut down. The car wash mode is enabled for approximately 5 minutes by the software.

5.1.3.11 Deadman Function

Release of the Deadman with the master controller in the coast or power positions caused application of the full service friction brake.

Release of the Deadman with the master controller in medium to full service brake caused no change to the blended braking mode.

5.1.3.12 Conclusions of Results

The major conclusions of the acceleration and deceleration tests were:

- The propulsion system and dynamic brake system were fully adjustable and satisfied the specification requirements. Testing investigated the load weigh, default load weigh, linearity, time to speed, wheel wear, jerk rate, and car wash mode characteristics.

- The friction brake system satisfied the specification requirements when fitted with new, carefully bedded brake pads, however, these pads adversely effected the blending from dynamic to friction brake. The disc brakes were adequate to stop the vehicle the required three times in succession.

- The critical emergency rate from 30 mph at AW3 was met with track brake and replacement pads.

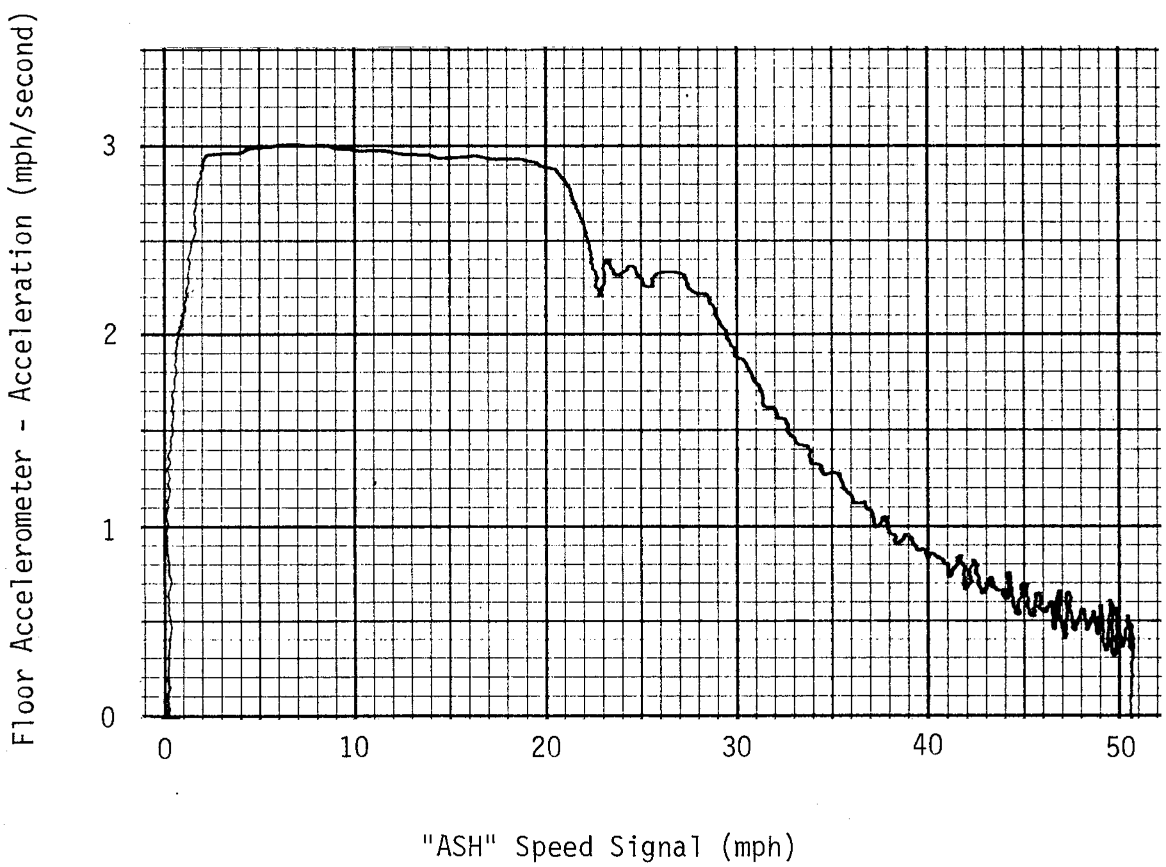


FIGURE PER1. ON-BOARD PLOTTER CHARACTERISTICS OF RUN 37.

#37 ACCELERATION
36.818 ELAPSED SECONDS

TIME	SPEED	ACCEL.(MPH/S)
.300	1.346	2.286
.812	2.676	2.922
1.312	4.155	2.995
1.804	5.643	3.058
2.296	7.130	2.986
2.788	8.600	2.998
3.271	10.063	3.051
3.755	11.522	2.983
4.239	12.960	2.955
4.724	14.415	3.052
5.207	15.860	2.924
5.691	17.310	3.075
6.174	18.755	2.911
6.657	20.153	2.870
7.141	21.513	2.756
7.624	22.731	2.285
8.108	23.870	2.424
8.591	25.015	2.319
9.074	26.158	2.409
9.558	27.298	2.306
10.041	28.399	2.248
10.525	29.392	1.859
11.008	30.290	1.859
11.491	31.137	1.643
11.975	31.918	1.590
12.458	32.646	1.419
12.942	33.321	1.373
13.425	34.007	1.468
13.908	34.655	1.213
14.392	35.275	1.351

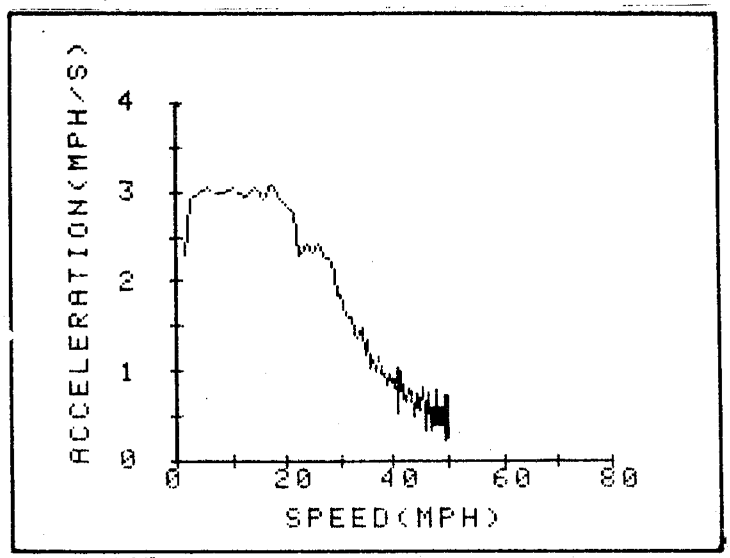


FIGURE PER2. DESK-TOP COMPUTER PRINTOUT OF RUN 37.

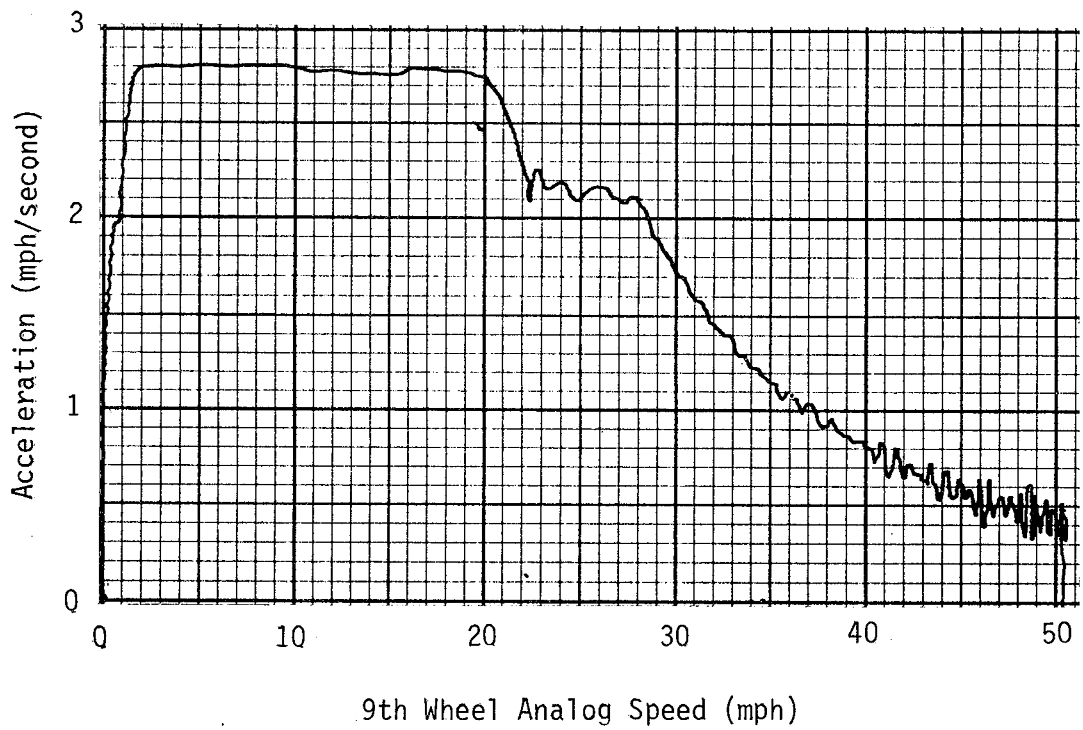


FIGURE PER3. INITIAL ACCELERATION AT AW2.

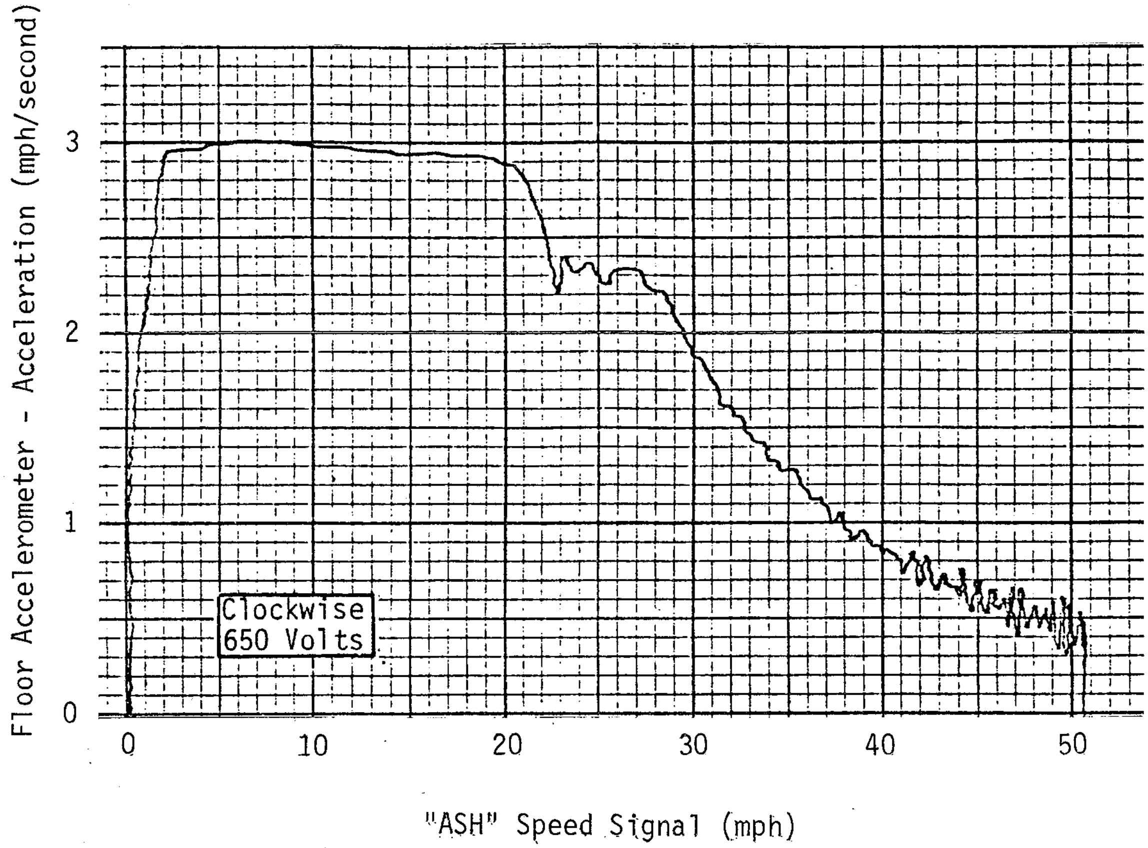


FIGURE PER4. CLOCKWISE ACCELERATION IN 15 TO 20 MPH WIND AT AW2.

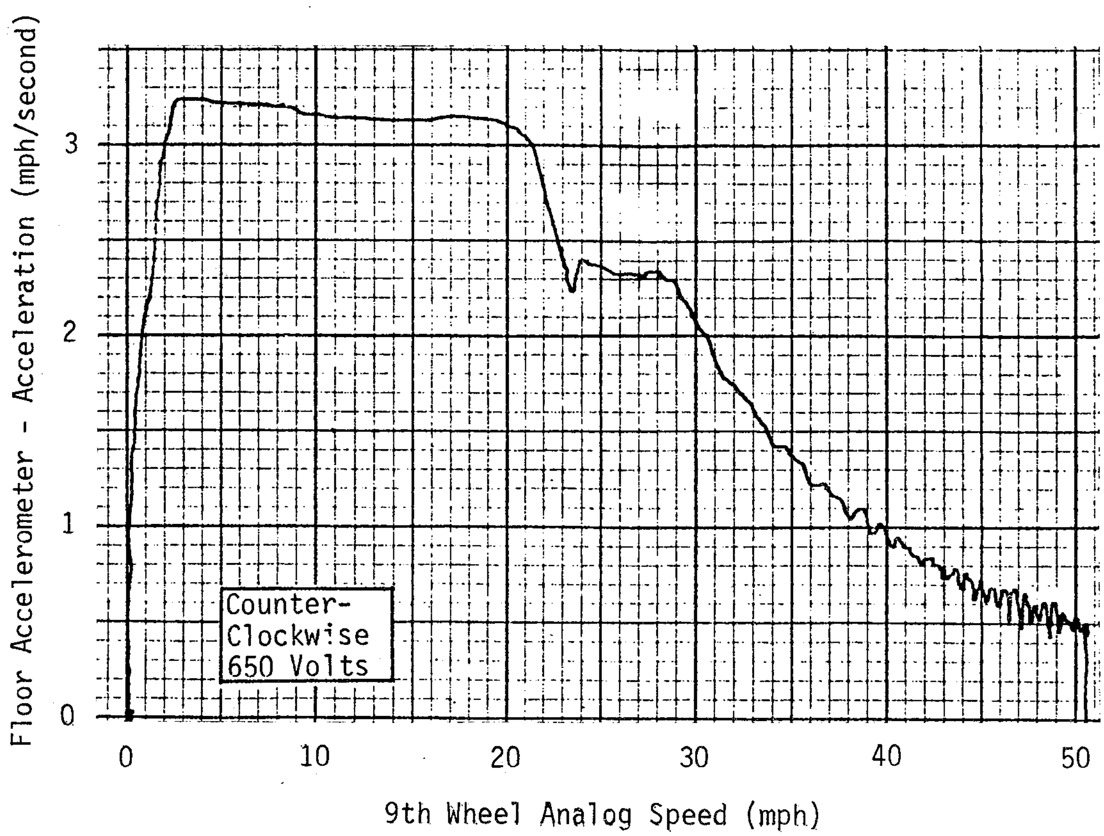


FIGURE PER5. COUNTERCLOCKWISE ACCELERATION IN 15 TO 20 MPH WIND AT AW2.

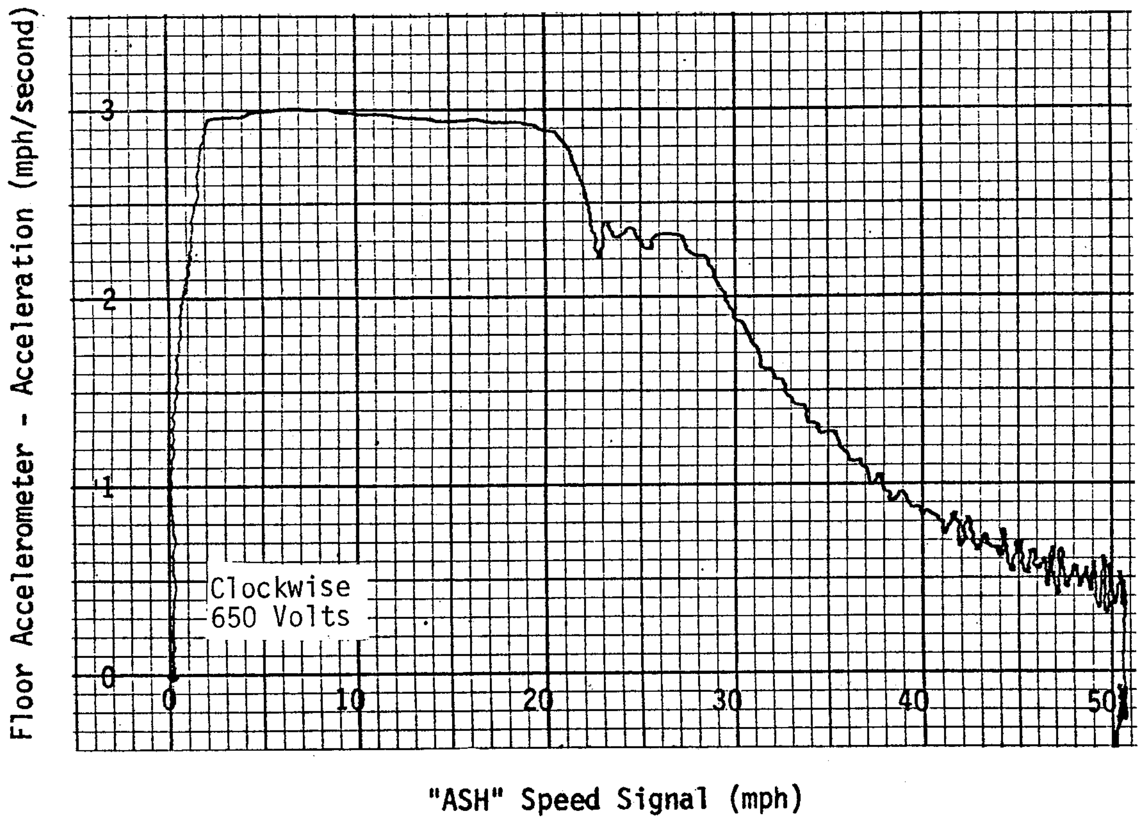


FIGURE PER6. ACCELERATION WITH 650 VOLTS AT AW2.

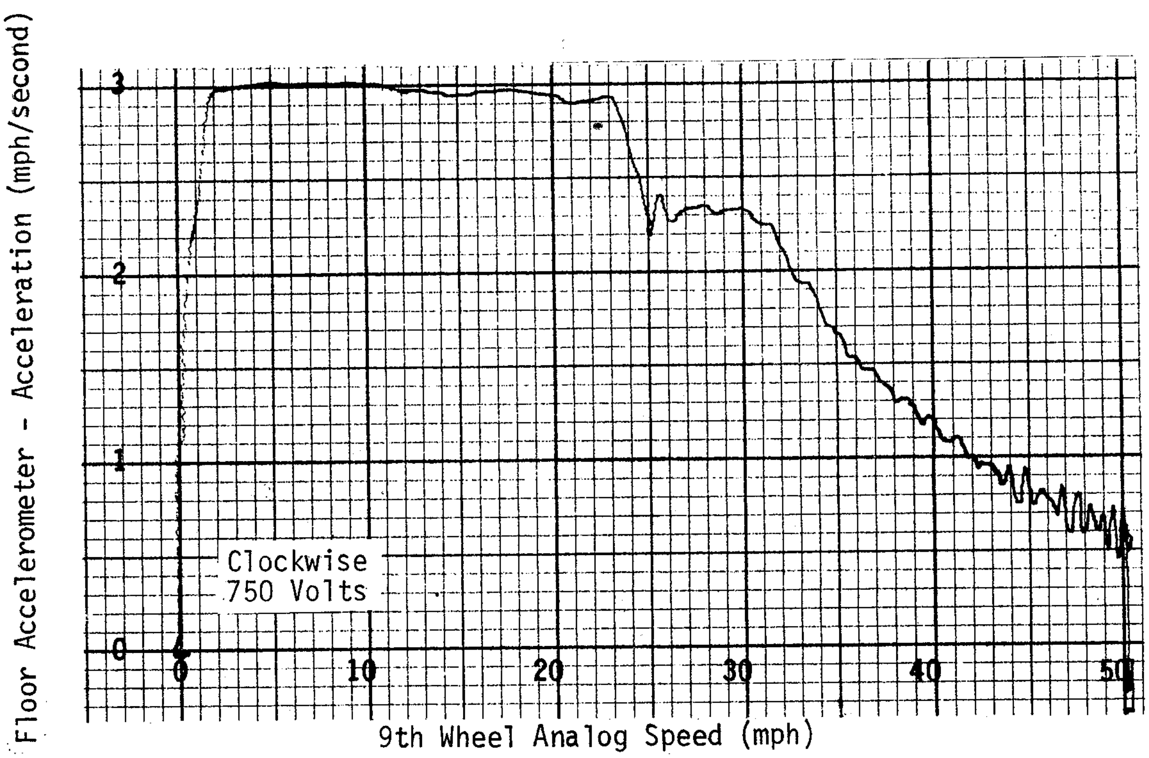


FIGURE PER7. ACCELERATION WITH 750 VOLTS AT AW2.

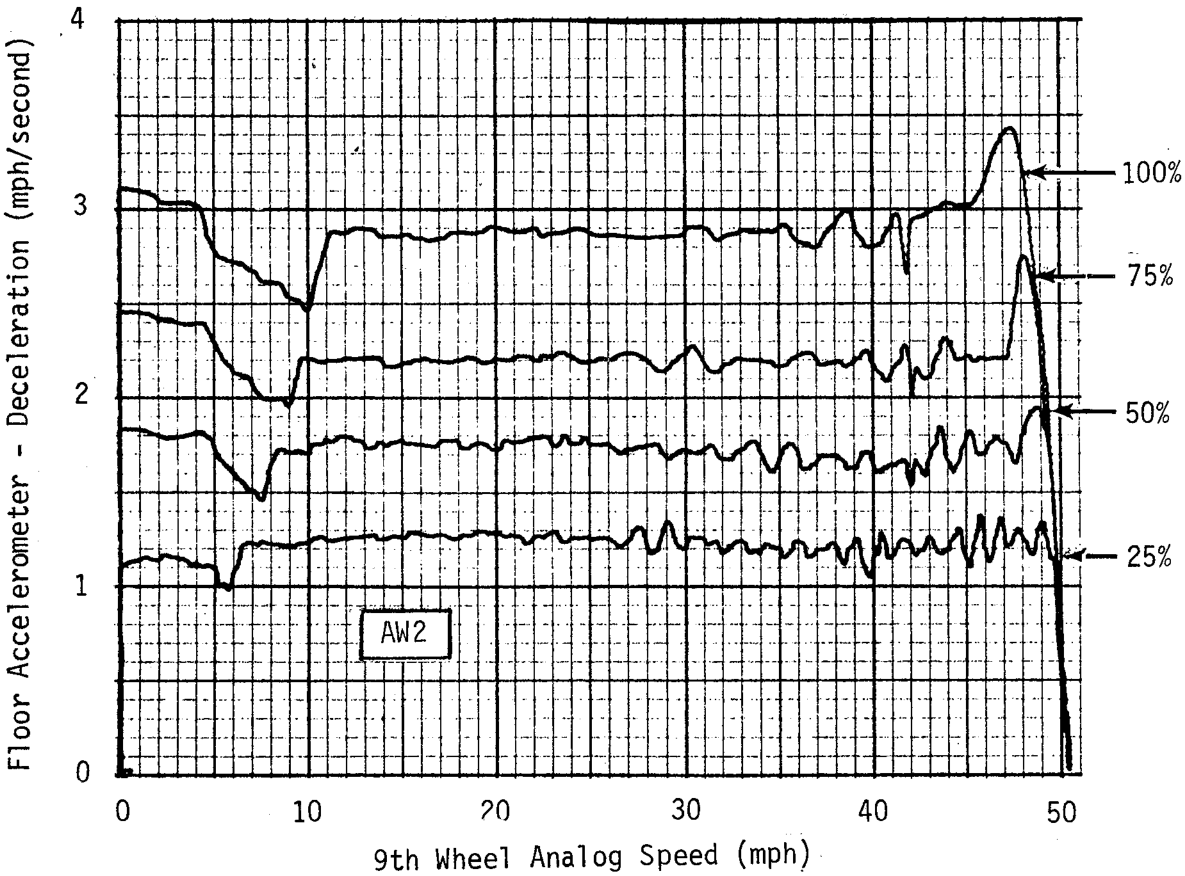


FIGURE PER8. OVERLAY OF BLENDING CHARACTERISTICS.

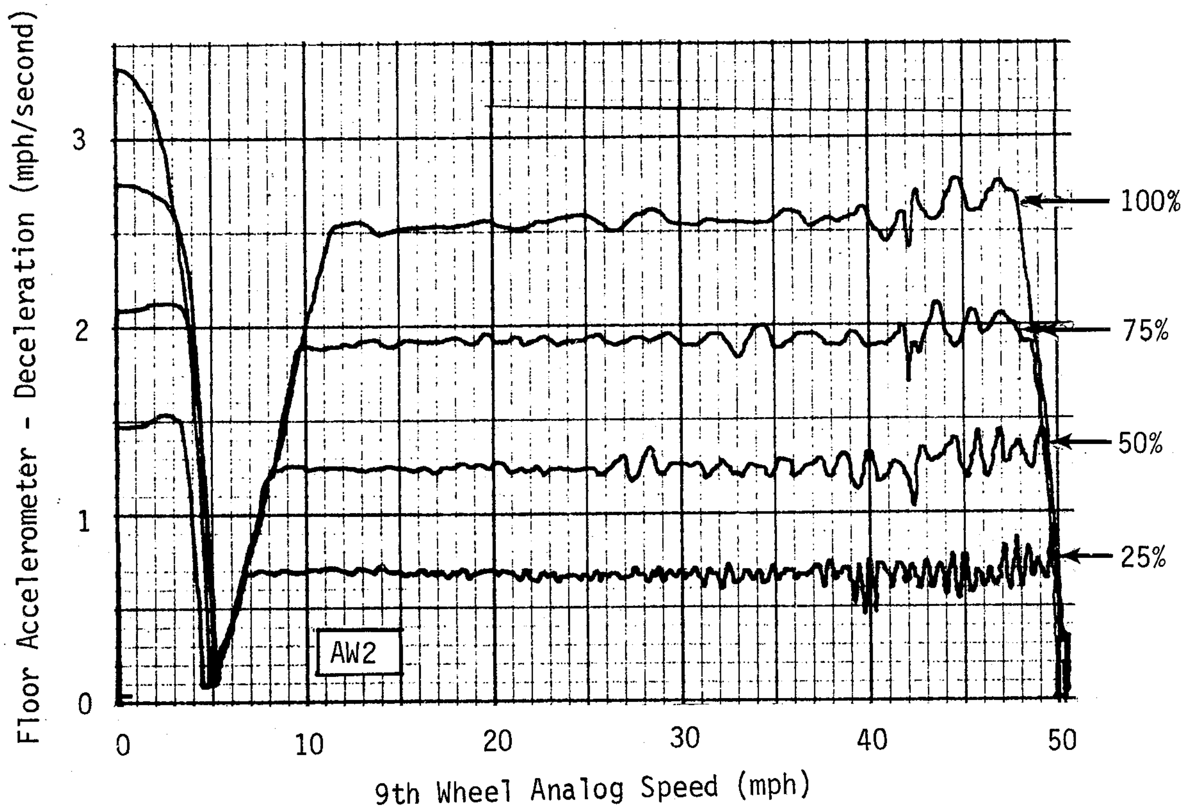


FIGURE PER9. OVERLAY OF DYNAMIC ONLY CHARACTERISTICS.

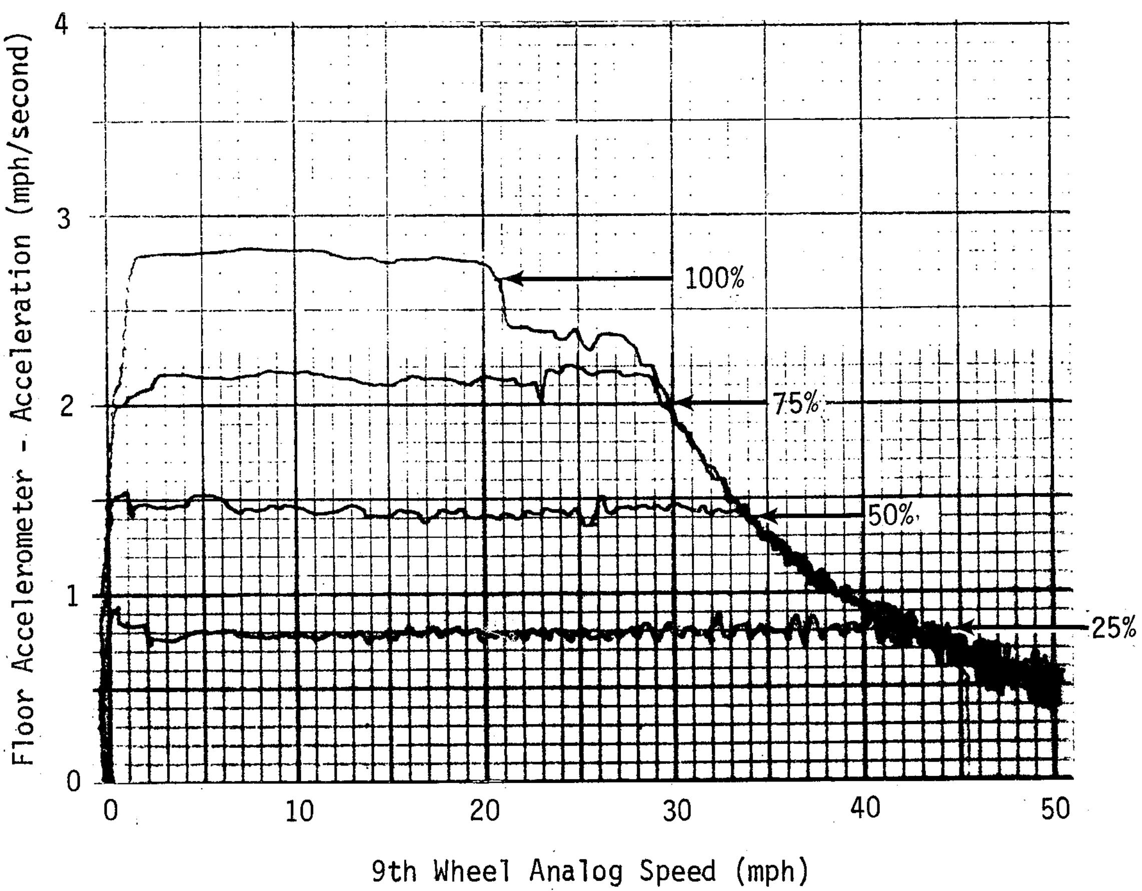


FIGURE PER10. OVERLAY OF P-WIRE VERSUS ACCELERATION CHARACTERISTIC.

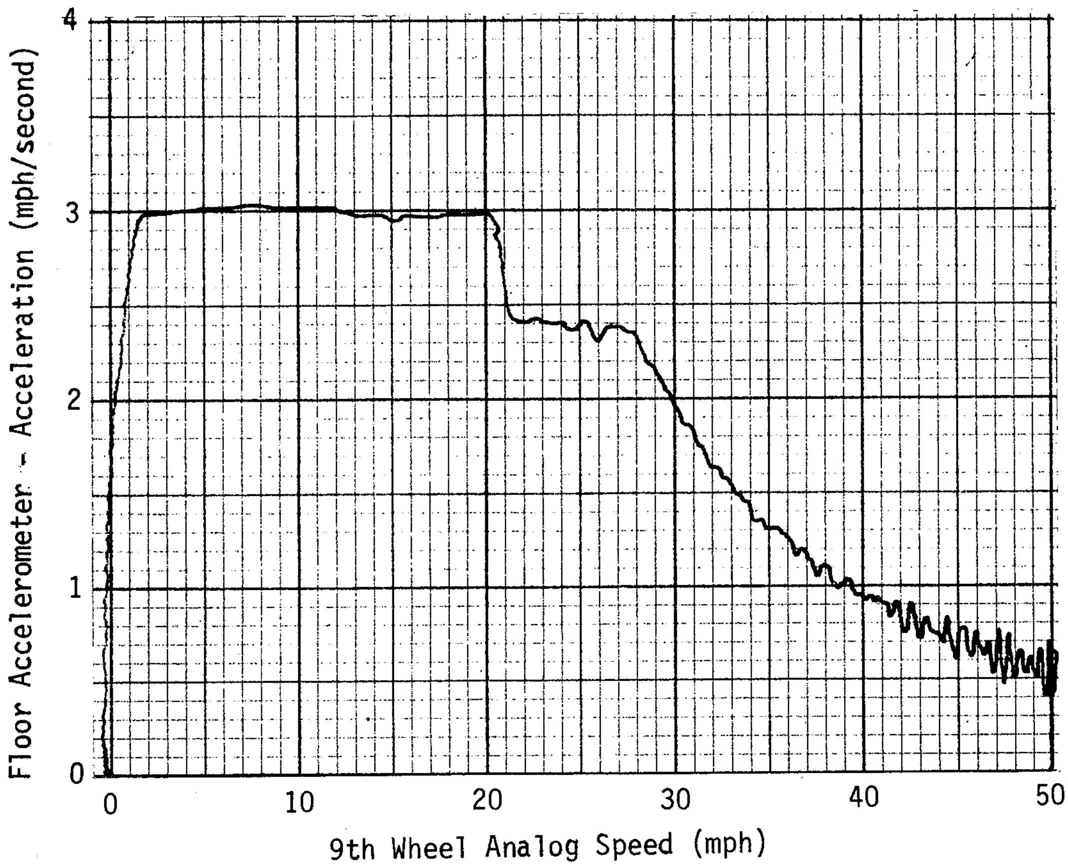


FIGURE PER11. LOAD WEIGH DEFAULT CHARACTERISTICS.

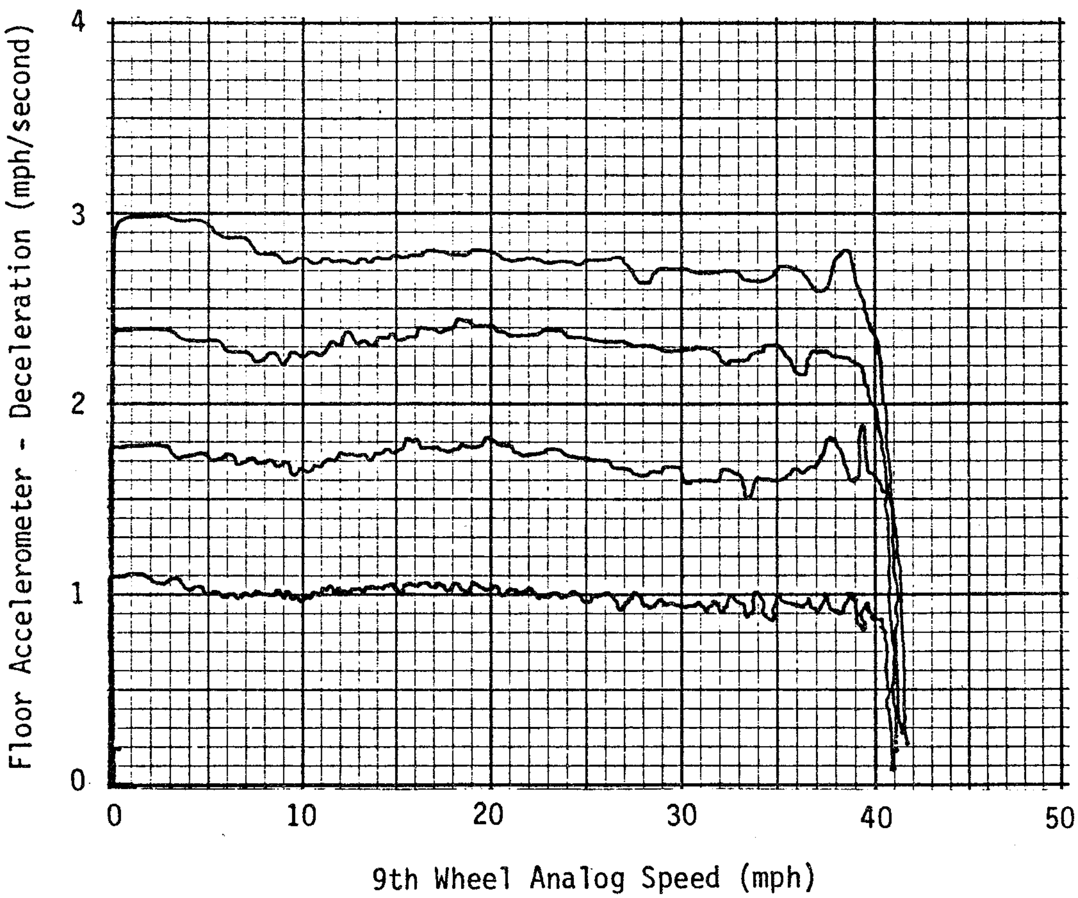


FIGURE PER12. FRICTION ONLY DECELERATIONS AT AW2.

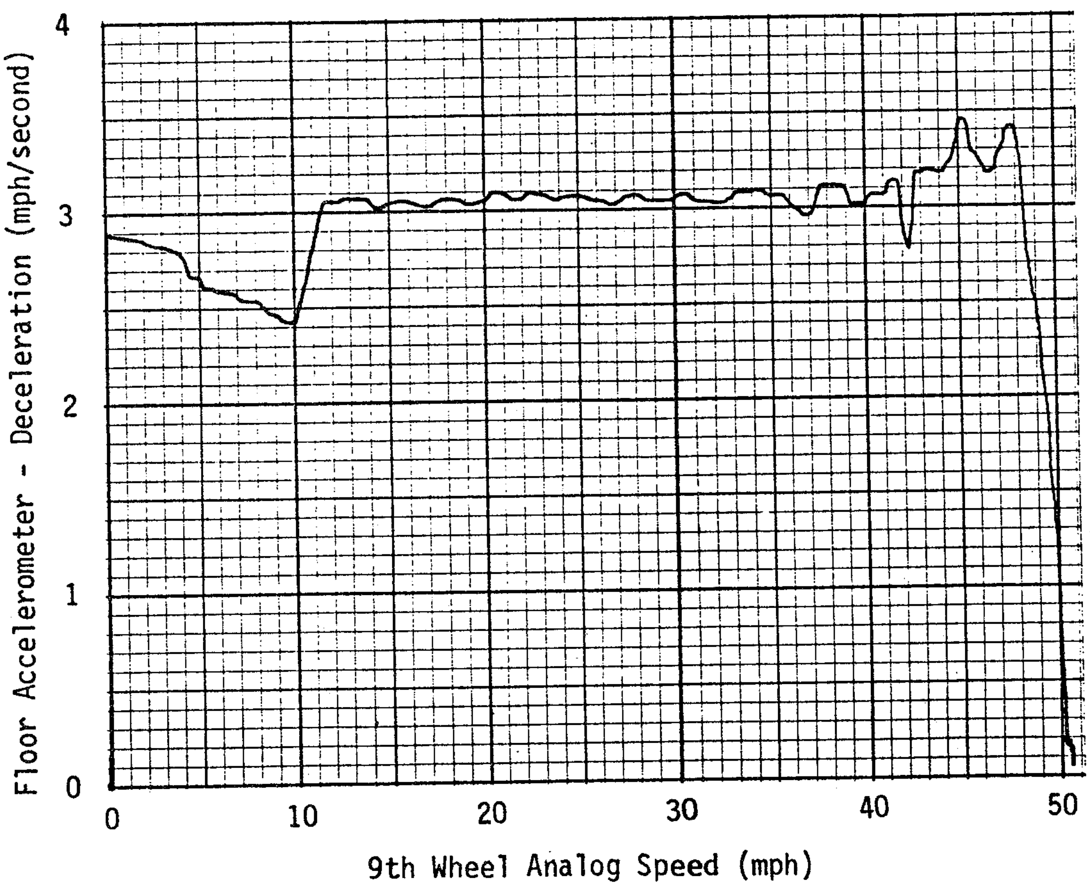


FIGURE PER13. 100% BLENDED AT AW2.

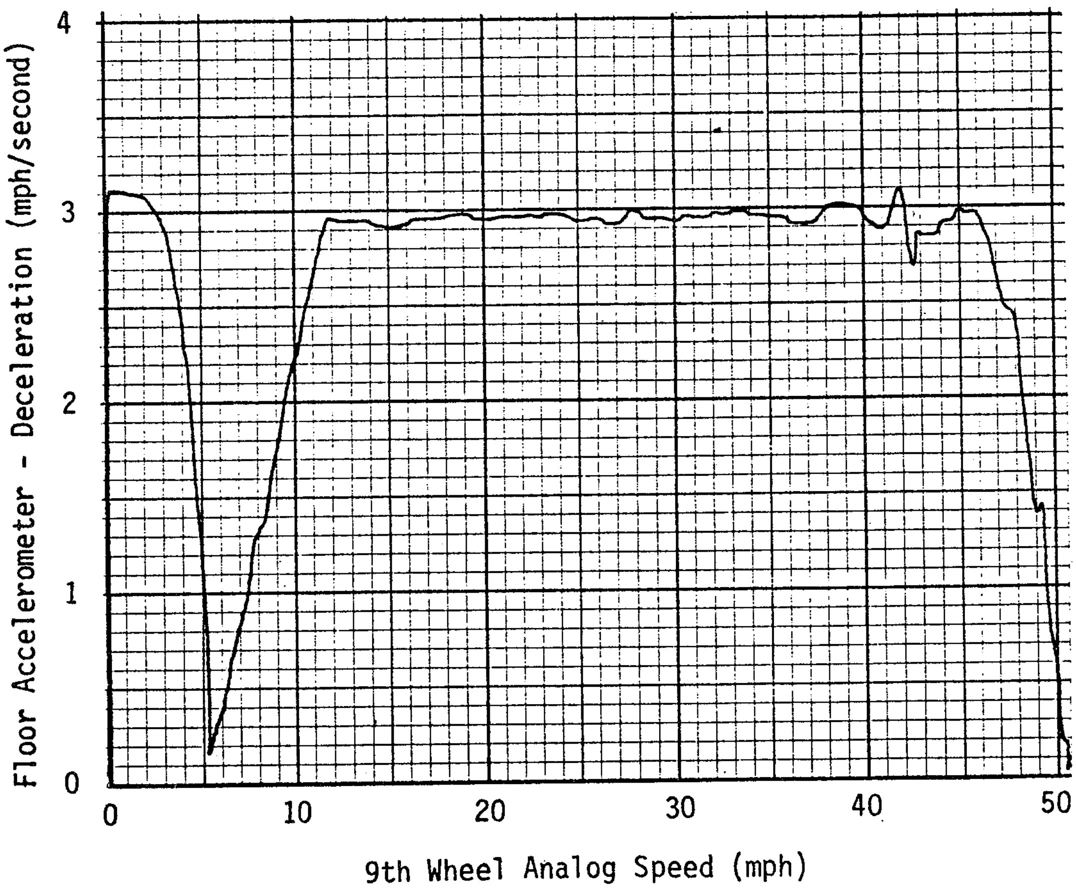
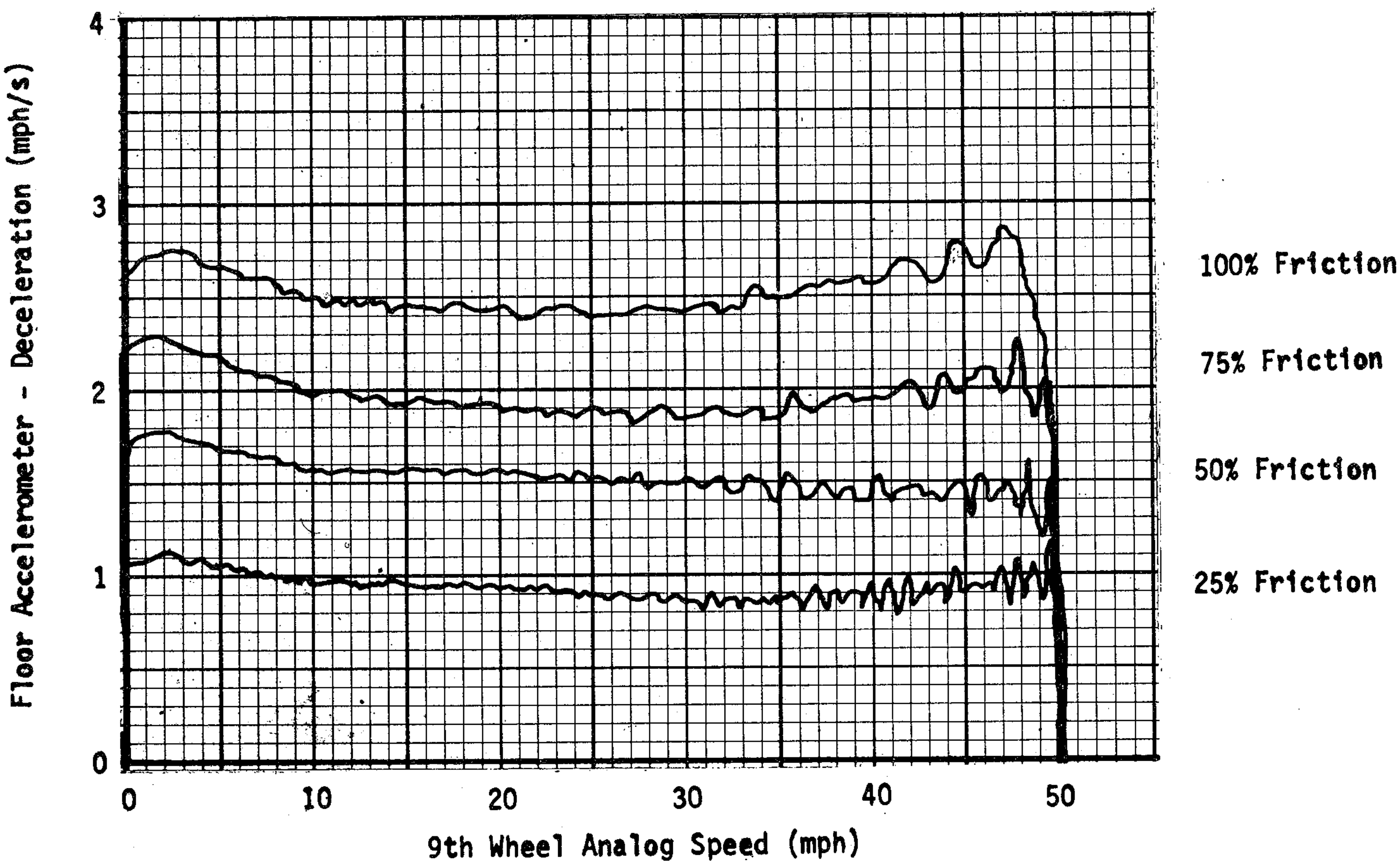
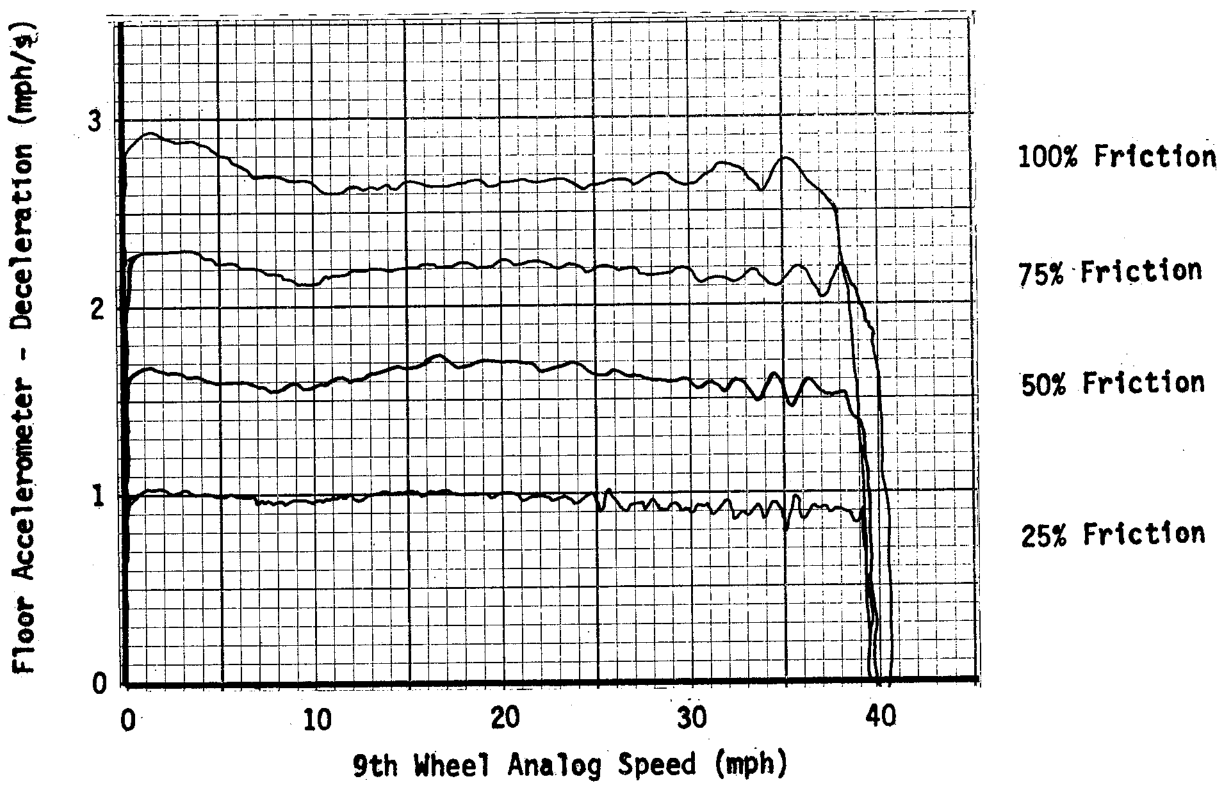


FIGURE PER14. DYNAMIC ONLY DECELERATION AT AW2.



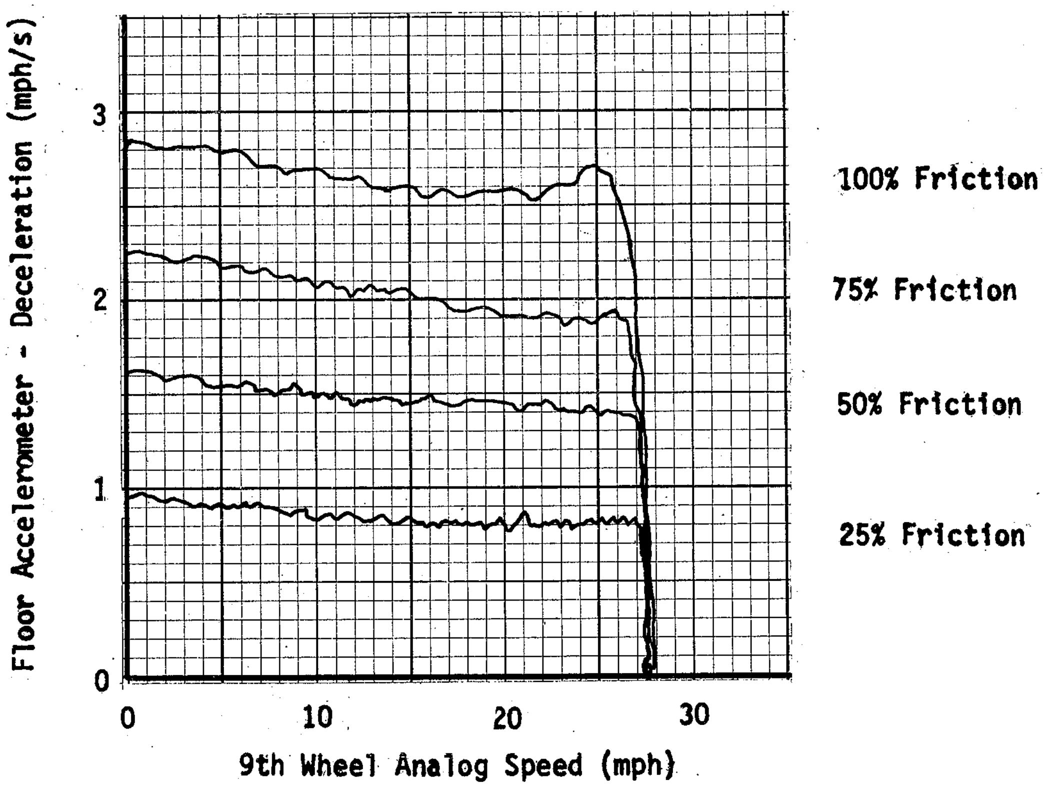
(Hand Traced from Original Plots.)

FIGURE PER15. FRICTION ONLY OVERLAY AT AW3 WITH 50 MPH ENTRY SPEED.



(Hand Traced from Original Plots.)

FIGURE PER16. FRICTION ONLY OVERLAY AT AW3 WITH 40 MPH ENTRY SPEED.



(Hand Traced from Original Plots.)

FIGURE PER17. FRICTION ONLY OVERLAY AT AW3 WITH 28 MPH ENTRY SPEED.

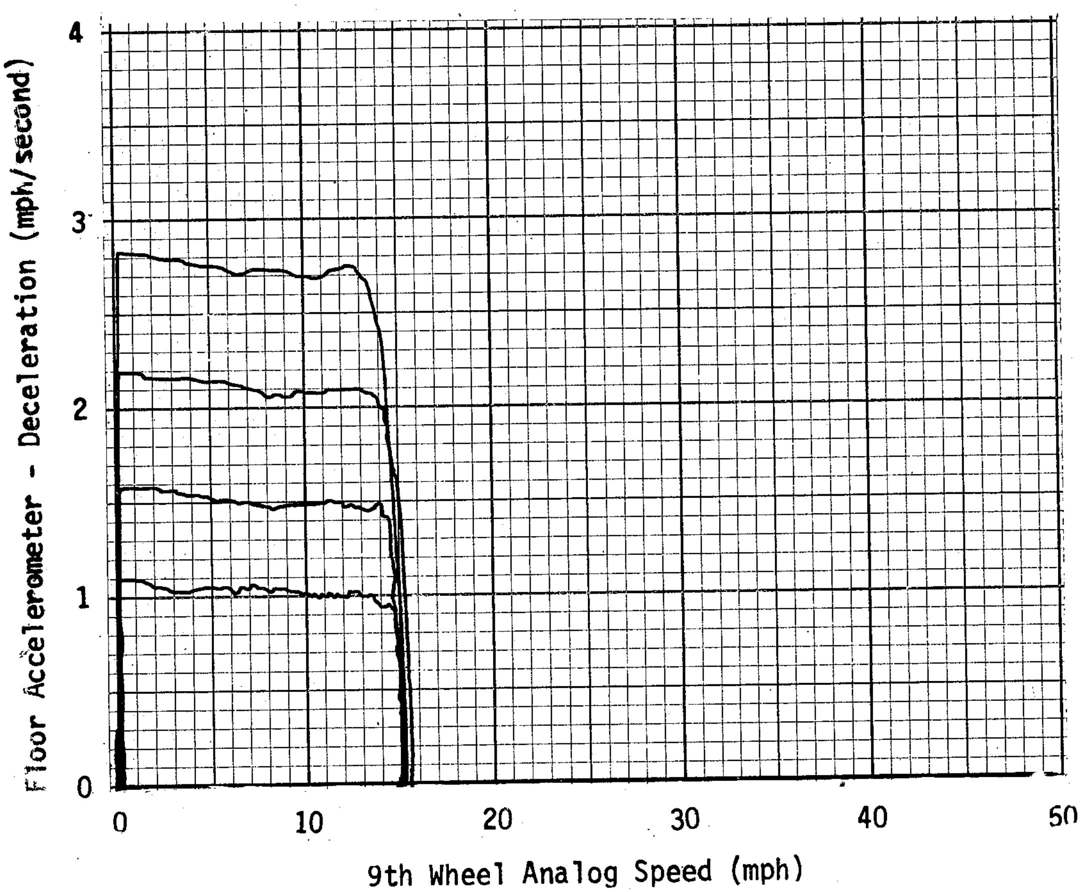


FIGURE PER18. FRICTION ONLY OVERLAY AT AW3 WITH 15 MPH ENTRY SPEED.

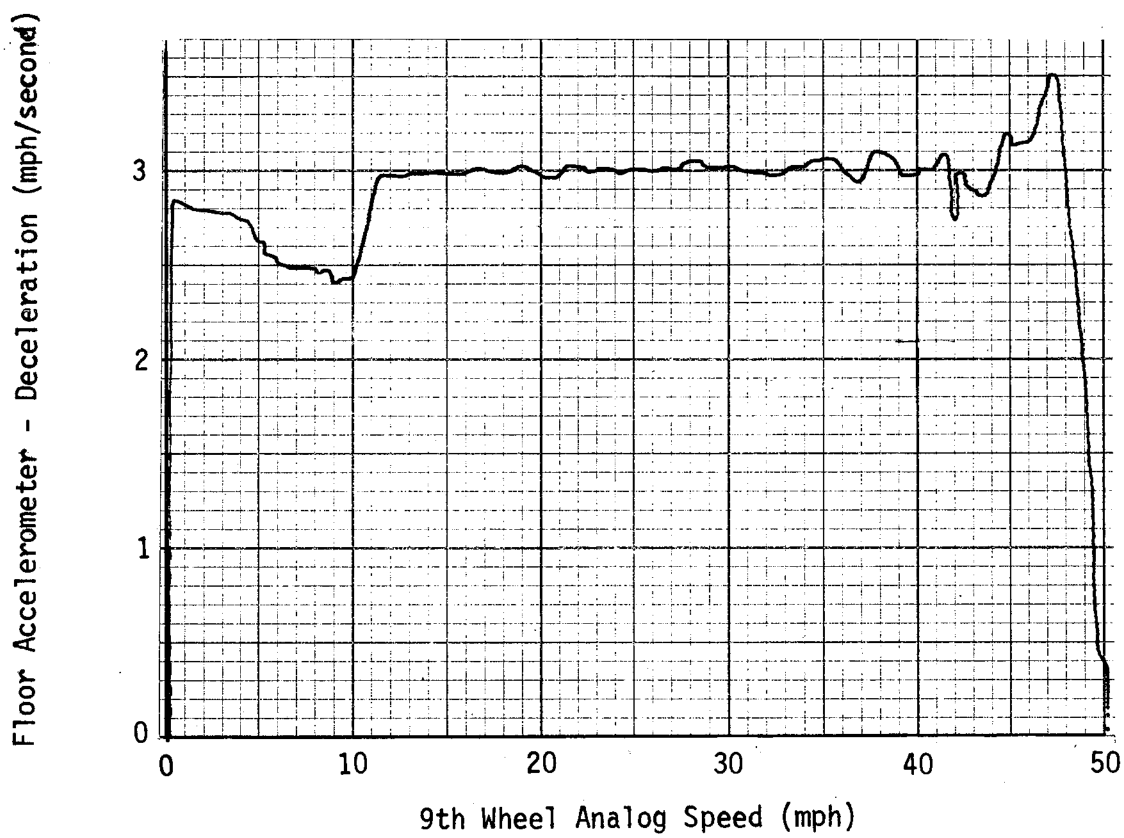


FIGURE PER19. BLENDED BRAKING AT AW3 WITH FADE SPEED OF 11.5 MPH.

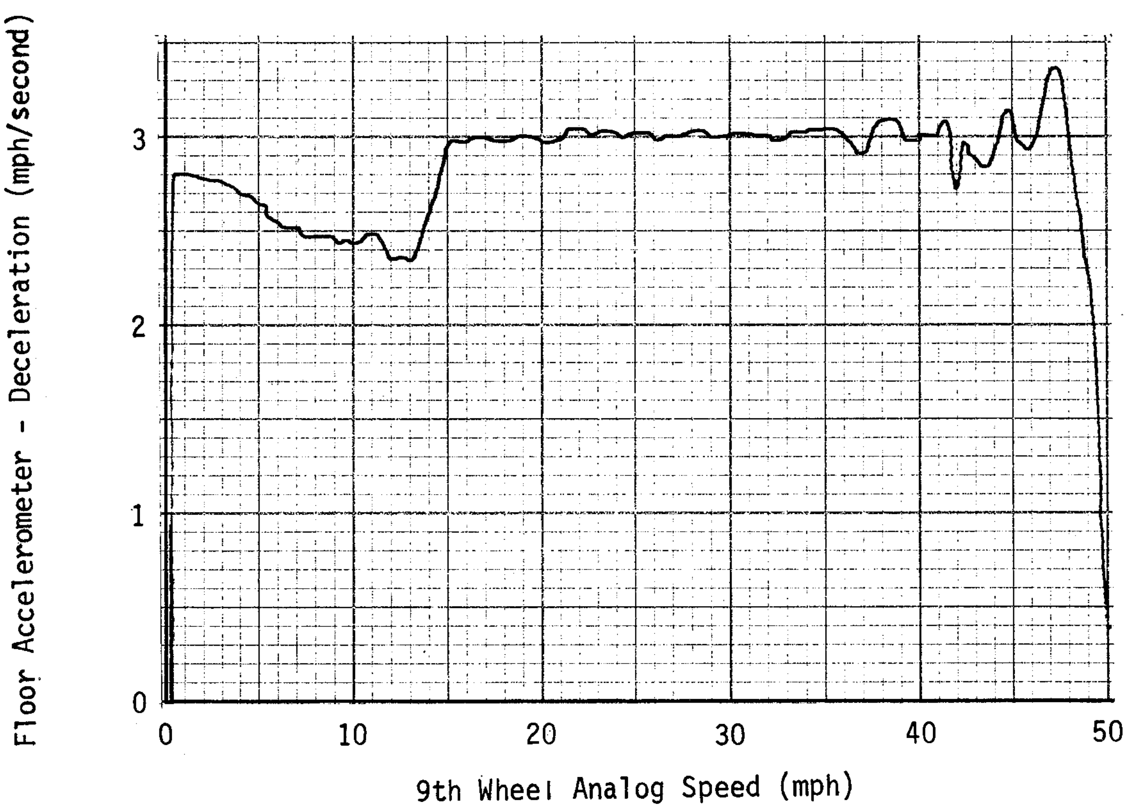


FIGURE PER20. BLENDED BRAKING AT AW3 WITH FADE SPEED OF 14.75 MPH.

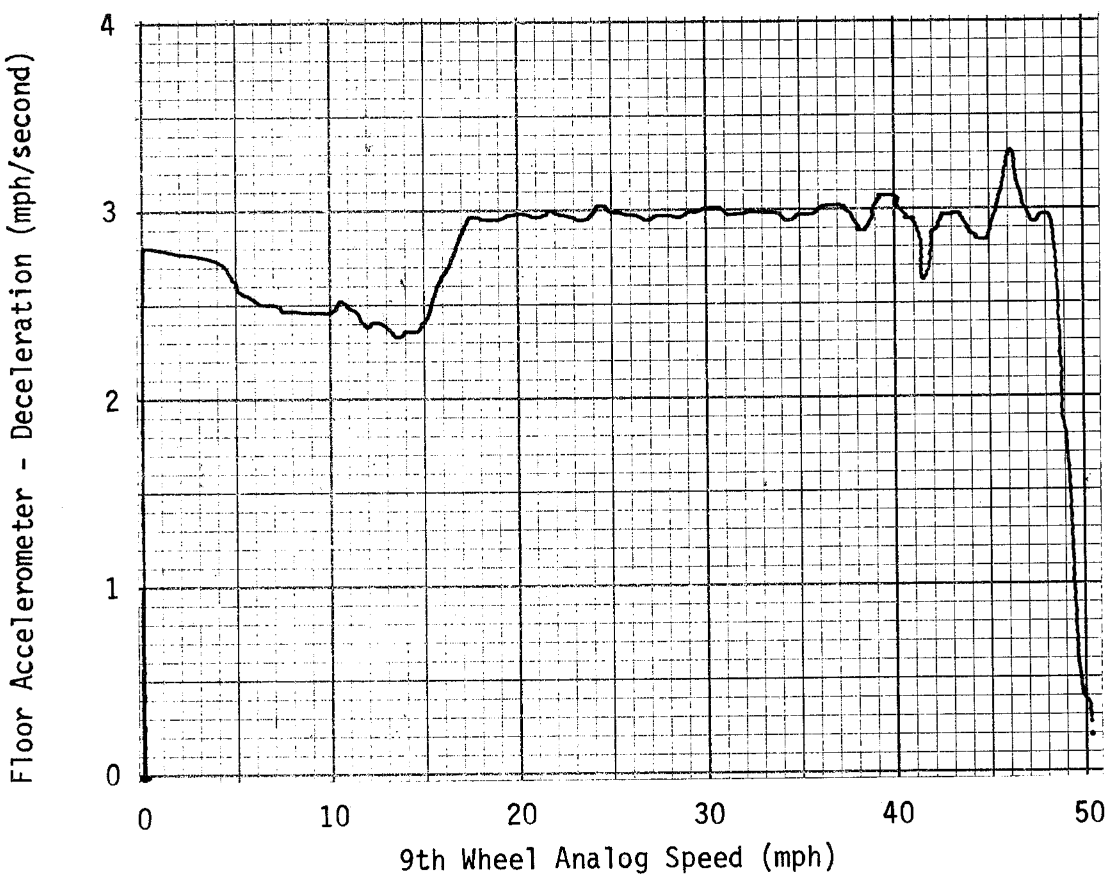


FIGURE PER21. BLENDED BRAKING AT AW3 WITH FADE SPEED OF 17.2 MPH.

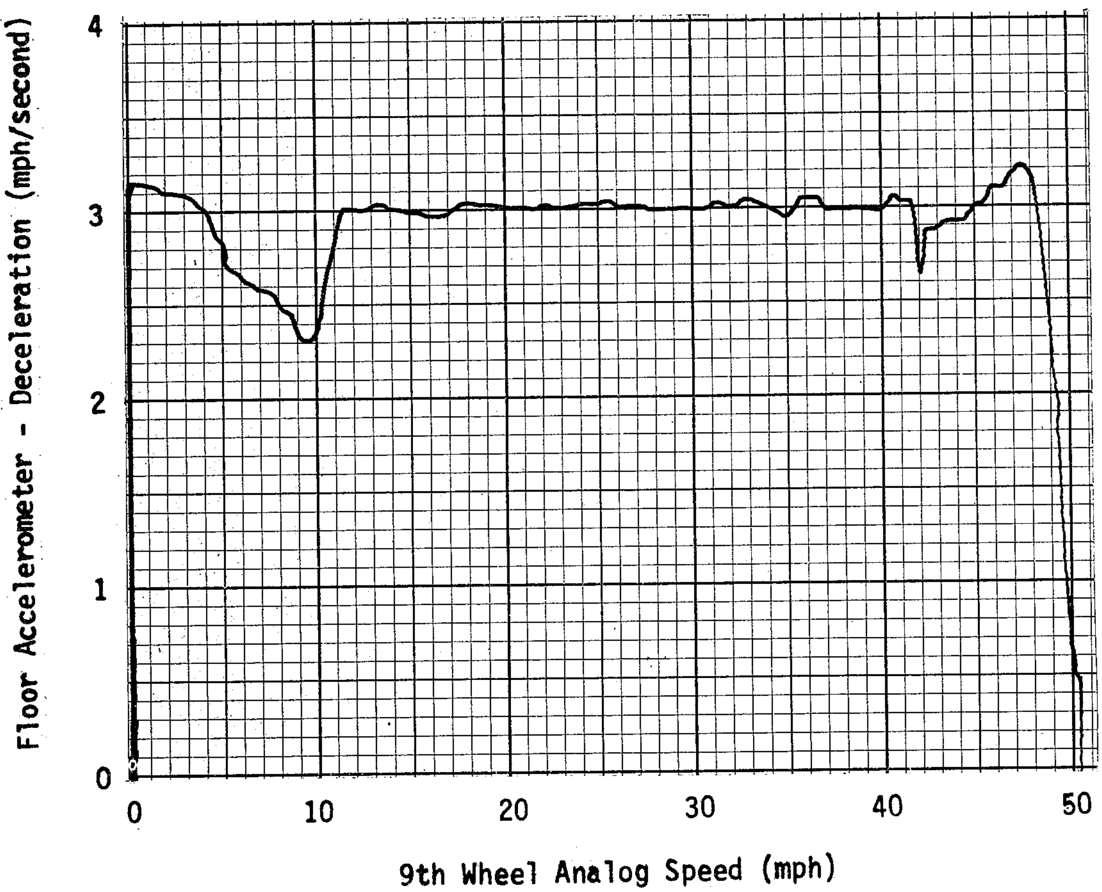


FIGURE PER22. BLENDING CHARACTERISTICS AT AW3 FROM 50 MPH.

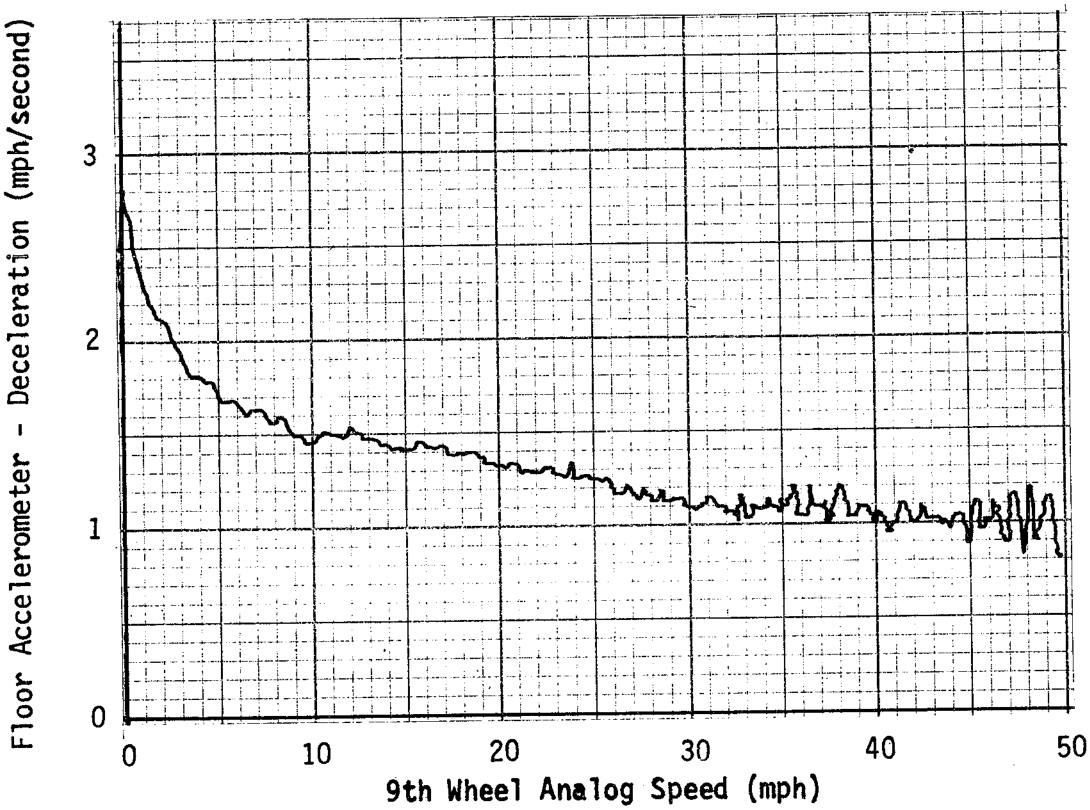


FIGURE PER23. TRACK BRAKE ONLY WITH INITIAL SPEED OF 50 MPH AT AW3.

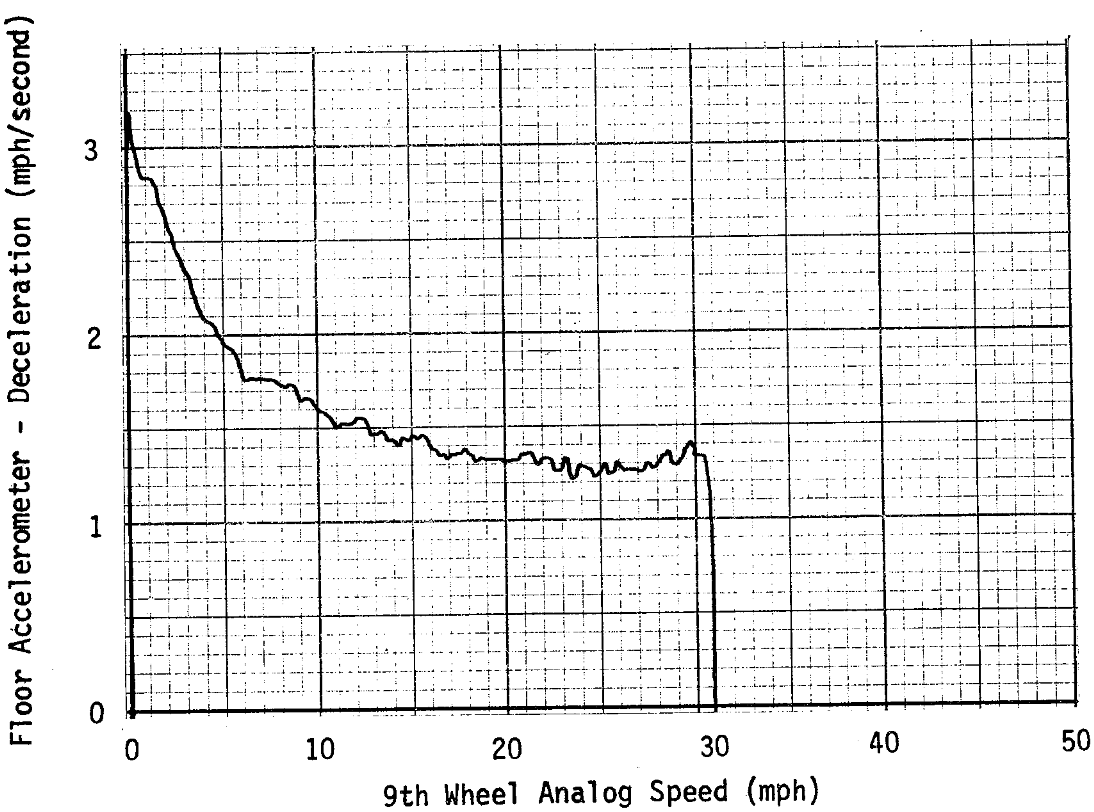


FIGURE PER24. TRACK BRAKE ONLY WITH INITIAL SPEED OF 30 MPH AT AW3.

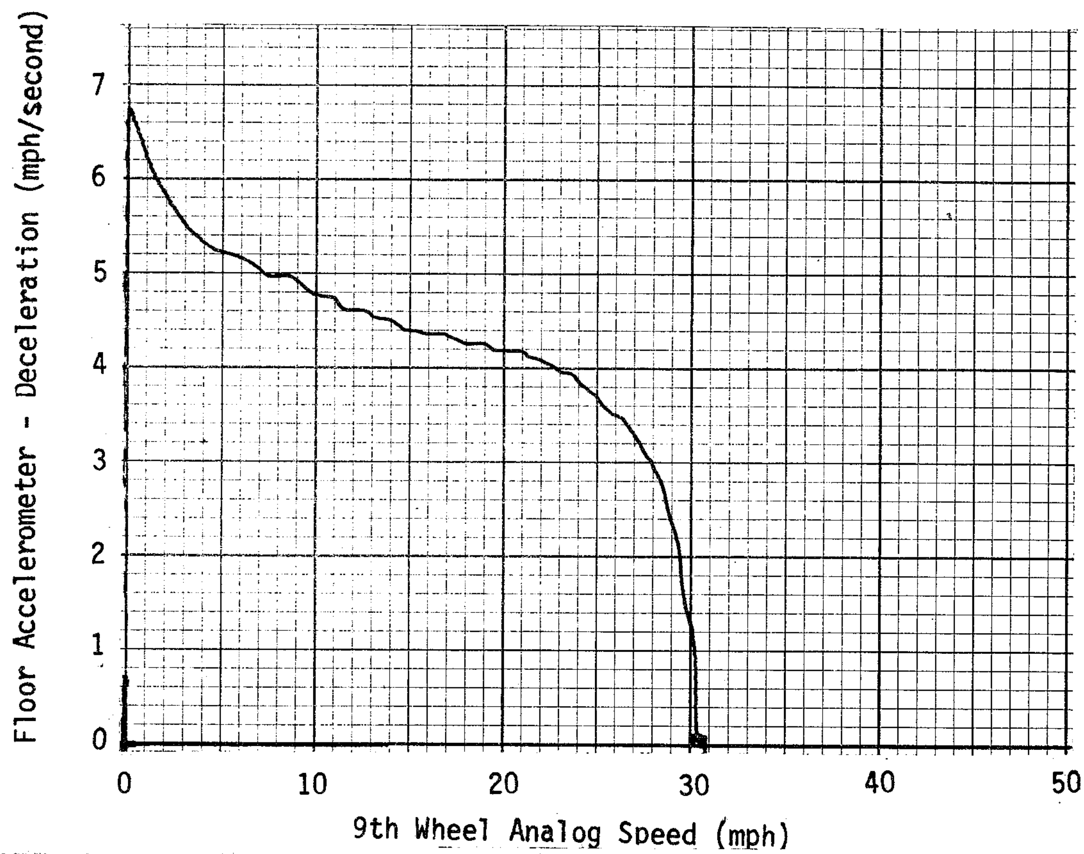


FIGURE PER25. FRICTION PLUS TRACK BRAKE AT AW3 WITH INITIAL SPEED OF 30 MPH.

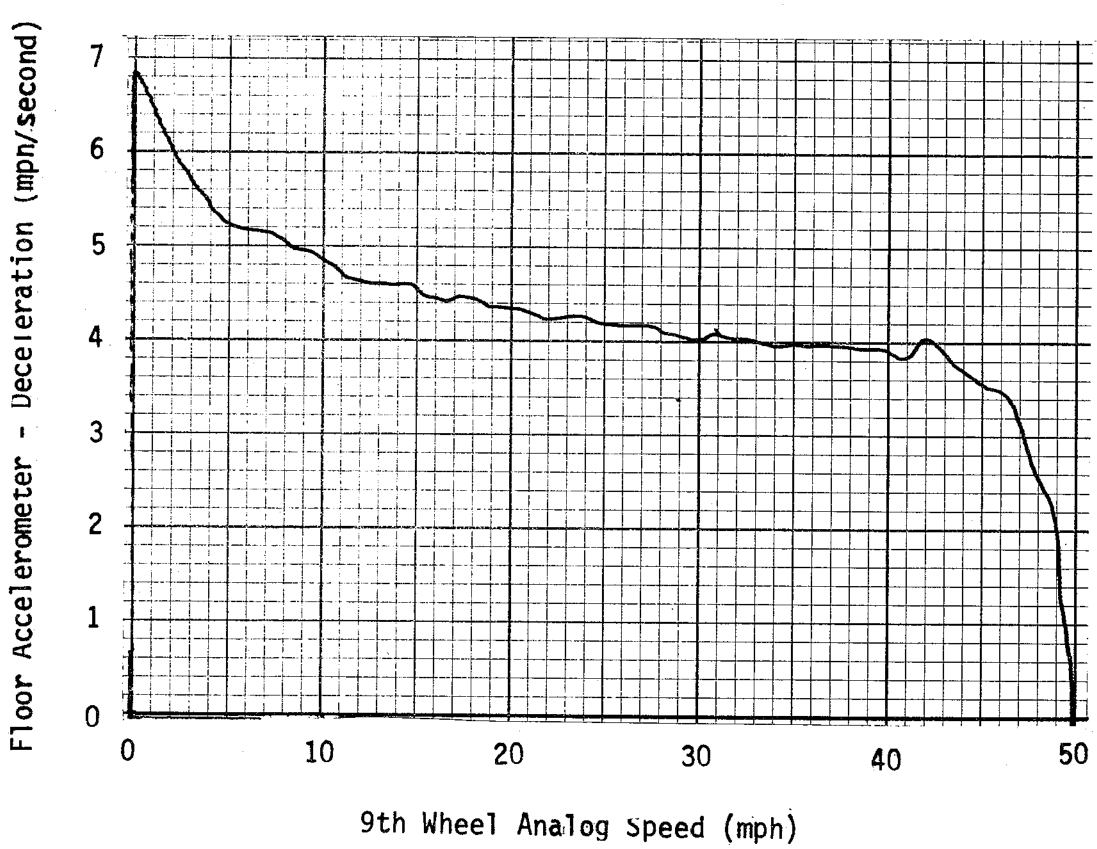


FIGURE PER26. FRICTION PLUS TRACK BRAKE AT AW3 WITH INITIAL SPEED OF 50 MPH.

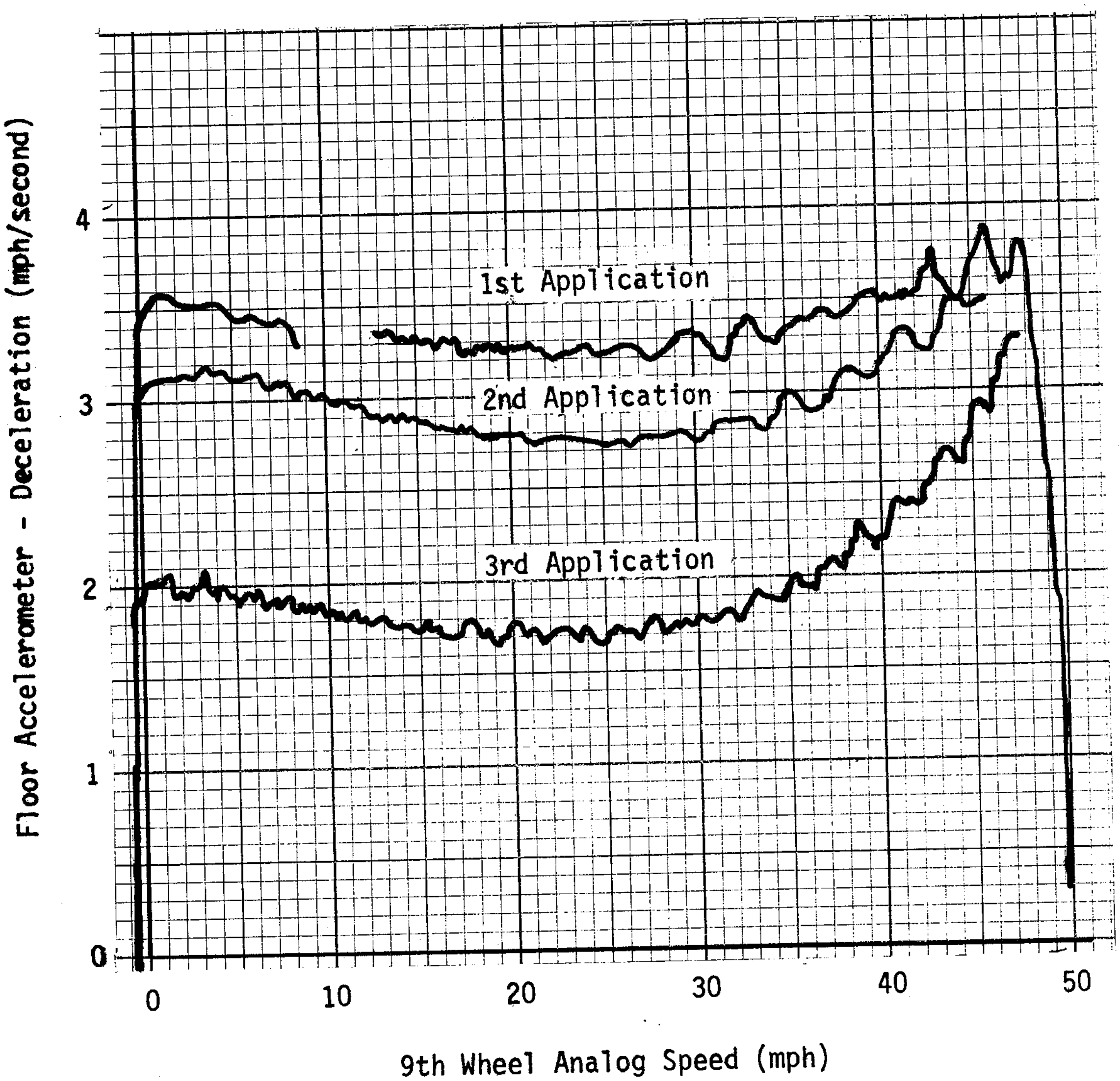


FIGURE PER27. BRAKE FADE CHARACTERISTICS ON SUCCESSIVE APPLICATIONS.

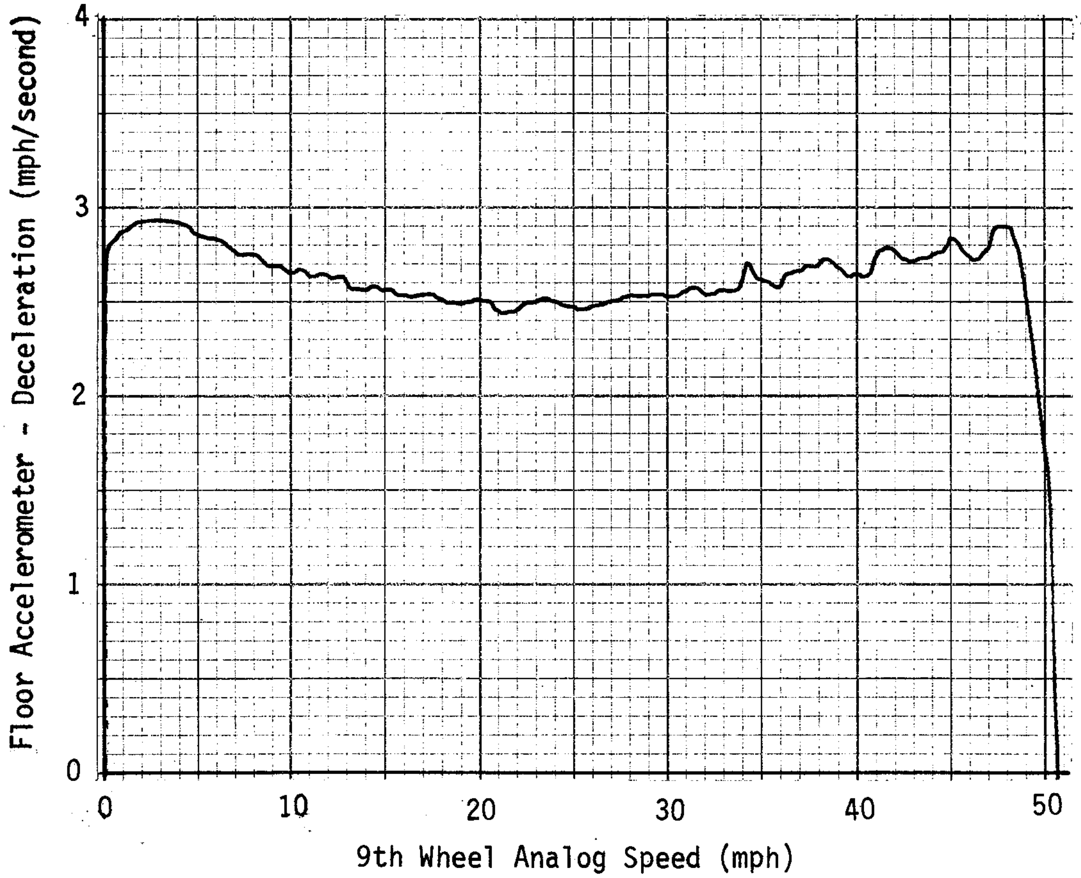


FIGURE PER28. FRICTION ONLY CHARACTERISTICS AT AW3.

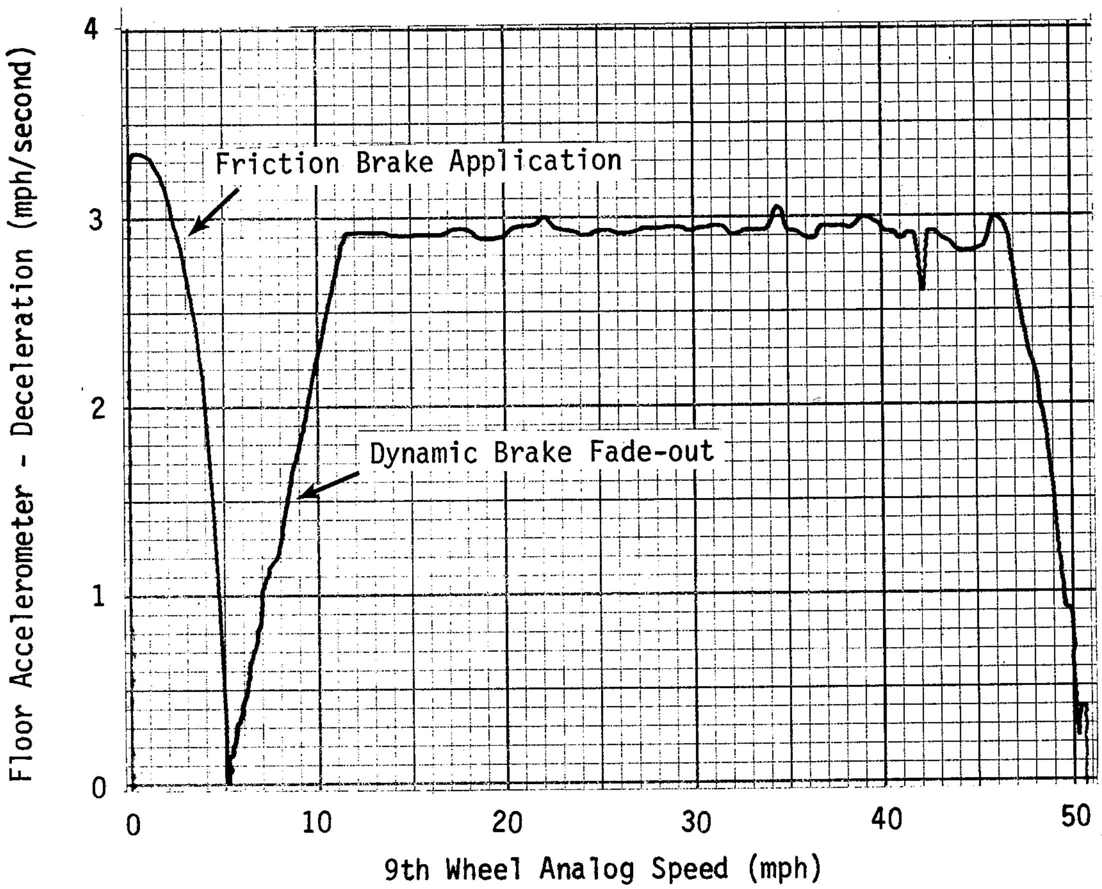


FIGURE PER29. DYNAMIC ONLY CHARACTERISTICS AT AW3.

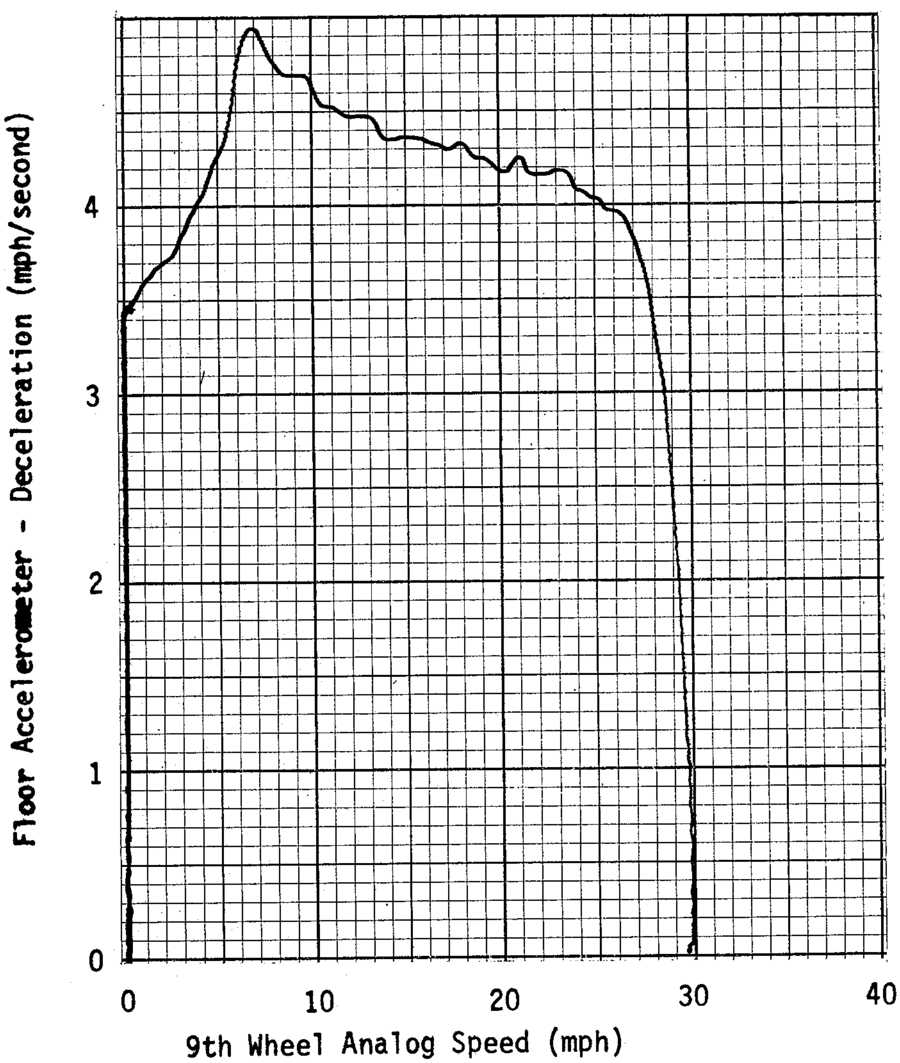


FIGURE PER30. TRACK BRAKE RELEASE.

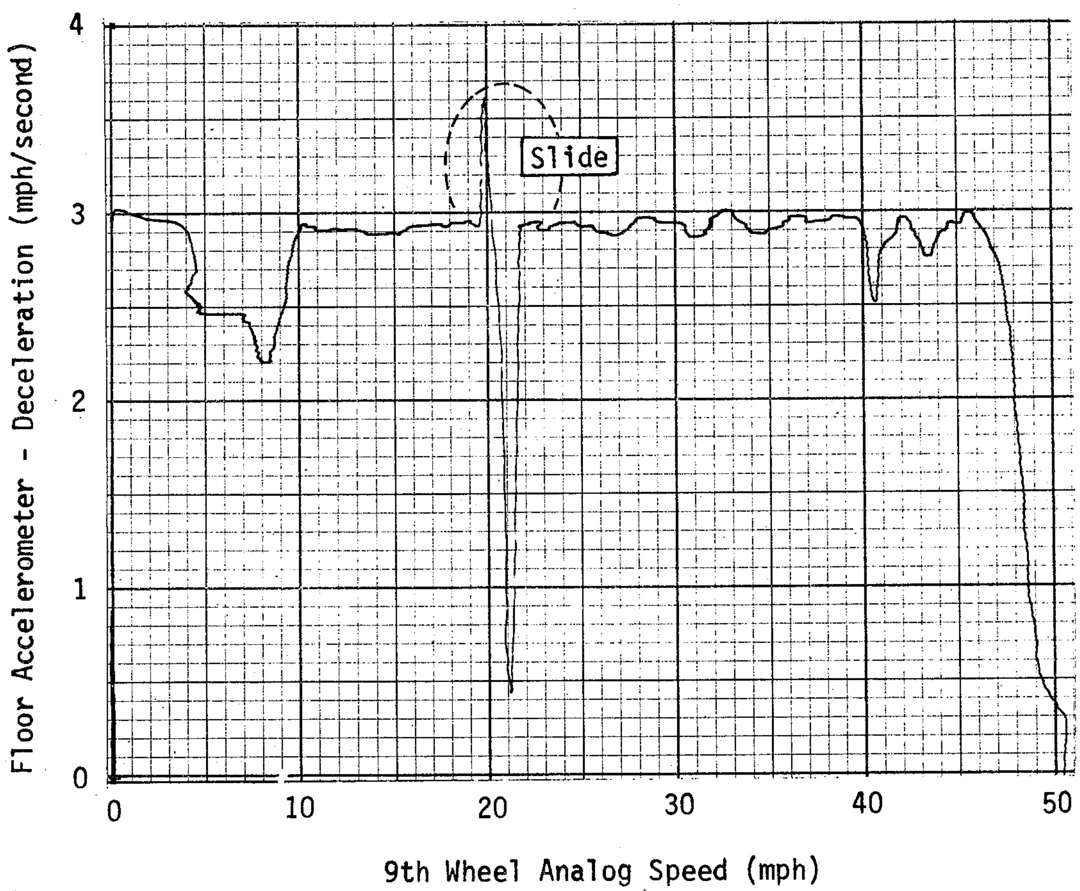


FIGURE PER31. SLIDE OCCURRENCE.

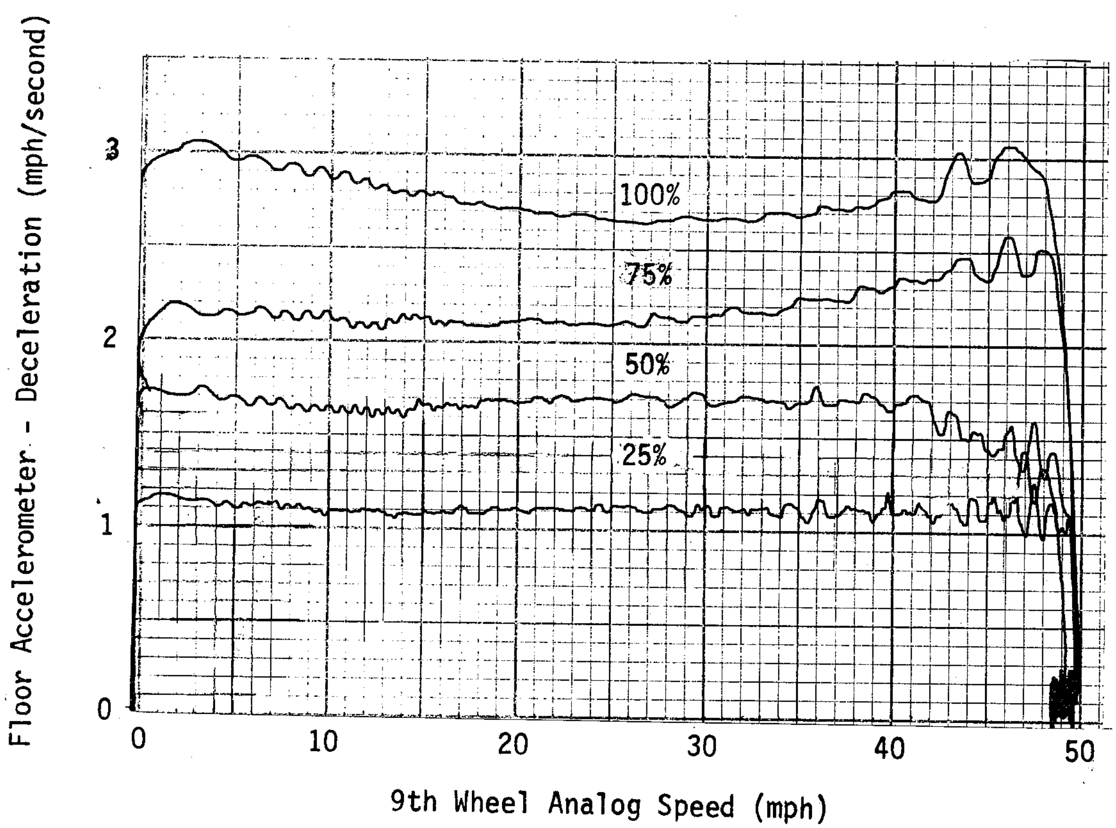


FIGURE PER32. FRICTION ONLY AT AW2 WITH ORIGINAL PADS.

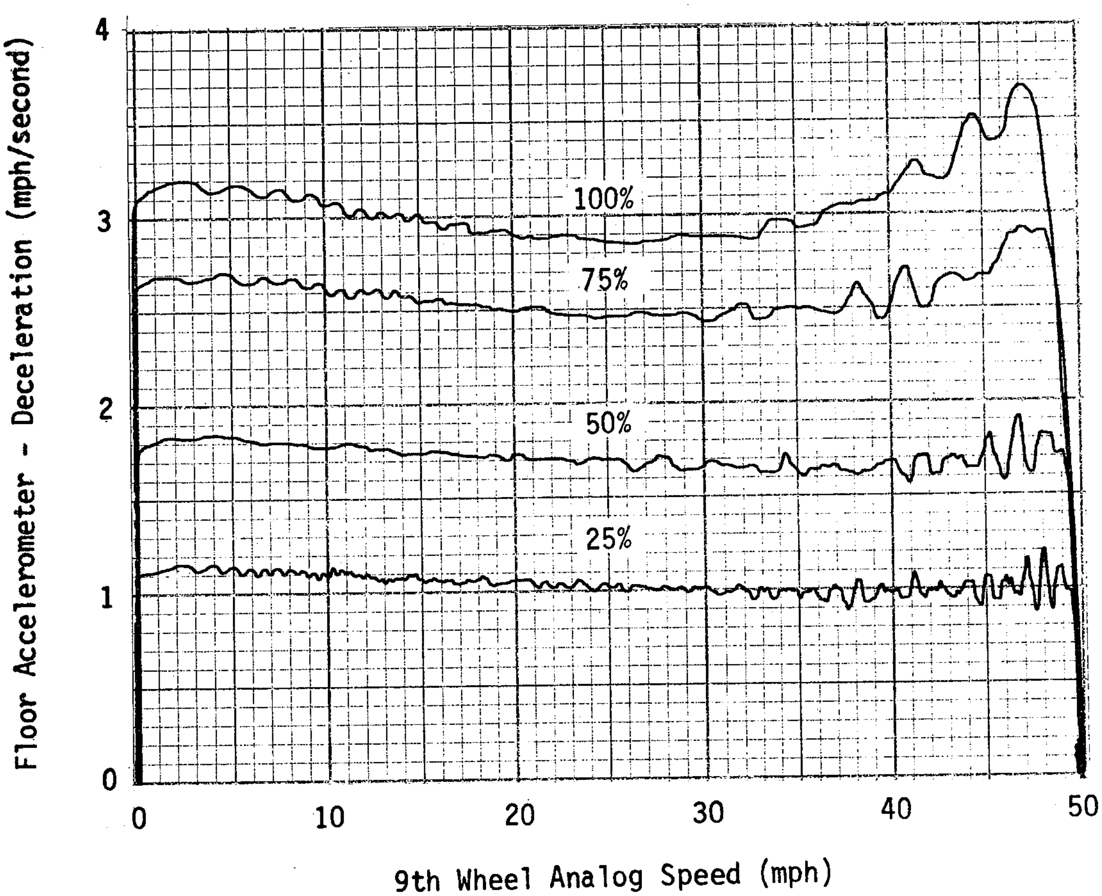


FIGURE PER33. FRICTION ONLY AT AW2 WITH REPLACEMENT PADS.

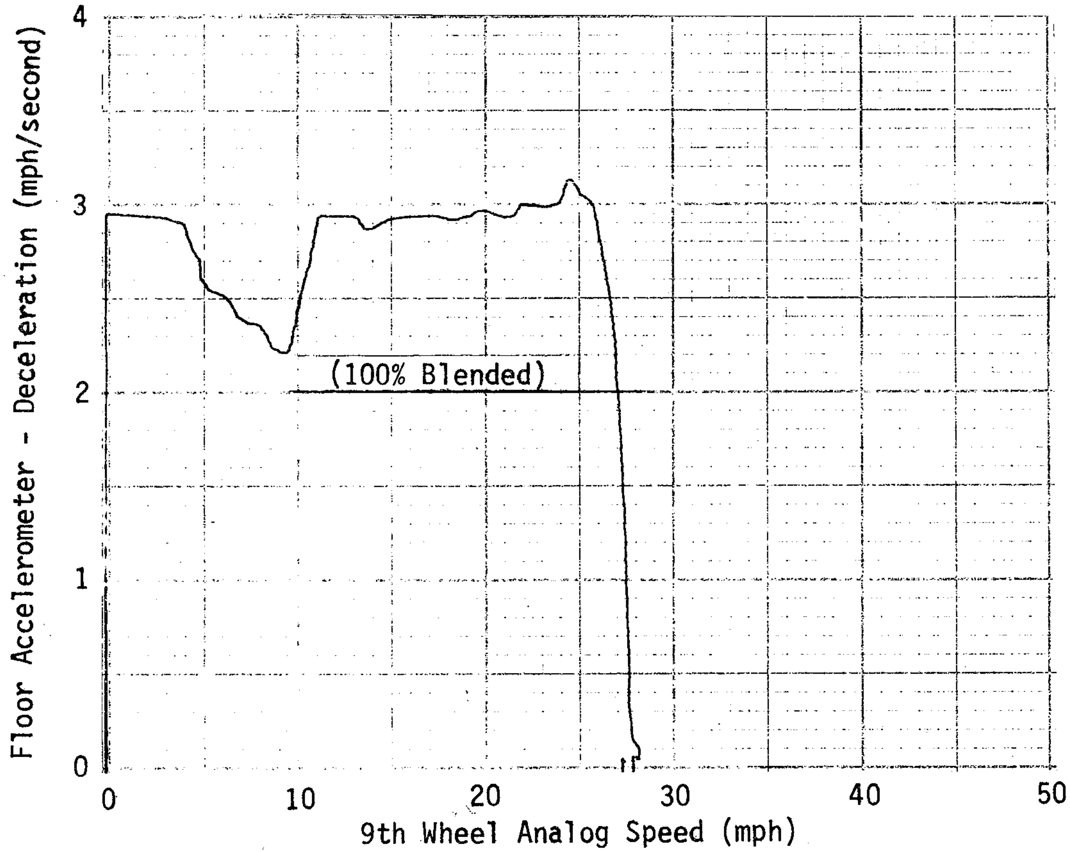


FIGURE PER34. BLENDED BRAKING AT AW2 WITH ORIGINAL PADS.

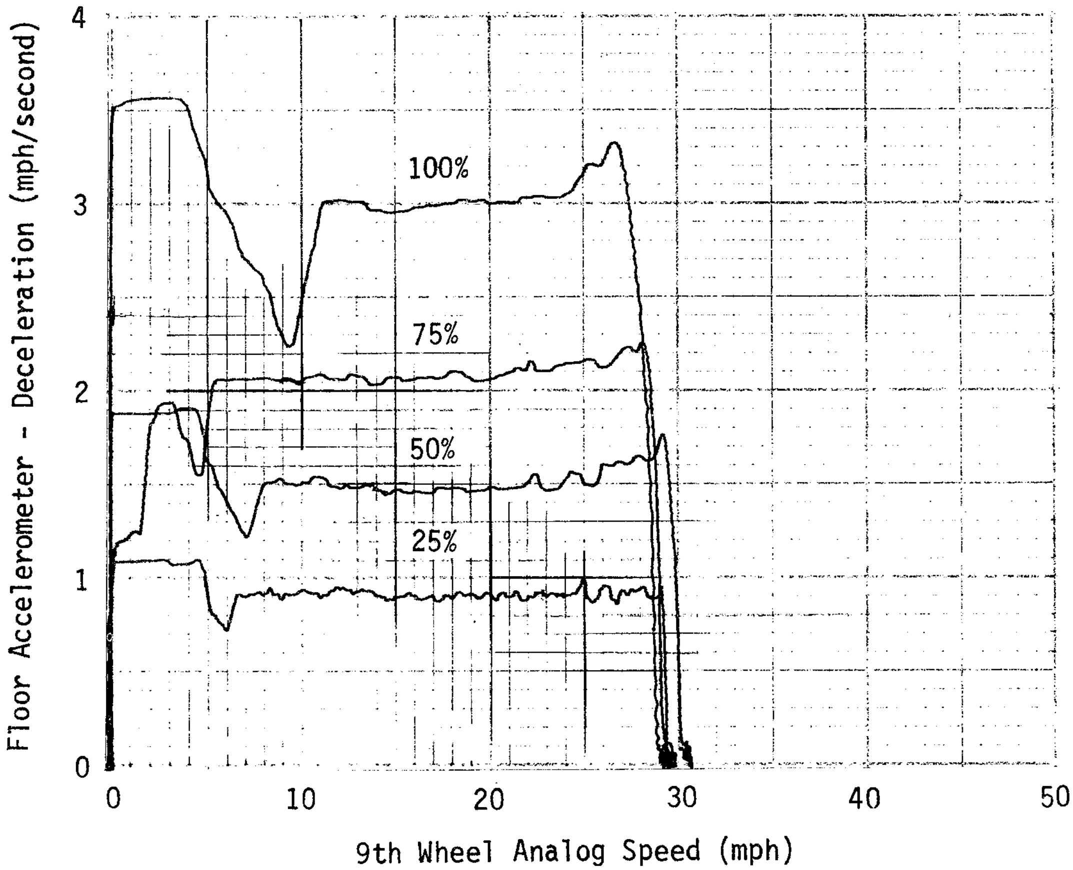


FIGURE PER35. BLENDED BRAKING AT AW2 WITH REPLACEMENT PADS.

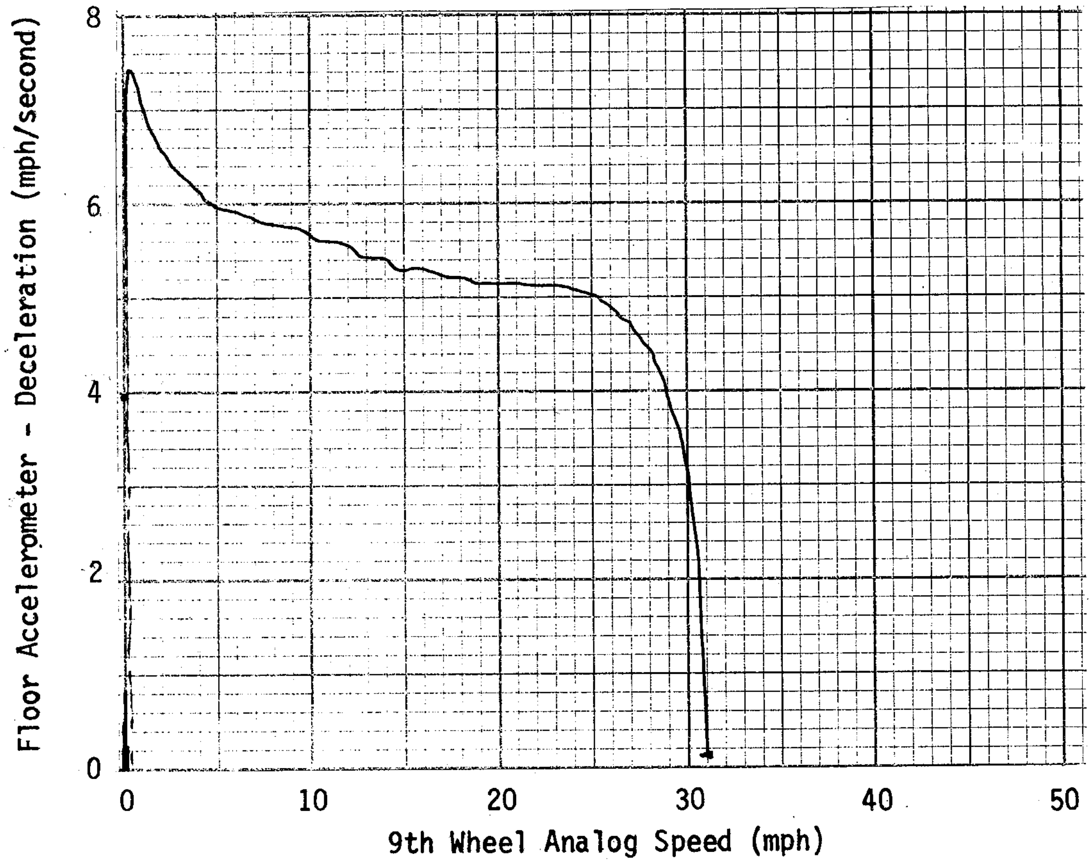


FIGURE PER36. EMERGENCY BRAKING AT AW3 WITH REPLACEMENT PADS, FROM 30 MPH.

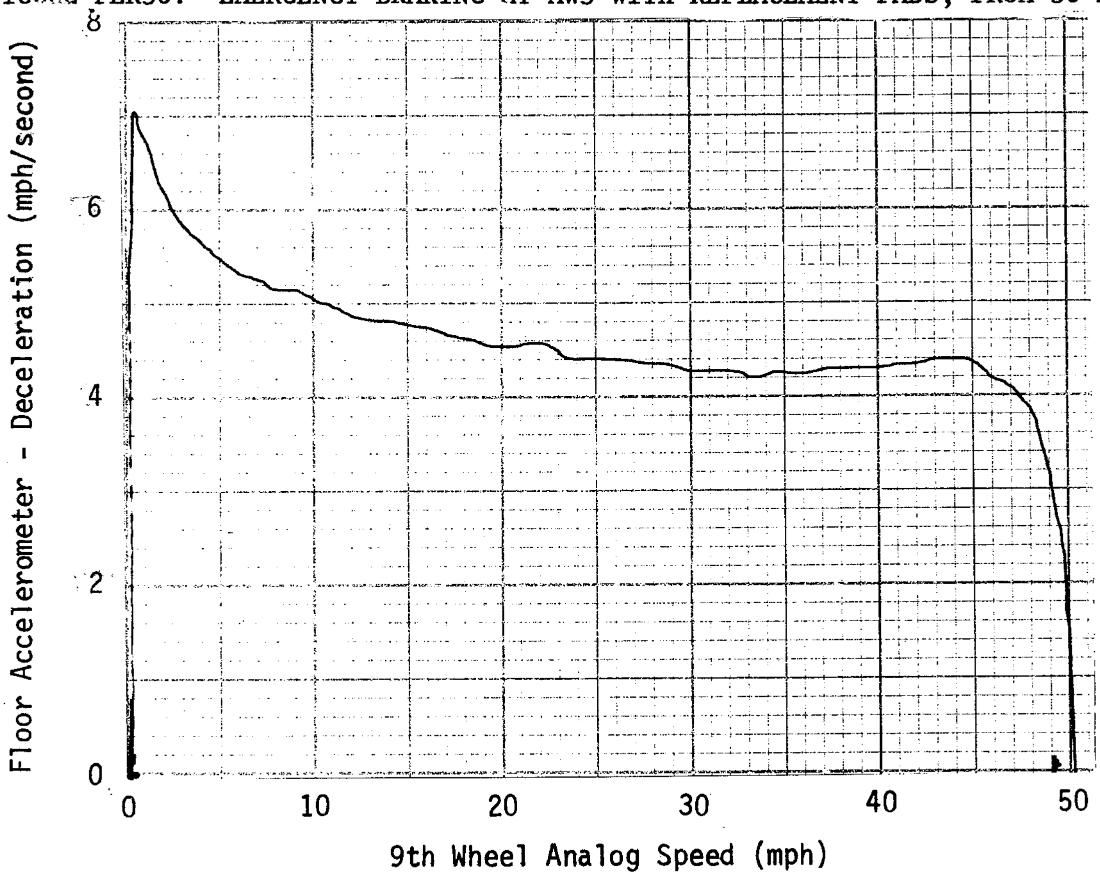


FIGURE PER37. EMERGENCY BRAKING AT AW3 WITH REPLACEMENT PADS, FROM 50 MPH.

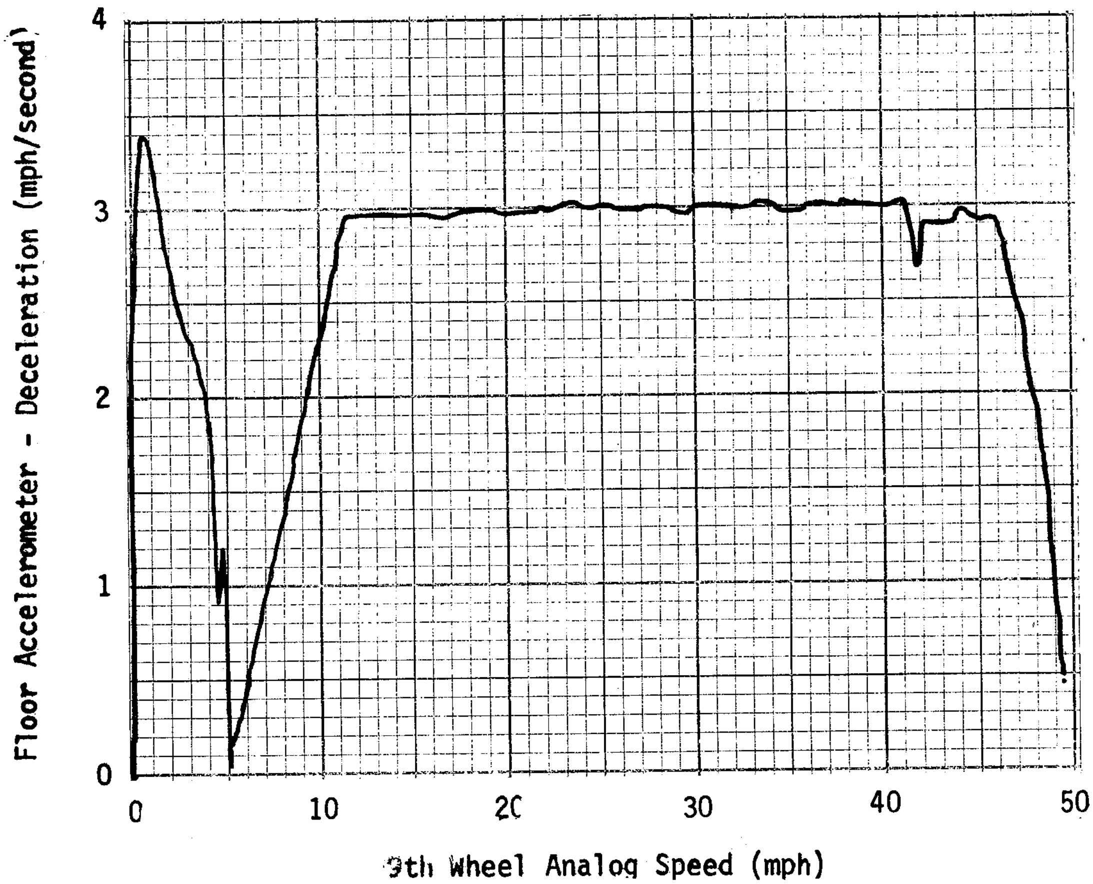


FIGURE PER38. LOADWEIGH FAILURE FROM 50 MPH, DYNAMIC ONLY.

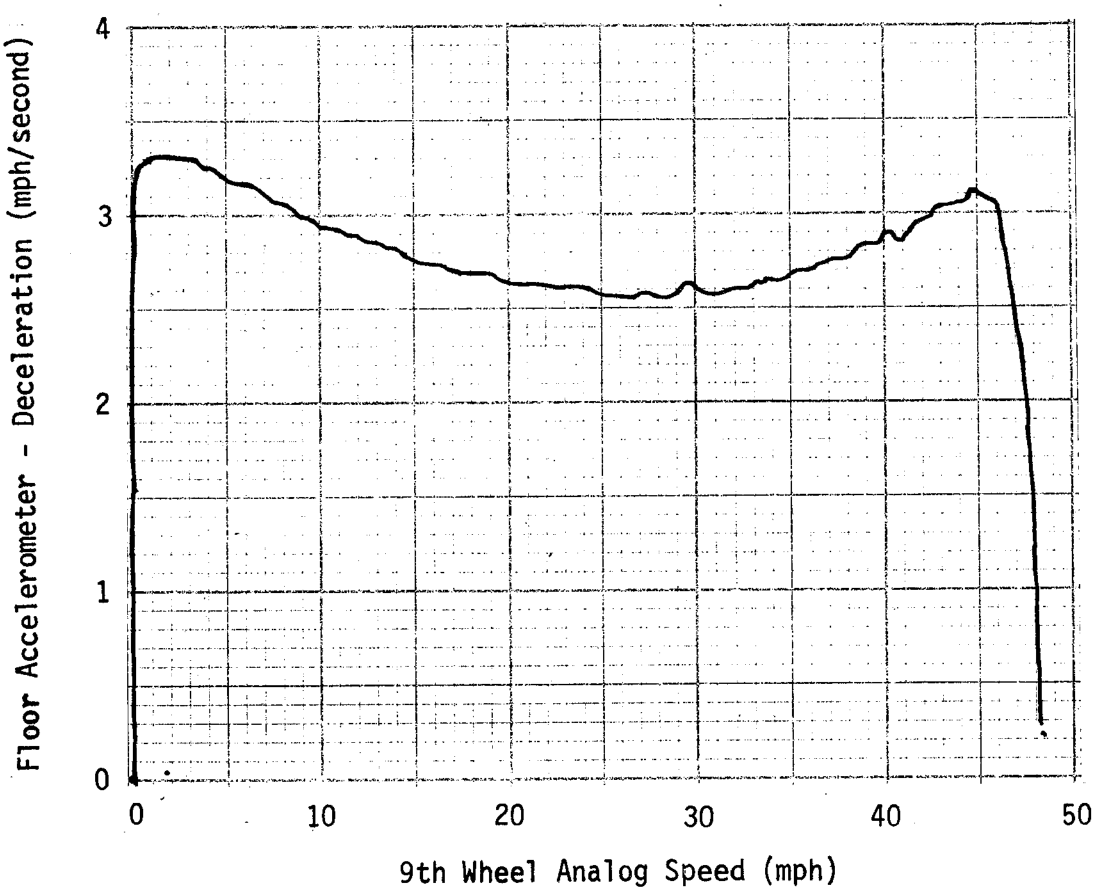


FIGURE PER39. LOADWEIGH FAILURE FROM 50 MPH, FRICTION ONLY.

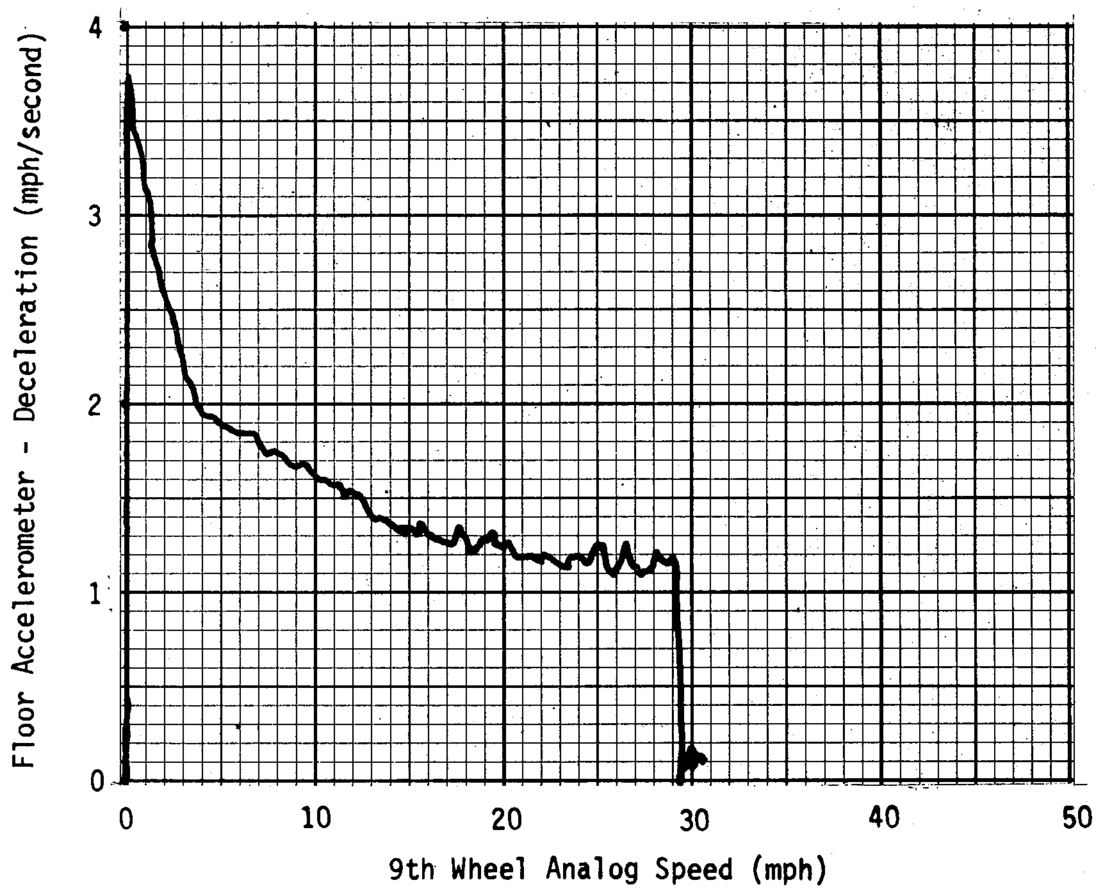


FIGURE PER40. TRACK BRAKE AT AW3.

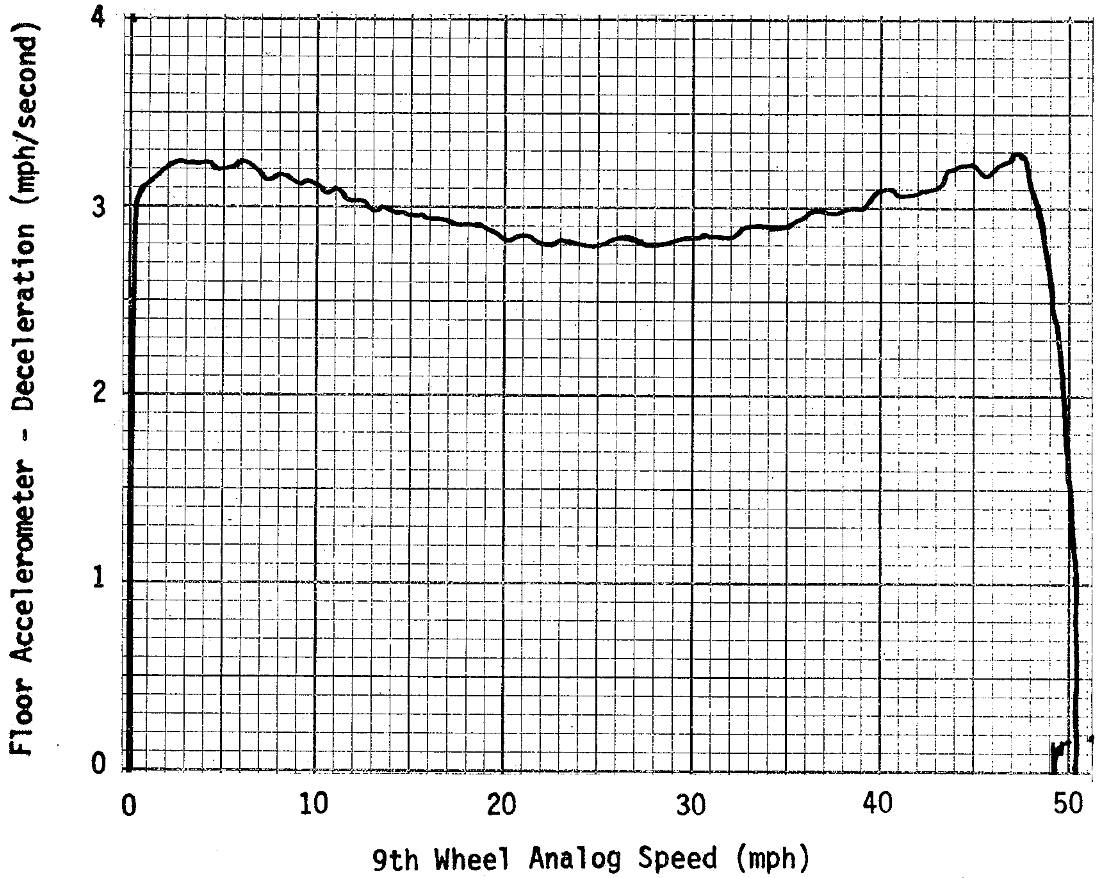


FIGURE PER41. FRICTION ONLY AT AW3.

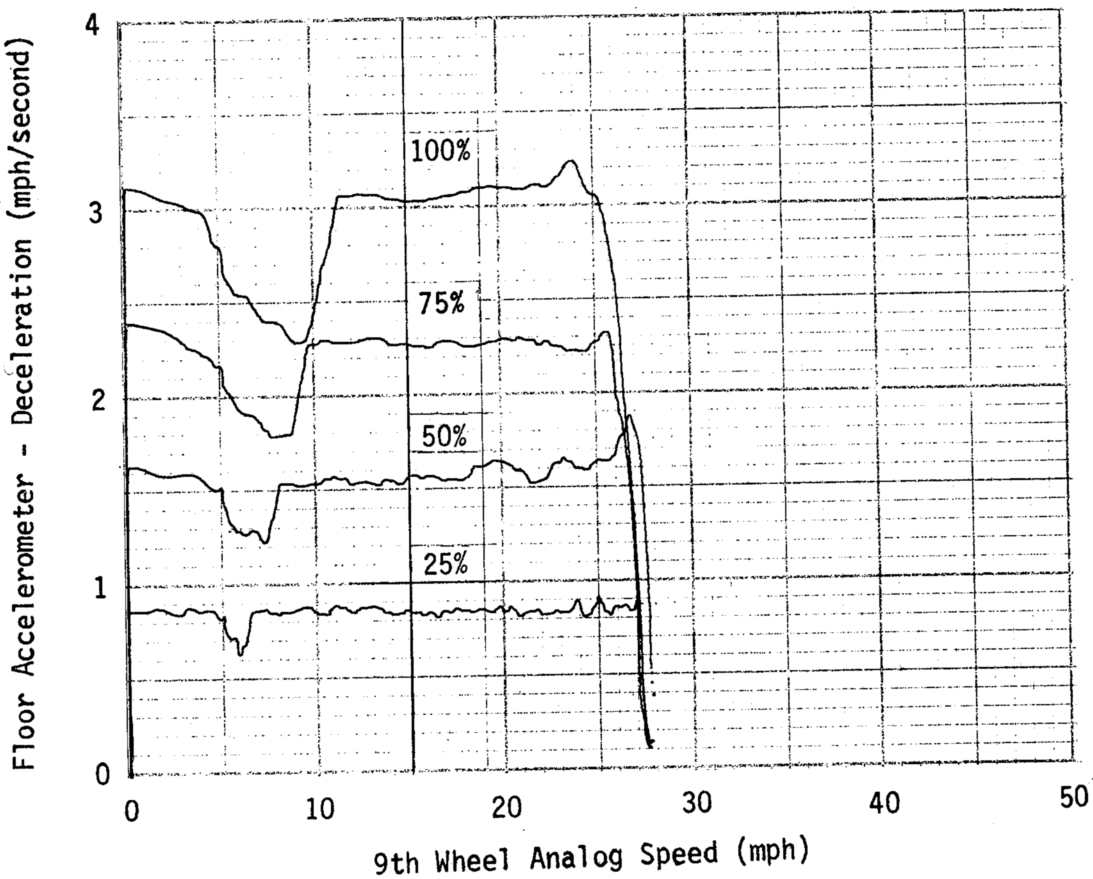


FIGURE PER42. BLENDED ONLY AT AWO WITH ORIGINAL PADS.

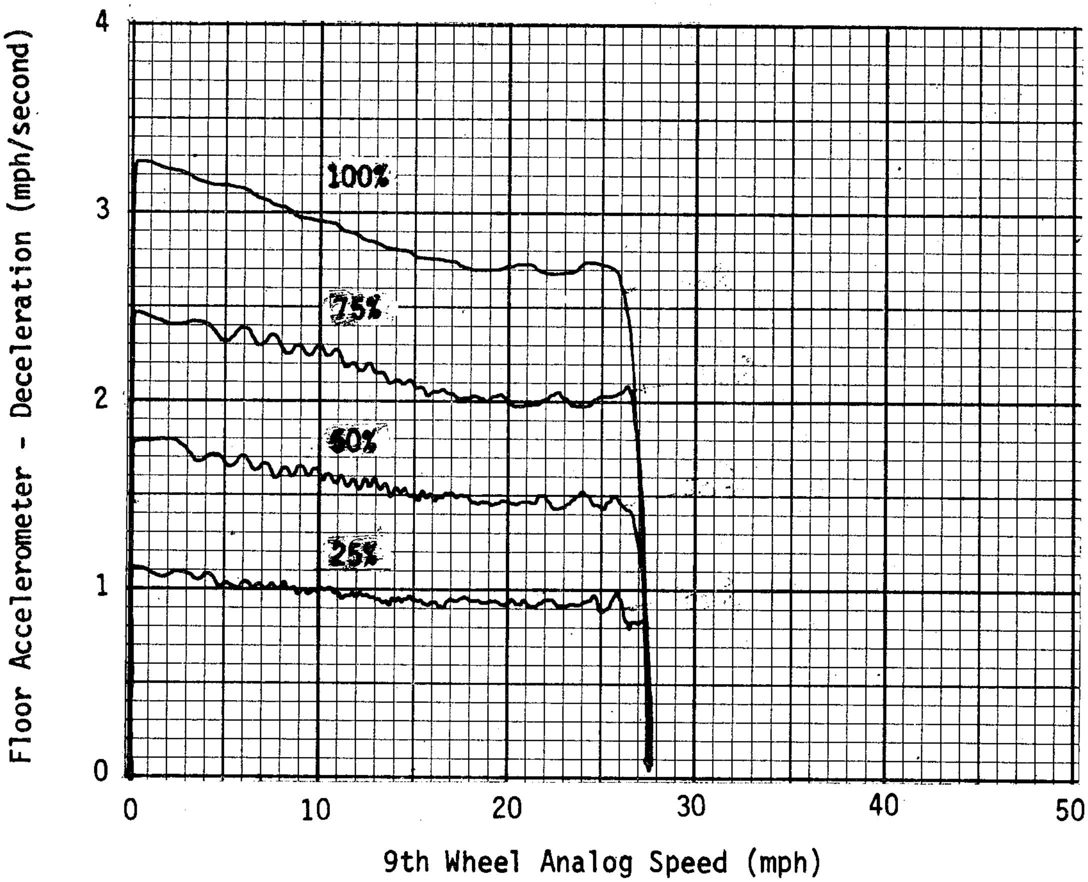


FIGURE PER43. FRICTION ONLY AT AWO WITH ORIGINAL PADS.

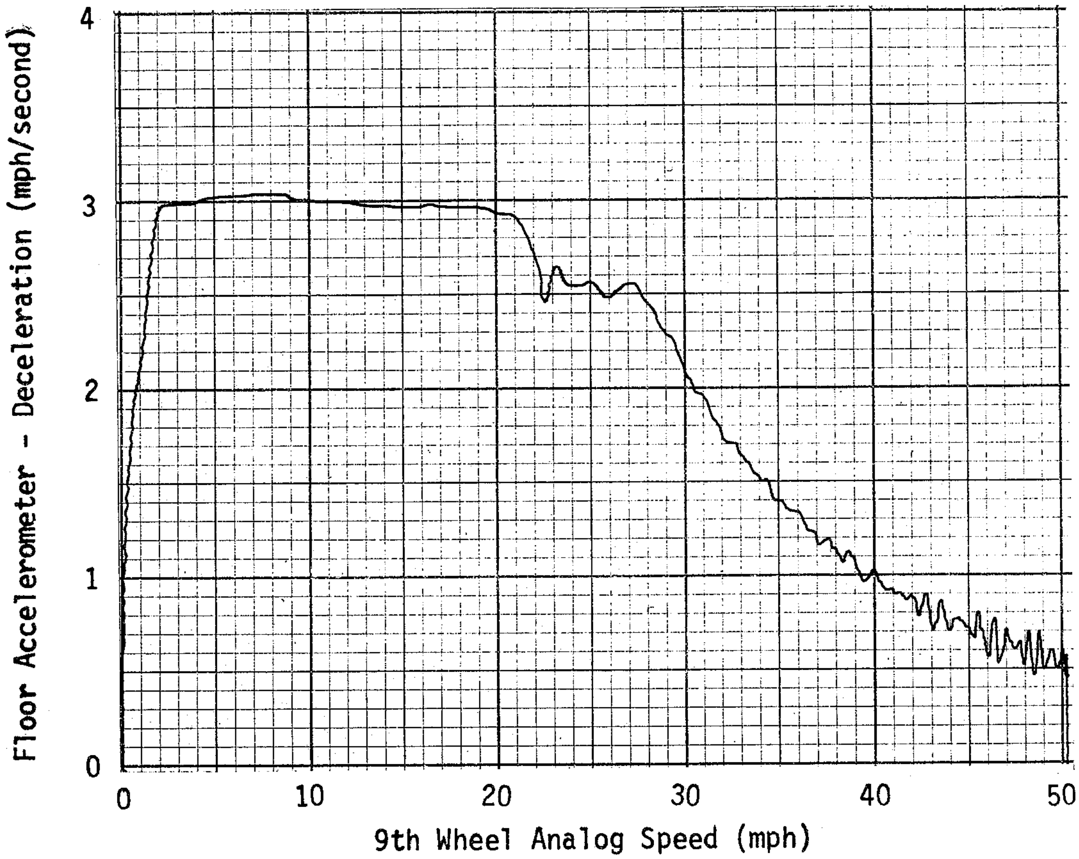


FIGURE PER44. STEP 0 OF WHEEL WEAR AT AWO.

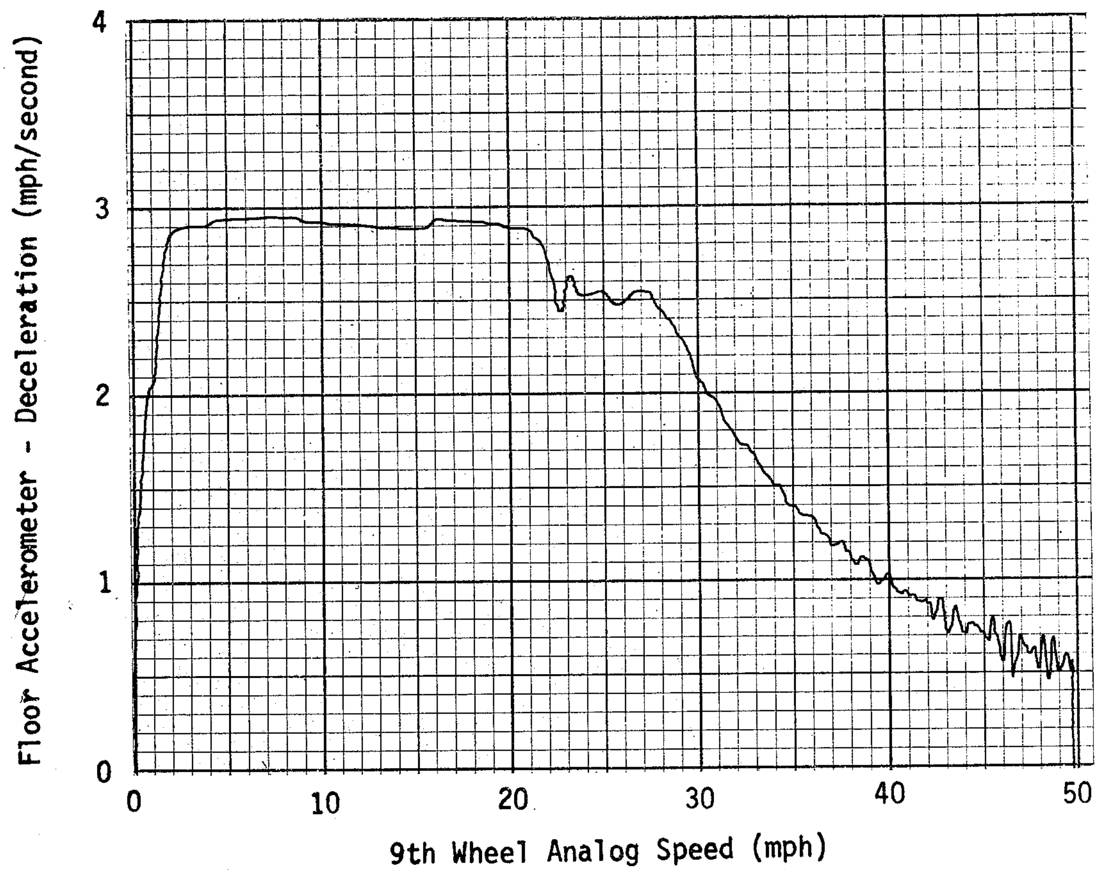


FIGURE PER45. STEP 1 OF WHEEL WEAR AT AWO.

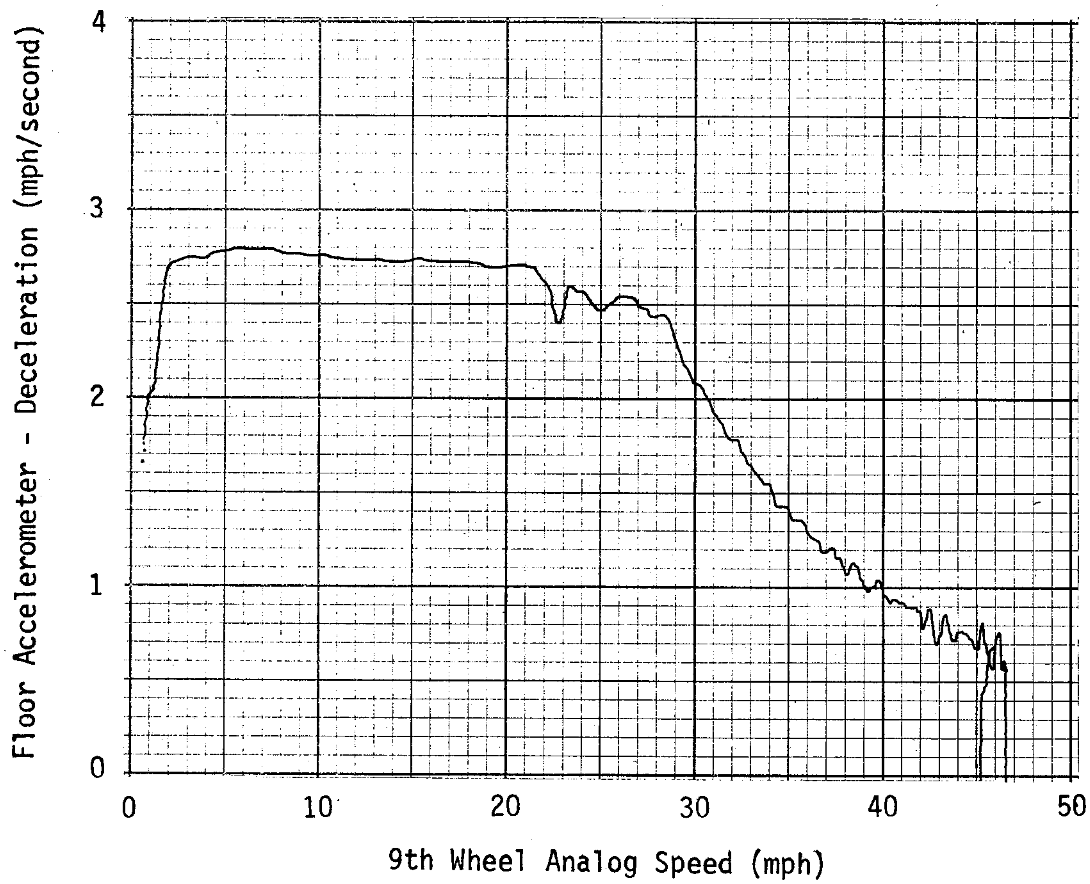


FIGURE PER46. STEP 10 OF WHEEL WEAR AT AWO.

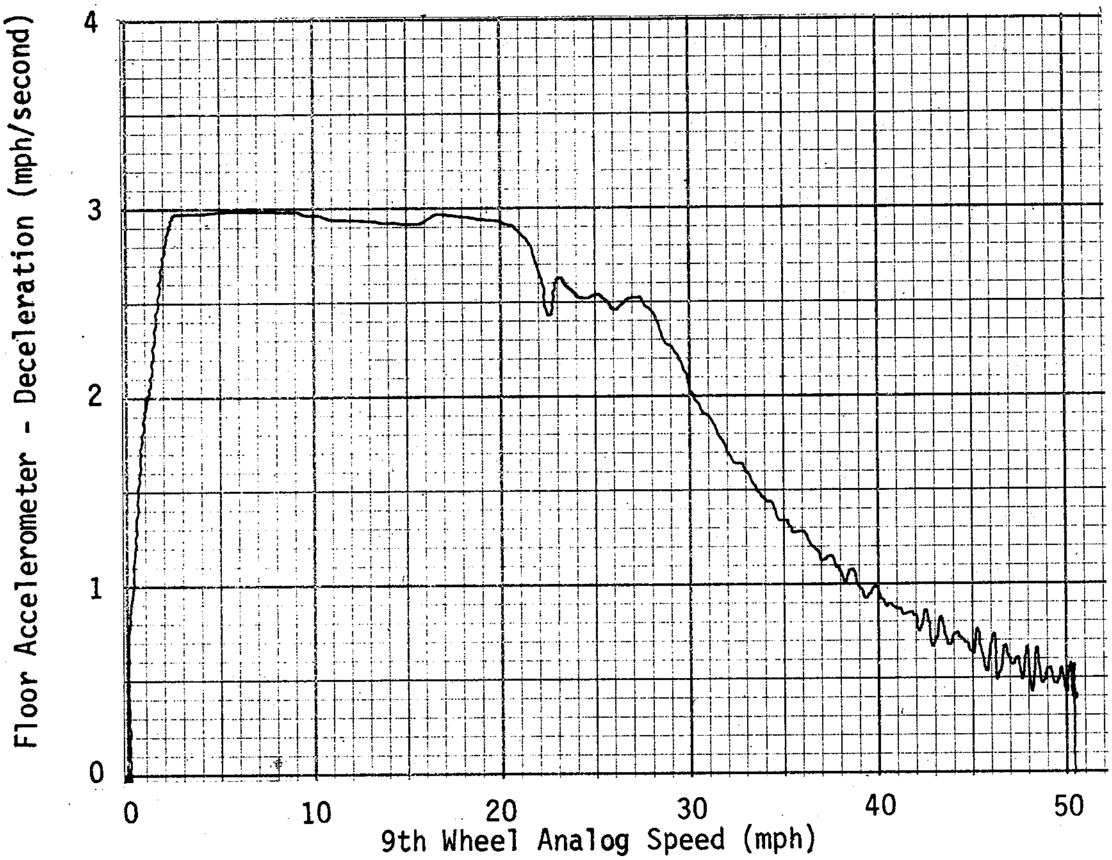


FIGURE PER47. AW0 CHARACTERISTICS.

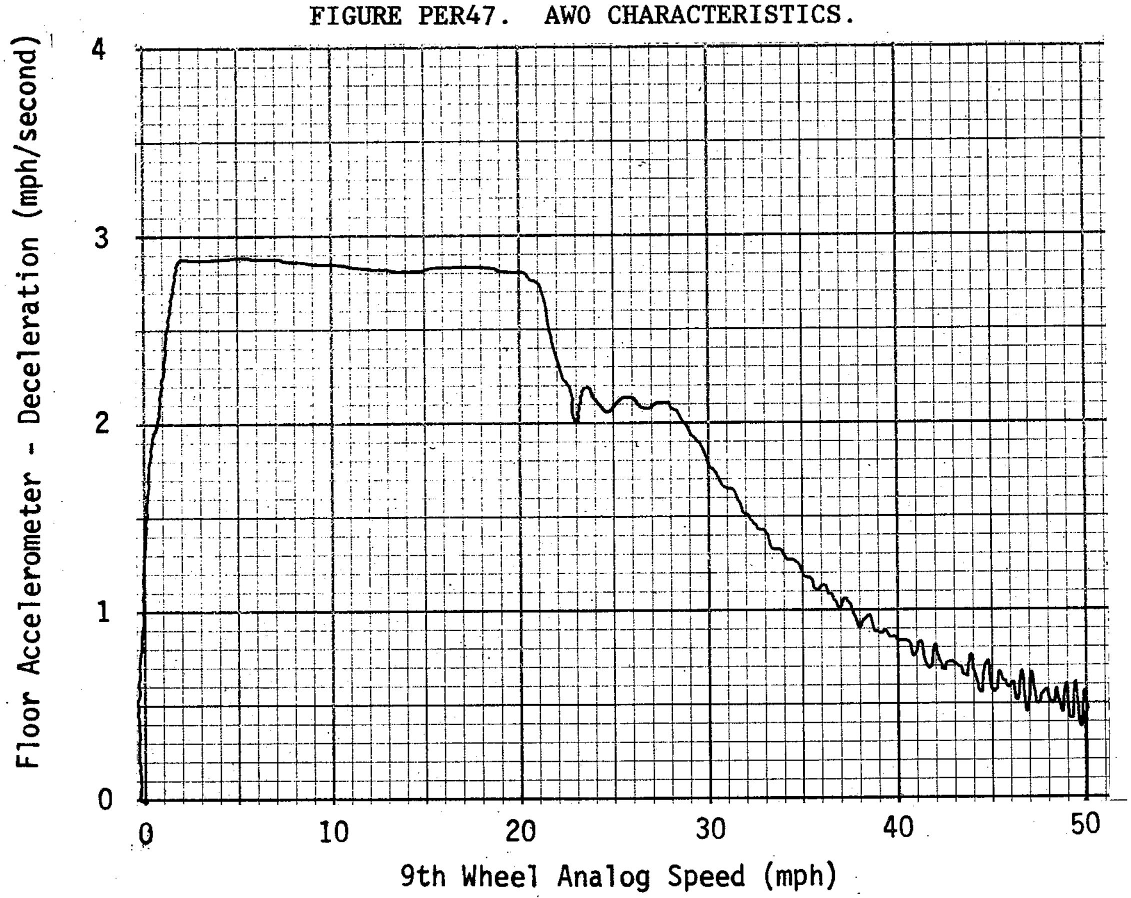


FIGURE PER48. AW2 CHARACTERISTICS.

5.2 WHEEL SPIN/SLIDE PROTECTION SYSTEM

5.2.1 Objective

The objective of the test was to evaluate the spin/slide protection system for acceleration and deceleration.

The major requirement of the specification is that under a coefficient of adhesion of 0.1 or greater, the efficiency of the system should be 40% in acceleration and 75% in braking over the speed range of 5 mph to maximum.

5.2.2 Test Method

Testing was performed on two occasions, an initial test at AW3, applying the standard approach, and a followup test in an attempt to estimate the coefficient of adhesion more accurately, again at AW3.

The normal adhesion level of the tangent section of the test track was artificially reduced by a soap solution.

The soap solution was contained in a 30 gallon drum under air pressure on-board the vehicle and was piped to all wheels by small bore flexible tubes. Adjacent to the wheel a copper tube directed a fine stream at the wheel rail interface. Flow was controlled by valves at the tank. After a wetting run, the vehicle was given acceleration or deceleration commands in excess of the available adhesion which caused the Knorr Spin/Slide System to operate.

5.2.3 Test Results

A number of deceleration runs were made, typical is that shown in Figure SS1. Here the wheel slip protection system is operational from the 50 mph entry speed to zero. The demand of 3 mph/second resulted in an actual rate of approximately 50% of this. The system is in a default mode of friction only.

To compute the spin/slide efficiency, the "area" method was used, wherein the maximum deceleration rates at "peaks" of the deceleration/time characteristic are assumed to be the points of maximum adhesion (for syncronous slides on all axles). The calculations were performed on the onboard desk-top computer and based upon digitized values of the accelerometer signal. The computer calculated the efficiency as the ratio of the areas beneath the locus of the peaks and the area beneath the characteristic. This is shown in Figure SS2, which is the output of the desk-top computer on the digital plotter. The efficiency by this method was 83.7%, which is above the specification requirement of 75%. Similar efficiencies were obtained for repeat runs.

A potential problem with spin/slide operation may be overheating of the discs. If the vehicle is operated in poor adhesion conditions, then deceleration could be performed under the default friction only mode for extended periods of time. This may exceed the thermal limit of the discs and cause overheating.

In order to determine whether the 'area' method produces a realistic estimation of available adhesion, a special test was conducted wherein the determination of available adhesion was attempted by observing the point at which a wheel slide occurs when the vehicle is subjected to gradually increasing demand. During this special test, the spin/slide detection system was activated, but, by disconnecting the dump valves, its output was not delivered to the brakes. The data obtained were examined to see if the spin/slide detection signal occurred close to the actual wheel breakaway and slide.

The acceleration behavior shown in Figure SS3 is a full 100% demand characteristic to 30 mph. Data up to 8 mph are missing because of 9th wheel failure due to the soap spray. The acceleration characteristic shows complete wheel protection during acceleration and the expected greater variation of acceleration than that during braking runs. The corresponding computer efficiency calculation, again based on the area method, is 52.4%.

Results showed that repeated runs with the spin/slide system activated produced an apparent continuous lowering of adhesion level, which had not stabilized by the time the soap solution ran out. Runs were also made with the dump valves disconnected, no conclusive results were found before the weather became too hot for further stable testing. The test did show the inadequacy of the on-board soap tank method, and it is not recommended for further work. Trackside spraying should produce stable adhesion. The method appears, on face value, to hold promise of giving better estimation of available adhesion.

The results of the tests were:

- The Knorr wheel slip protection system adequately protected the wheels against damage throughout the speed range. The system satisfied the specification efficiency requirement based on the "area" method and from calculated values based on the apparent adhesion at the occurrence of the first slide.

- Continuous operation in spin/slide mode could cause disc overheating.

- The special spin/slide tests were not conclusive, but did indicate the need for trackside water spraying to produce steady adhesion levels.

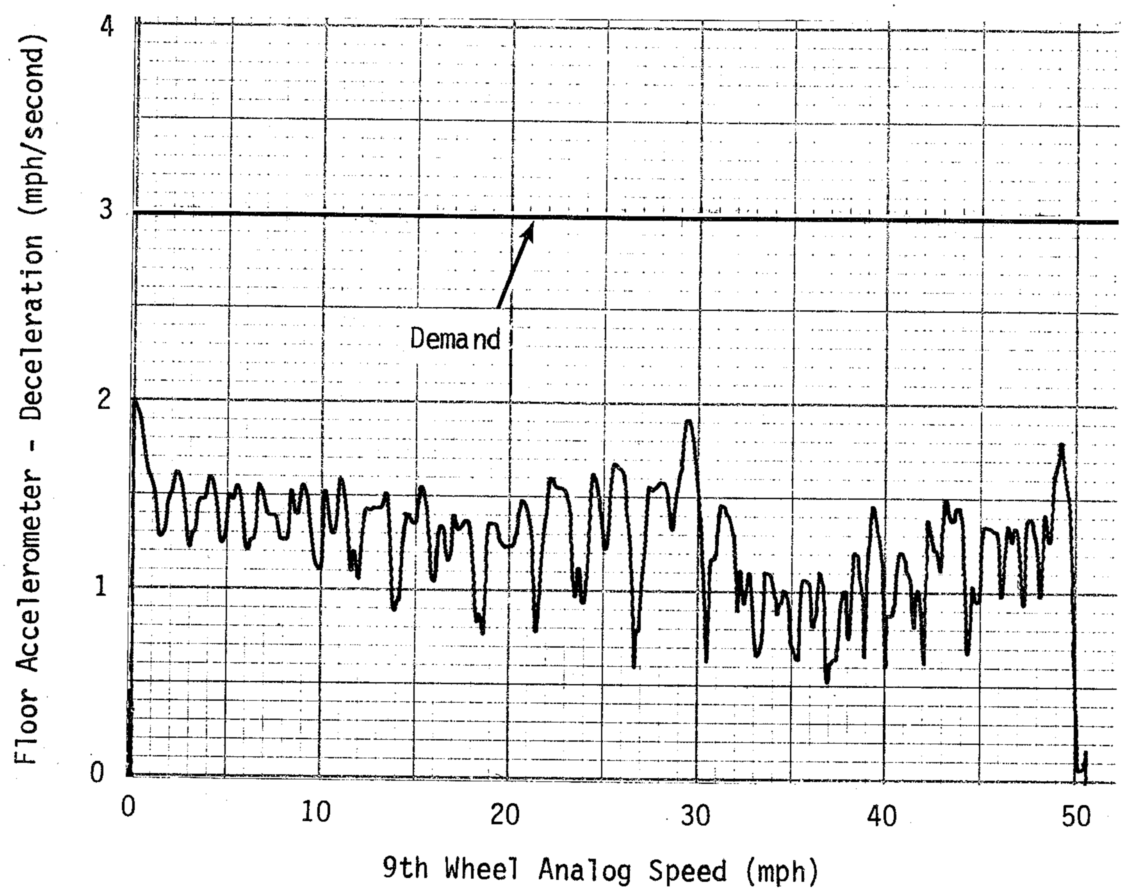


FIGURE SS1. TYPICAL DECELERATION RUN.

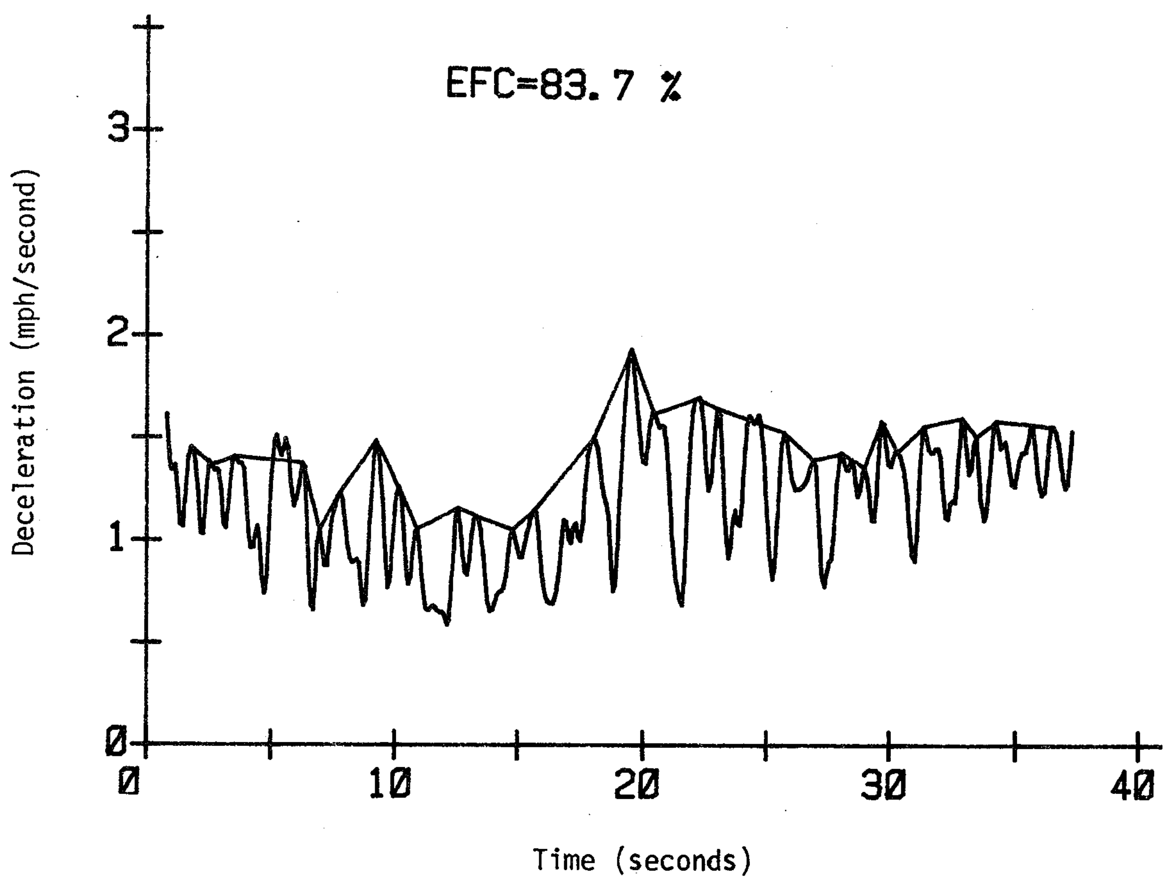


FIGURE SS2. "AREA" METHOD OF DETERMINING SPIN/SLIDE EFFICIENCY.

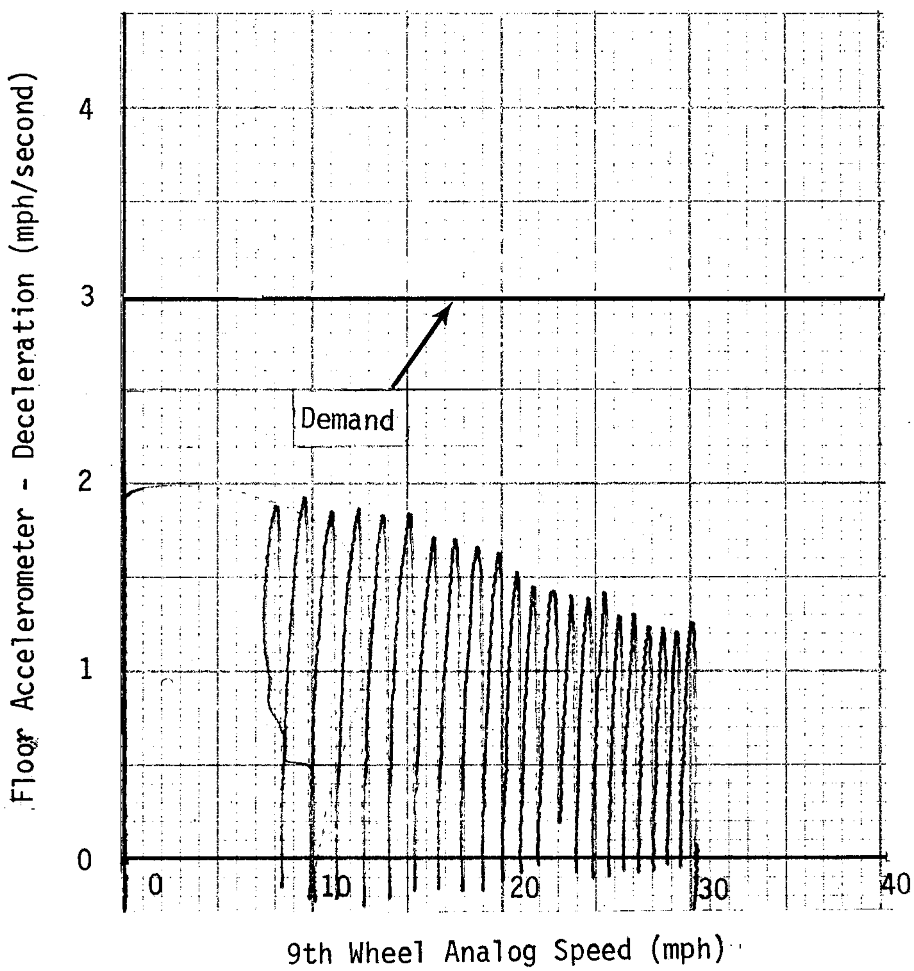


FIGURE SS3. ACCELERATION BEHAVIOR IN 100% DEMAND MODE.

5.3 TRAIN RESISTANCE

5.3.1 Objective

The objective of the test was to obtain the open-air resistance/speed characteristic of the vehicle during forward and reverse running at vehicle weight AW2. There is no specification requirement for this characteristic.

5.3.2 Test Method

The technique used to determine the train resistance was the coasting method. In this method the vehicle is allowed to coast without power on level tangent track and the deceleration rate is measured. The deceleration rate, which is proportional to the retarding force divided by the effective train weight, is used to predict the train resistance force. The test was performed not at the intended weight of AW2 but at AW0 due to test restraints. The actual weight of the vehicle, including test personnel and instrumentation, was 74,080 lbs. The allowance for the rotational inertia of the vehicle was taken at 10% of AW0 at 7,408 lbs. The total effective weight of the vehicle being 74,080 + 7,408 = 81,488 lbs.

The test vehicle was allowed to coast through the 4,000 foot level tangent track section between stations 30 and 34. The initial speed at entry was set at 50 mph and the speed at exit after 4,000 feet of coast was noted. The vehicle was then allowed to enter the section for a repeat coast run at an entry speed equal to the previous exit speed plus 2 mph. This produced a series of overlapping runs which covered the entire speed range from 50 mph to zero.

Deceleration was computed from the rate of change of speed of the vehicle. To obtain a very accurate measure of vehicle speed, which was averaged over a time interval long enough to remove variations due to carbody oscillations, etc., the pulse signal from the ninth wheel was processed by an HP 5345A electronic counter. The counter was controlled by an HP 85 desk-top computer. The counter was set to measure the pulse frequency averaged over a 1-second time window, and from the number of pulses per revolution of the wheel and its circumference, the speed could be computed.

Speed samples were taken at 3-second intervals. By subtracting successive speeds and by dividing by the interval, deceleration values were computed. A computed deceleration value was paired to the mean of the speeds from which it was derived to produce a deceleration/speed pair. Since the retarding force was directly proportional to the effective weight of the vehicle times the deceleration, retarding force/speed data pairs were computed and plotted.

5.3.3 Test Results

Figures TR1 and TR2 show the retarding force/speed characteristic obtained for clockwise running and counterclockwise running of the vehicle. Each small circle is a retarding force/speed data point derived from the deceleration/speed data points.

The data show a smooth characteristic from 50 mph to zero for both cases. The data for the 8 runs required in each direction to make up the characteristic show very good blending. The vehicle obviously has an identical characteristic for forward and reverse running as expected. There is no evidence of brake shoes dragging, etc.

A fair curve through each data set is shown in Figures TR3 and TR4. Here the intercept at zero speed is 200 lbs and the retarding force at 50 mph is approximately 600 lbs. Had the test been performed at sea level, the retarding force/speed characteristic produced would have been slightly different because of the altitude effect at the TTC which effects the aerodynamic drag on the vehicle and also the windage loss in the motors. The characteristics produced relate to the apparent train resistance since it is derived from the case where the train is driving the motors and, therefore, includes friction losses of the motor-axle bearings, gears armature bearings, brushes, and windage. These losses are all attributed to the motors when the power is 'on'. To obtain a tractive resistance/speed characteristic, the retarding force/speed characteristic would have to be modified by subtraction of the motor/gear losses.

The retarding force characteristic at 50 mph and AW0 equates to 600/40.2 = 14.9 lbs per ton. This value equates favorably to the assumed resistance of a slow moving train vehicle at 25 lbs per ton for general conditions.

In conclusion, the test showed a smooth retarding force characteristic indicating no abnormal operation of equipment and good steering qualities of the truck in both directions. The data are limited to the characteristic obtained on tangent track and do not indicate performance on a tight turn.

The retarding force at 50 mph was approximately 600 lbs; at zero speed, it was approximately 200 lbs.

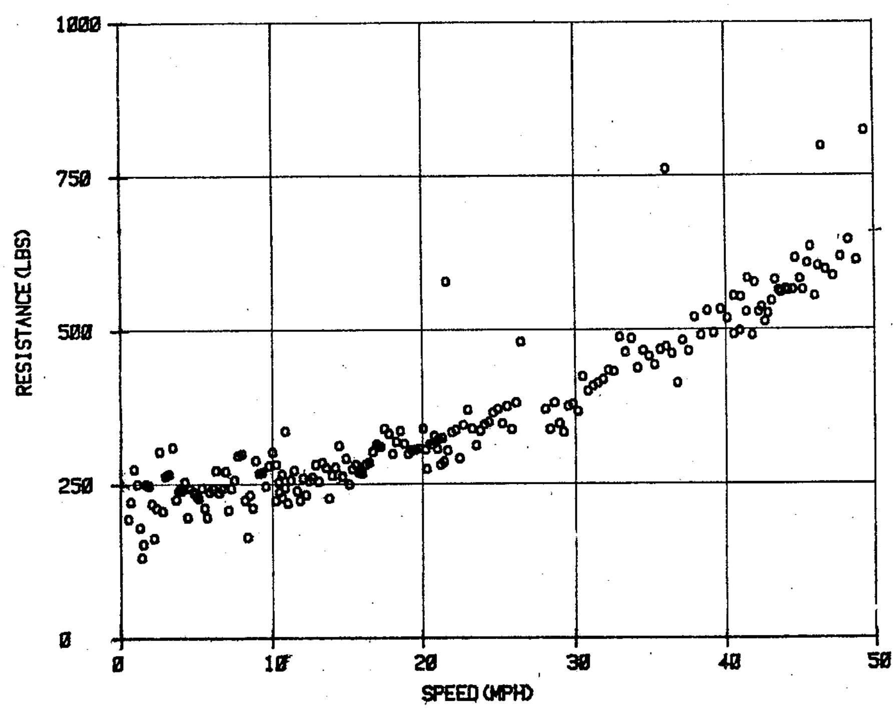


FIGURE TR1. RETARDING FORCE/SPEED CHARACTERISTIC DATA POINTS AT AWO, CW.

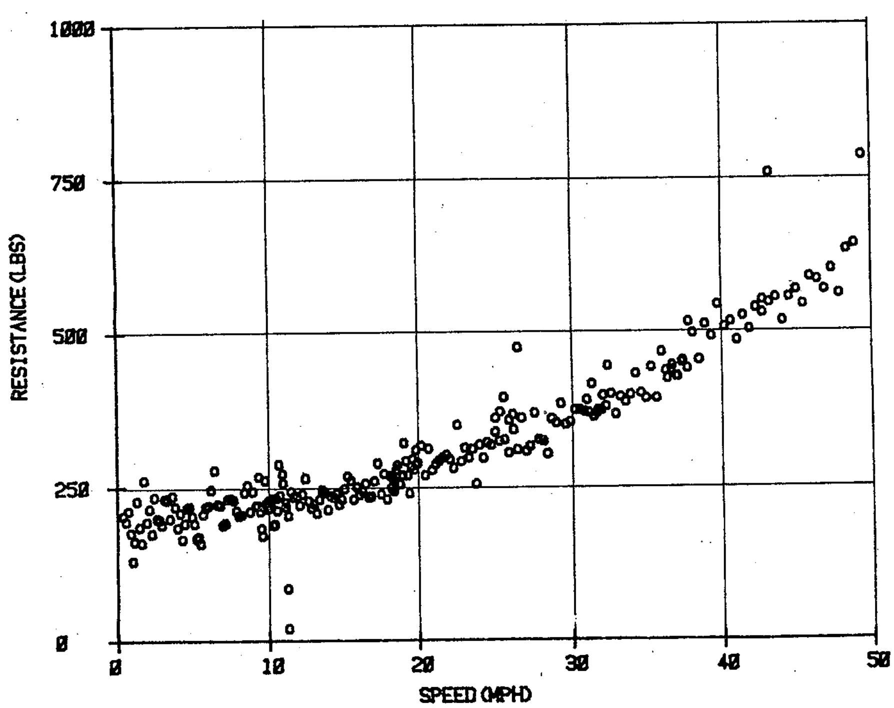


FIGURE TR2. RETARDING FORCE/SPEED CHARACTERISTIC DATA POINTS AT AWO, CCW.

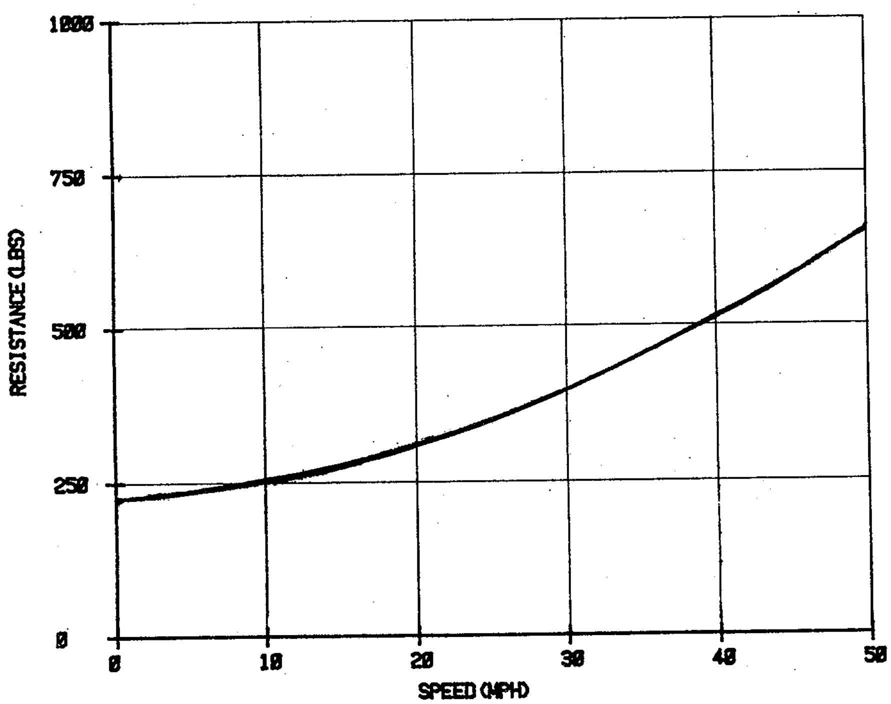


FIGURE TR3. RETARDING FORCE/SPEED CHARACTERISTICS, CW

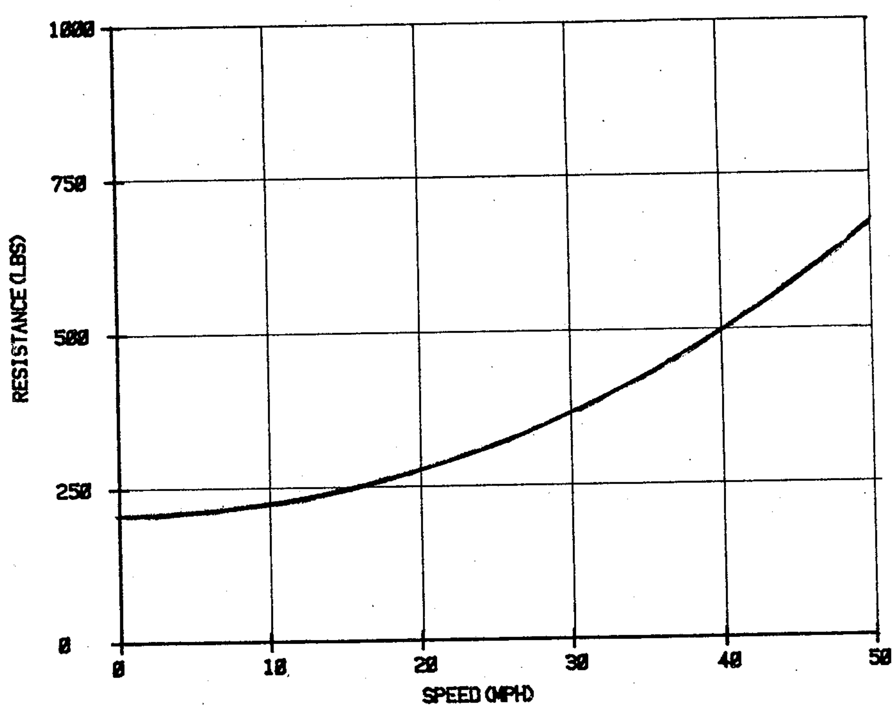


FIGURE TR4. RETARDING FORCE/SPEED CHARACTERISTICS, CCW

5.4 ENERGY CONSUMPTION

5.4.1 Objective

The objective was to monitor the energy consumed by the vehicle while simulating journeys from Auditorium to South Campus Stations.

5.4.2 Test Method

The facilities at the test track were able to simulate the Auditorium/ South Campus profile with the following limitations:

- No grade simulation was possible since running was limited to level track.
- No below ground running was possible, all test track running was outside in the open air.
- No running on curves was made, all running was made on tangent track.
- Running at the test track was performed with a mixture of forward and reverse operation because of the limited length of the catenary section.
- Running at the test track is at higher altitude than at Buffalo with an air density approximately 0.85 that of sea level.

The profile between Auditorium and South Campus was simulated by following Table EC1. The table shows the simulated station stops at the TTC track station locations, the distance between, and the maximum speed reached. The direction of travel is also noted. The total distance for the round trip was 67,350 feet, or 12.756 miles. The vehicle was at AW3 weight. Nominal voltage was 650 VDC. The doors were cycled at each station stop where the aim was to simulate the specification requirements for dwell and turnaround of 15 and 30 seconds respectively.

Energy consumption on a cumulative basis was computed by a watt-hour meter designed and constructed at the TTC. The meter input was the line voltage and a propulsion current signal from the propulsion logic. Thus, the energy consumption was computed for propulsion only. Line (at the pantograph) current was observed to be 40 amps higher due, in part, to the auxiliaries and, also, the air conditioning, which was required on the day of testing.

Full acceleration and full blended brakes were used, with the motorman's discretion for minor adjustments.

5.4.3 Test Results

During the test day, 5 complete round trip profiles were run from Auditorium to Auditorium, and one partial profile from Auditorium during which time traction motor flashovers occurred simultaneously on all four traction motors. A summary of the energy used is given in Table EC2.

TABLE EC1. NFTA PROFILE

DEPART NFTA STATION	TTC STATION	DISTANCE	SPEED	BRAKE	STOP	DIRECTION	ARRIVE NFTA STATION
Auditorium	37.3	1,300'	28	36.2	36.0	CCW	Seneca
Seneca	36.0	1,000'	28	35.2	35.0	CCW	Church
Church	35.0	1,000'	28	34.2	34.0	CCW	Lafayette
Lafayette	34.0	1,000'	28	33.2	33.0	CCW	Huron
Huron	33.0	1,000'	28	32.2	32.0	CCW	Theater
Theater	32.0	4,352'	50	35.7	36.3	CW	Allen-Hosp
Allen-Hosp	36.3	1,775'	50	35.1	34.5	CCW	Summer-Best
Summer-Best	34.5	2,675'	50	32.4	31.8	CCW	Utica
Utica	31.8	4,600'	50	35.8	36.4	CW	DeLavan
DeLavan	36.4	2,150'	50	34.8	34.2	CCW	Humbolt
Humbolt	34.2	5,750'	50	29.2	28.5	CCW	Amherst
Amherst	28.5	3,800'	50	31.7	32.3	CW	LaSalle
LaSalle	32.3	3,300'	50	35.0	35.6	CW	South Campus
South Campus	35.6						

TABLE EC2. ENERGY CONSUMPTION.

Profile Number	Start Time	End Time	Cumulative kWh's Start	Cumulative kWh's End	kWh's for the Profile
1	14:00	14:50	0	94.8	94.8
2	14:50	15:22	94.8	189.4	94.6
3	15:22	15:55	189.4	284.9	95.5
4	15:55	16:28	284.9	379.5	94.6
5	16:28	16:59	379.5	474.0	94.5
6	16:59	Flashover	474.0	---	

The specific energy consumption for the first profile was 94.8/12.756 = 7.431 kWh/mile.

The energy consumed for the other four profiles shows excellent repeatability; the average energy consumption for the five completed profiles was 94.8 kWh.

The test results showed a specific energy consumption of 7.431 kWh/mile for a vehicle at AW3, and over a complete round trip profile of 12.756 miles. A series of five complete profiles gave almost exactly repeatable power consumed. The test at sea level would produce slightly higher level due to the greater aerodynamic drag at sea level. The TTC test was limited to tangent track, open air running. The test was stopped by traction motor flashover during the 6th profile.

5.5 DUTY CYCLE/ENDURANCE TEST

5.5.1 Objective

The objective was to subject the vehicle to the stress of continuous round trip profile operation in order to induce possible failure and the maximum steady temperatures of traction and auxiliary systems. It was agreed that when the traction motor exhaust temperatures were steady, an extra round trip profile would be run and the test would be complete.

The vehicle failed during the duty cycle tests on June 2, 1983 when simultaneous traction flashover occurred on all four traction motors during the 6th profile. Careful inspection of the commutators, brushes, and power systems did not indicate any probable cause. Studies were also made of the recorded data, including calculation of the RMS current level of a truck for a complete profile. This was found to be 301 amps. Therefore, there was considerable interest in a repeat Duty Cycle/Endurance test, particularly to see if the flashover would occur again after a similar number of profiles.

5.5.2 Test Method

The instrumentation setup was similar to that of the power consumption tests except that a data logger was used to list thermocouple temperatures, including traction motor exhaust temperature used as the criterion for the completion of the test.

A significant parameter measured was the thyristor temperature measured with Cr.Al. thermocouples. This was a problem area for measurement because of the high potential and the strong fluctuating magnetic fields present.

The round trip profiles were conducted at a vehicle weight of AW3 and a nominal track voltage of 700 volts. The weather for the test was partly cloudy with an ambient at the beginning of the test of 86°F.

The profiles were run without incident until an air leak in an air drier valve interrupted the testing of the profile. After the magnet valve was fixed, some 15 minutes later, testing resumed from where it left off.

Upon satisfactory completion of the 6th profile without flashover, a further test was performed at a higher voltage of 750 volts. At the completion of this profile the vehicle was returned to the URB where calibration was performed on selected thermocouples.

5.5.3 Test Results

Replay of the data to find the RMS values of the traction motor currents produced the following:

Profile #	I1 AMPS RMS	I2 AMPS RMS
1	309.6	299.6
6	307.9	301.2
7 (750 volt)	307.6	300.5

The data were produced by an HP 3497A data acquisition unit controlled by an HP 85 desk-top computer. These values are close to that found during the power consumption runs. Interestingly, the higher voltage produced no change in the RMS level of currents.

During the test it became apparent that the thermocouple setup for recording thyristor temperature was not yielding steady results. It appeared to be seriously effected by the controller position. It is concluded that the thermocouple isolation amplifier setup gave a fair approximation of temperature when the car was not powered, but that the thyristor environment is too severe for thermocouple measurements. Regretfully, the thermocouple data for the thyristor temperature for this test must be discounted. Other thermocouple data were satisfactory and indicated no abnormal temperatures.

The following are the major results of the tests:

- The vehicle completed the 7 return round trip profiles without flashover or other serious problems.
- The conditions of the test were: AW3 running, hot but very dry, with a low air density caused by altitude (5,300 feet and the hot day).
- The tests were restricted to tangent level track in the open air.
- Traction motor exhaust temperatures were stable after the 6th return profile. Thyristor temperature was not found because of severe difficulties with the thermocouple equipment.
- Traction motor RMS current per round trip profile was close to 300 amps per truck.

5.6 VEHICLE VIBRATION EXCITED BY EQUIPMENT AND AUXILIARIES

5.6.1 Objective

The main objective of the test was to provide data for comparison with the requirements of the technical specification. A further objective was to estimate the influence of the auxiliaries' vibration on the ride quality performance. In addition, vibration levels were used to indicate any problem areas of malfunctioning auxiliary equipment.

The vibration limits are addressed in the specification as follows:

> Equipment and auxiliaries mounted anywhere on the vehicle, carbody, or trucks shall not cause vertical or horizontal vibrations anywhere on the vehicle floor, walls, ceilings, panels, and seat frames in excess of 0.04g peak at any frequency up to 60 Hz.

The vibration limit specified applies to the vehicle floor (as in ride quality) with the addition of the vibration of walls, ceiling, panels, and seat frames.

It is inferred from the specification, for this analysis, that the 0.04g limit refers to the steady-state condition of an auxiliary, running continuously, and not the condition occurring, of a vibration transient caused by the 'switch on'/'switch off' mode of the auxiliary or equipment.

The limit of 0.04g peak converts to 0.04 x 0.707 = 0.0283g RMS. This further converts to 89 dBg re. 1 μ G using:

$$\text{Level dBg} = 20 \times \text{Log}_{10} (\text{Level G} \times 10^6)$$

5.6.2 Test Method

A B&K 1/3 octave Digital Frequency Analyzer, interfaced with an HP 85 desk-top computer, was used to establish the vibration levels, the same set up as was used in the ride quality analysis. The analyzer had a low end cut-off at the 1.6 Hz 1/3 octave band. Thus, for the analysis, the signal was analyzed between this cut-off and the 63 Hz 1/3 octave band. The analysis, therefore, covers seventeen (17) 1/3 octave bands. Each band acts as a band pass filter. Any vibration occurring within the band 'shoulders' will cause the analyzer to display a band level equal to the RMS level of the signal, averaged over the time window selected. The analyzer display was in dB.

The analyzer was a single channel type. Each channel of interest was analyzed one at a time.

A number of combinations of auxiliaries were run in order to give an indication of the relative contribution of major pieces of equipment. Vibration signals produced by the floor mounted accelerometers were recorded onto the FM 28 track recorder with a frequency range of DC to 100 Hz. At the same time, a single channel was fed to the B&K analyzer for an 'on-the spot' indication of trouble areas.

5.6.3 Test Results

With auxiliaries on, vibration associated with traction motor blowers was noticed. The vibration was worse at one end of the car than the other and reached a maximum on one of the seats. Although the ceiling was quiet, the windows were vibrating.

With the accelerometers on the floor in a "ride quality array", the following table shows the relevant AWO test runs recorded:

TABLE VIB1. AWO TEST RUNS.

RUN #	VOLTS	NOTES
545	690	Traction motor blowers on
546	690	Air conditioning only
547	690	All systems
548	637	All systems
549	736	All systems
550	639	'B' end accels moved to seat-All Systems On
551	639	'B' end accels moved to floor-All Systems On
552	639	Air conditioning only

The analyzed data are shown in Figures VIB1 through Figure VIB6. These consist of 1/3 octave format plots in the same style as the ride quality 1/3 octave format. The 1/3 octave plots relate to the following selected channels:

Channel	Location
2	'B' End Vertical (moved to seat and other locations)
3	'B' End Lateral
4	Mid Car Vertical
5	Mid Car Lateral
7	'A' End Motorman Cab Vertical
12	'A' End Motorman Cab Lateral

The 1/3 octave plots relating to the 'air conditioning on only' mode, Figures VIB1 through Figure VIB6 show no band levels exceeding 71 dBg RMS and, clearly, this is well below the specification maximum of 89 dBg RMS. This shows that the air conditioning system easily complies with the specification as related to the floor. However, this was true in general for the floor area, except for a particular small area presumably close to the compressor/condensor package which produced the levels shown in Figure VIB7. Here, significant bands are the 31.5 and 40 Hz bands with a maximum almost equal to the specification. This was, however, only limited to a small area and was not characteristic of the floor as a whole.

The 1/3 octave plots relating to the 'traction motor blowers on only' mode, Figures VIB8 through VIB13, show greater levels with the maximum occurring on 'B' end floor vertical. The 63 Hz center frequency band level falls just short of the 89 dBg RMS max level by 1 dB at 88 dBg.

The vibration levels shown in Figures VIB14 through VIB19 correspond to the "all on" mode and show almost identical levels to the "traction motor blower only" mode, giving the conclusion that the significant contributor to floor vibration is from the traction motor blowers, and this was confirmed by "seat of pants" investigation.

A test at a lower voltage of 637 volts produced the result shown in Figure VIB20, again for 'B' end floor vertical. Here, the reduced voltage has changed the blower speed and resulted in a higher level (92.3 dBg) of the 63 Hz band, which exceeds the specification. This points to an out-of-balance problem at the blower, which perhaps at the lower speeds caused a mounting resonance. A test at 736 volts for the same location caused an 11 dB fall in this band level (see Figure VIB21).

A "survey" of the floor, to find a high energy level caused by the TM blower, produced the 1/3 octave plot shown in Figure VIB22. Here, the specification is exceeded by 4 dBg.

It was noticed that the seats close to the traction motor blower were vibrating, and this is shown in Figure VIB23. Here the specification is greatly exceeded by (14 dBg) with a level of 103 dBg, again in the 63 Hz band. These data were taken by placing the floor mounted accelerometer on the seat. This is a valid approach in this case since the seat was of hard plastic construction and could be assumed to vibrate close to the same level with a person sitting upon it.

The vibration level on the seat was compared to ISO 2631, Second Edition, 1978 (Ref. 2) and is shown in Figure VIB24. In the figure, the 63 Hz band is adjacent to the 4 hour reduced comfort line. Against this criteria the vibration on the seat appears not so significant. This is because the ISO Standard for reduced comfort is based on vibration levels which interfere with such operations as eating, reading, and writing. In this case, although the seat vibration was very noticeable and fails the specification, it would not interfere with reading, etc.

During the test, one of the accelerometers was moved to various locations, and the maximum band level on the B&K 1/3 octave analyzer was noted down. No recording was made, however. The result of this survey is shown in Figure VIB25 where the maximum band levels are noted on a seat plan of the car.

The 'B' end traction motor blower produced vibration levels which were significantly above the vehicle specification and which, although they were not critical as far as the ISO reduced comfort criteria are concerned, were quite noticeable. The vibration levels appear to be a function of motor speed. Because the seats are of plastic construction, any auxiliary vibration problem is transmitted directly to a passenger without attenuation, and this factor must be considered when evaluating the advantages of this type of seating. If the 'B' end traction motor vibration levels were the same as the 'A' end, the vehicle would have passed the specification.

The control electronic equipment box is located on the floor without vibration isolation. The floor vibration levels were not significant near this equipment during these tests.

Throughout the operation of the car at the TTC, no vibration of ceiling, panels, etc., was observed. However, under certain conditions the doors rattled (see Ride Quality).

In conclusion, given that the vibration of the 'B' end traction motor could be improved, the vibration environment of the car was excellent. However, any deterioration of any equipment will probably be immediately felt by passengers because of the rigid nature of the plastic seats.

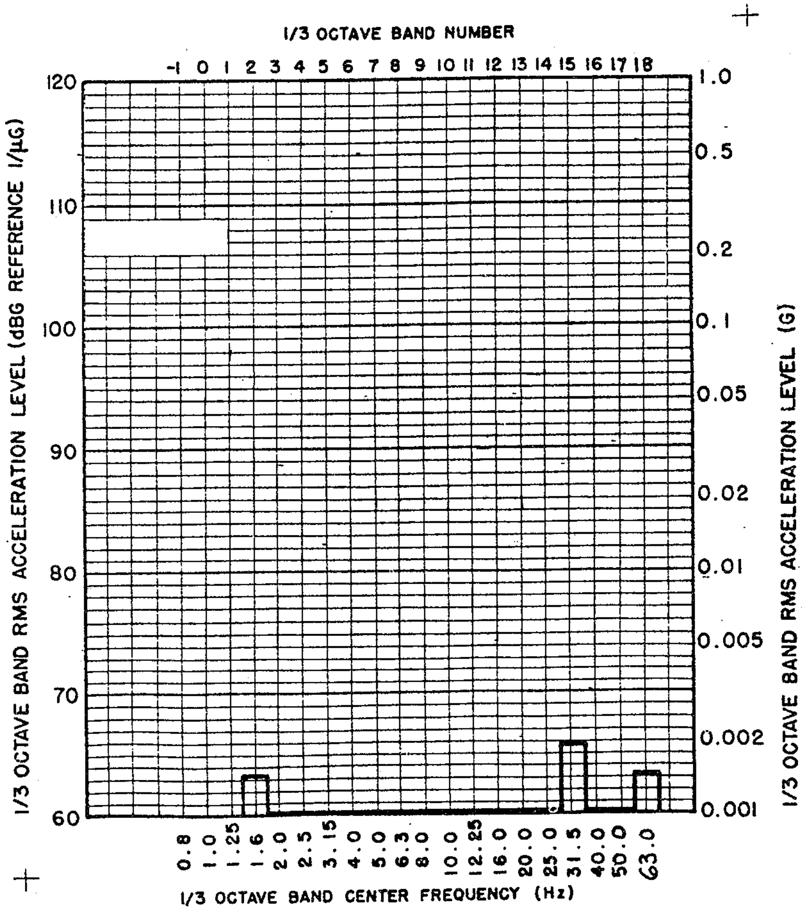


FIGURE VIB1.

AIR CONDITIONING ONLY - 'B' END VERTICAL.

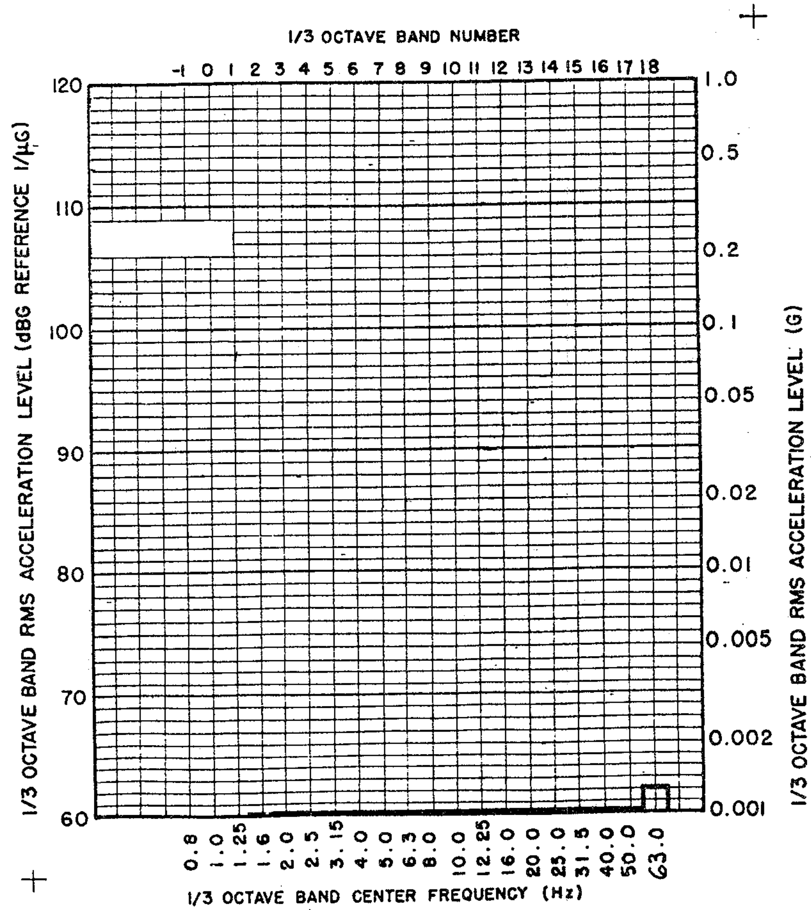


FIGURE VIB2.

AIR CONDITIONING ONLY - 'B' END LATERAL.

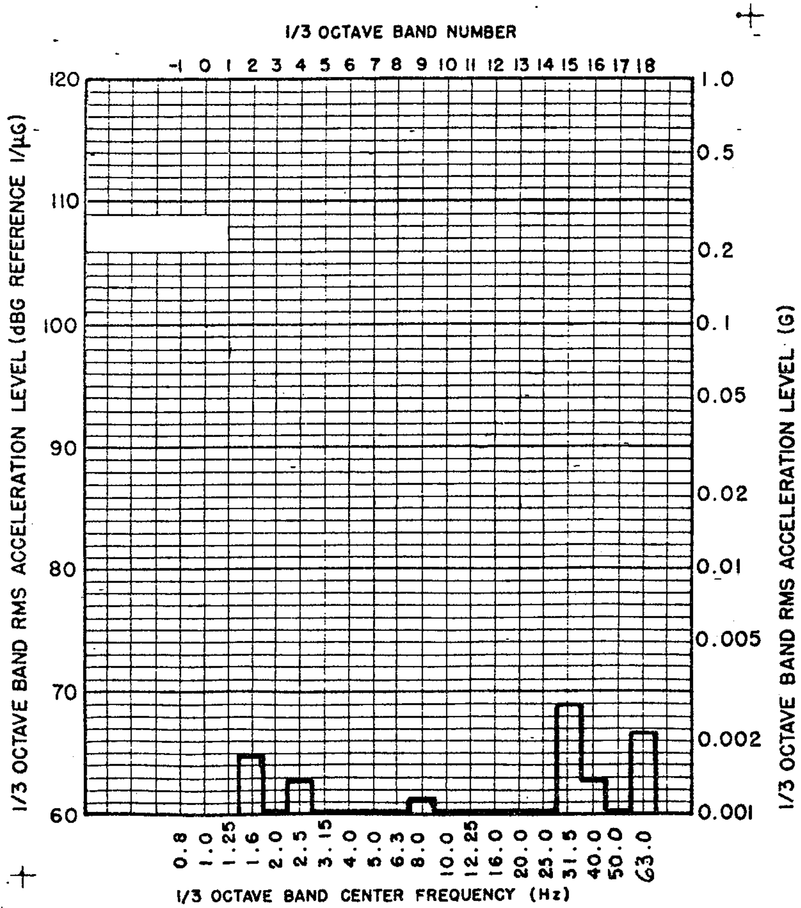


FIGURE VIB3.

AIR CONDITIONING ONLY - MID CAR VERTICAL.

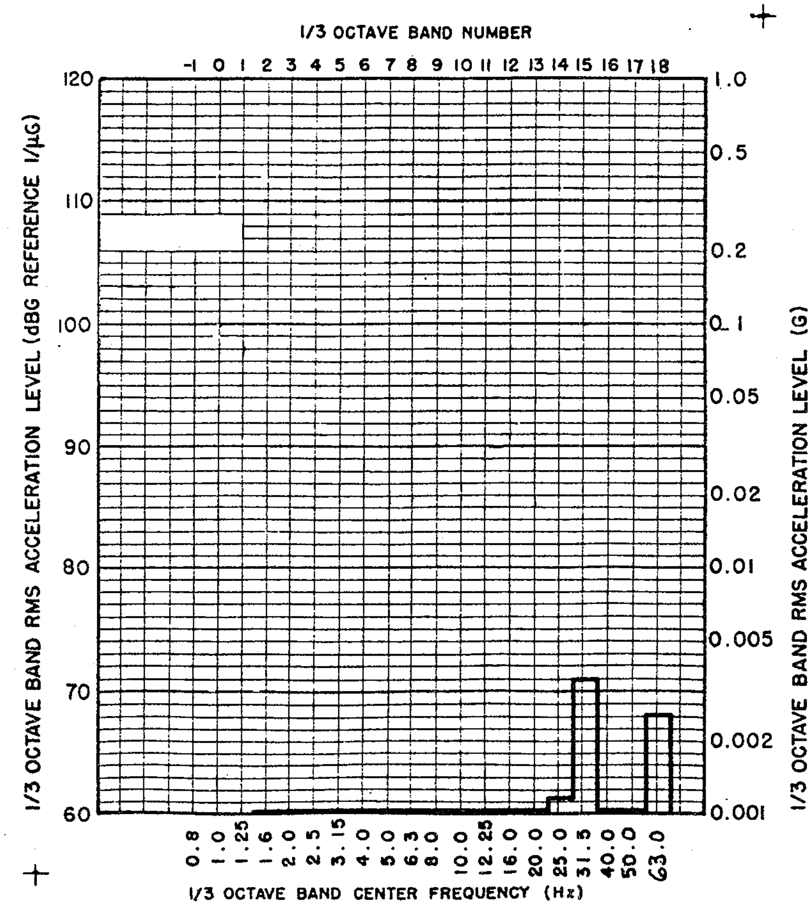


FIGURE VIB4.

AIR CONDITIONING ONLY - MID CAR LATERAL.

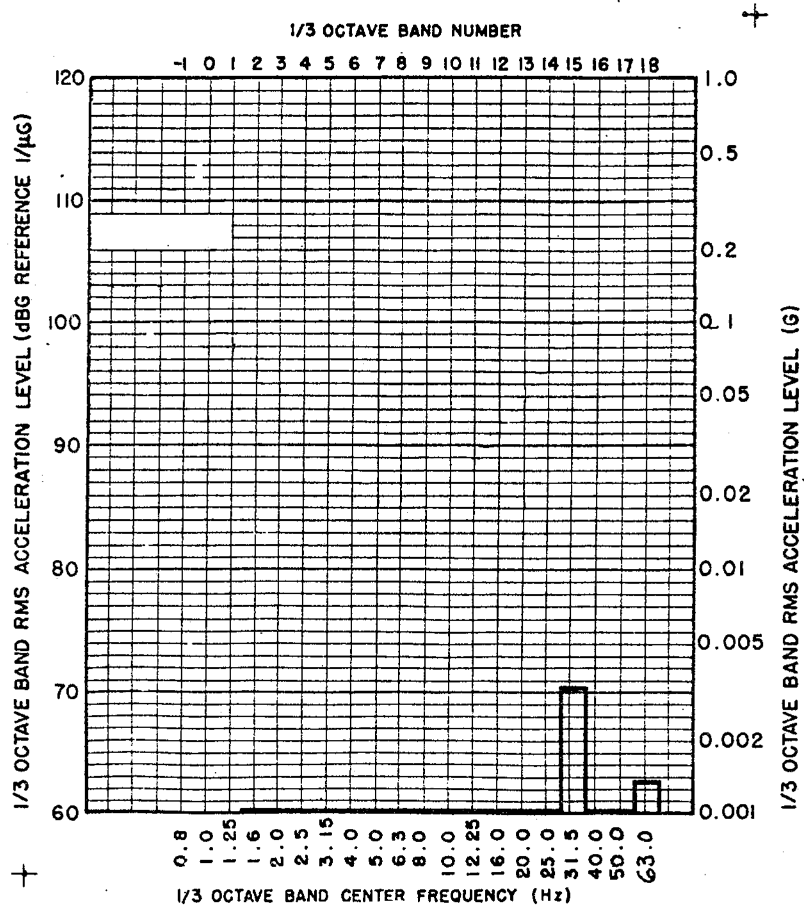


FIGURE VIB5.

AIR CONDITIONING ONLY - 'A' END VERTICAL.

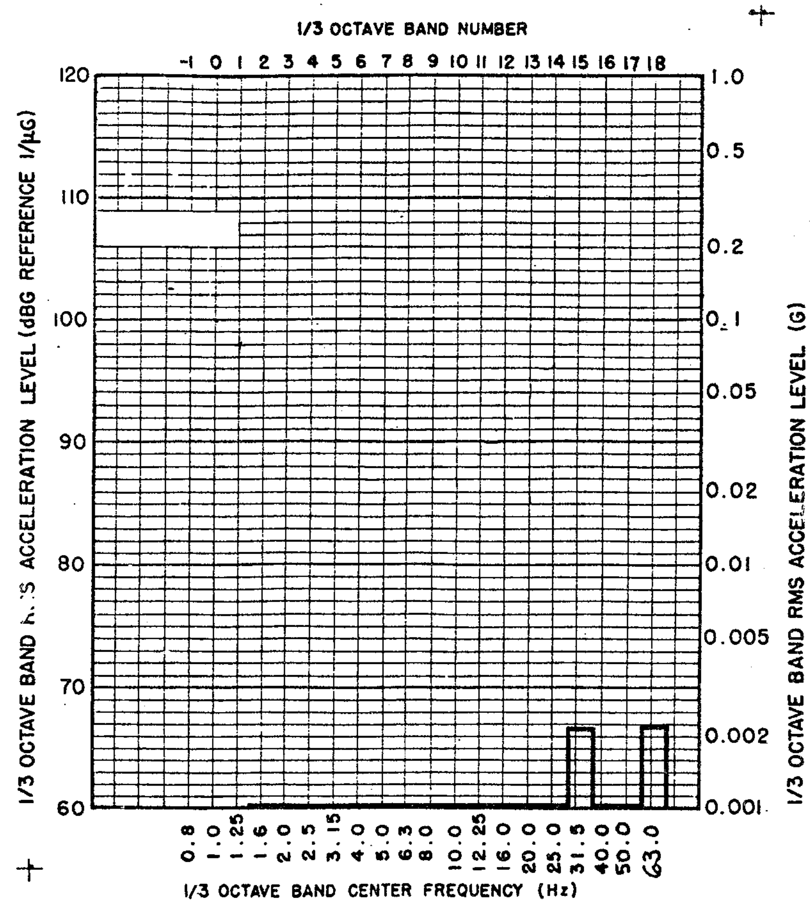


FIGURE VIB6.

AIR CONDITIONING ONLY - 'A' END LATERAL.

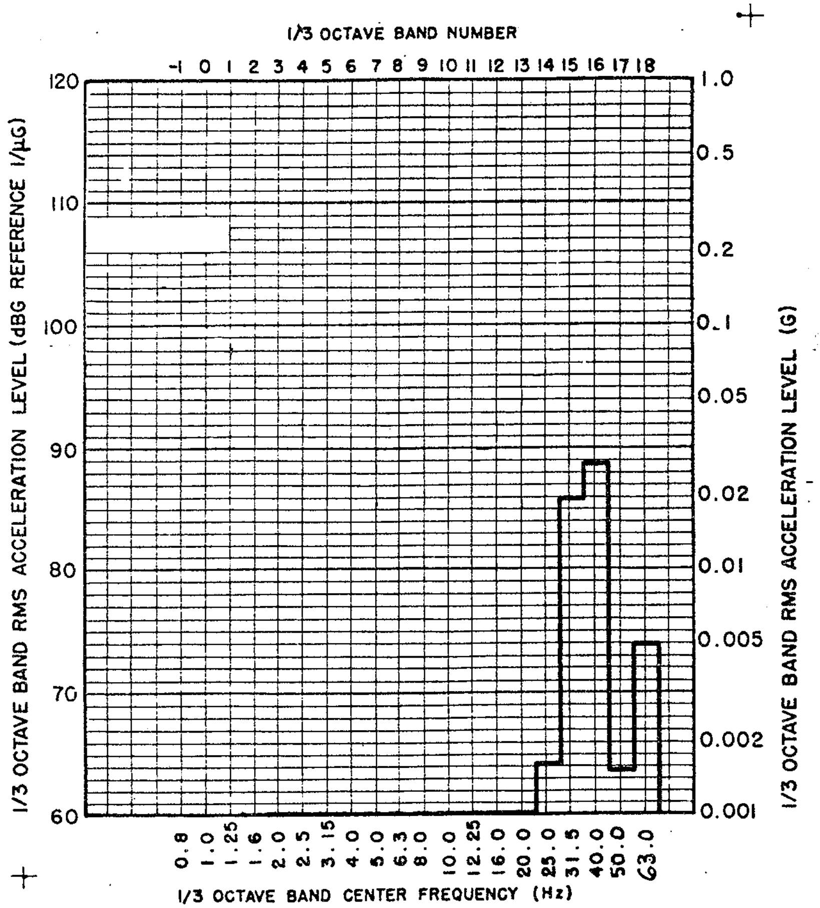


FIGURE VIB7.

AIR CONDITIONING ONLY - FORWARD OF DOORWAY ON FLOOR.

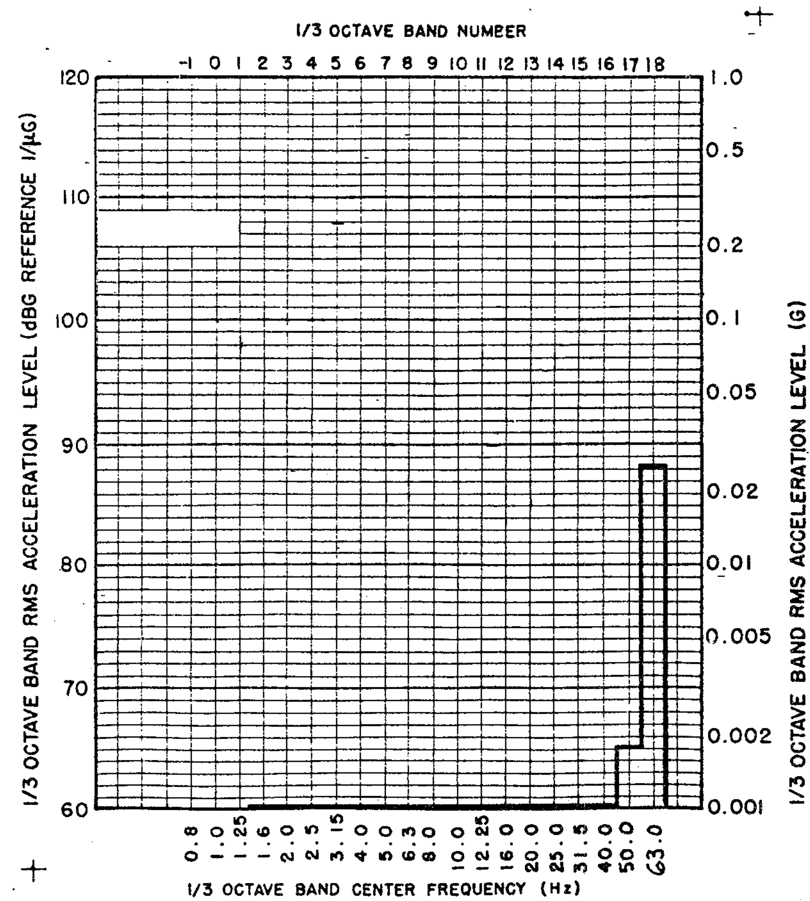


FIGURE VIB8.

TRACTION MOTOR BLOWERS ONLY - 'B' END VERTICAL.

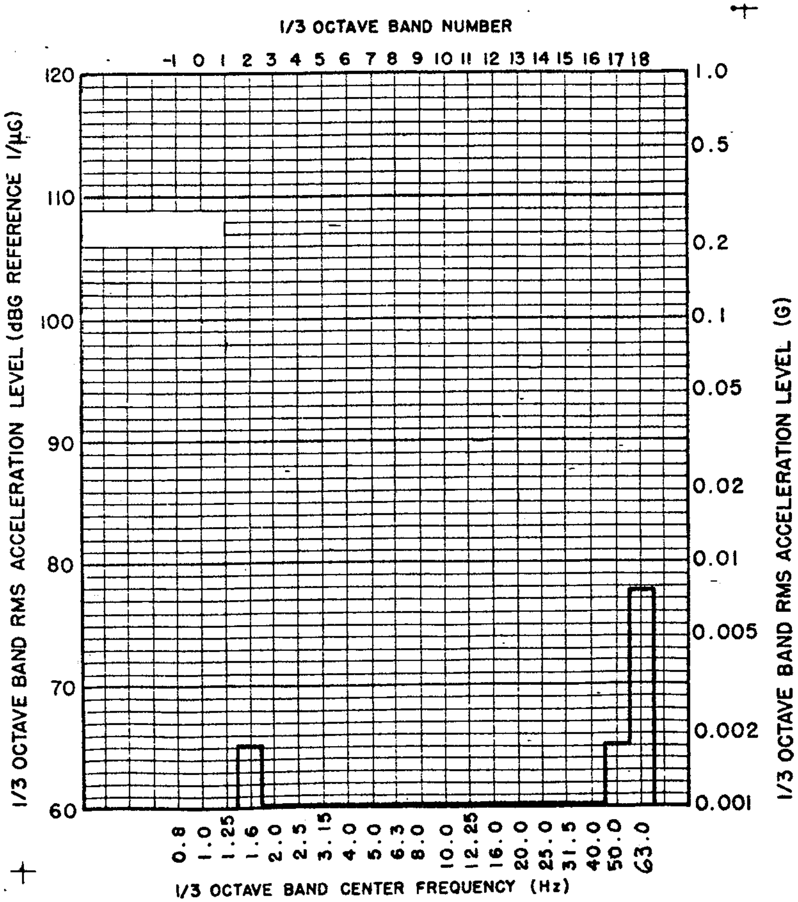


FIGURE VIB9.

TRACTION MOTOR BLOWERS ONLY - 'B' END LATERAL.

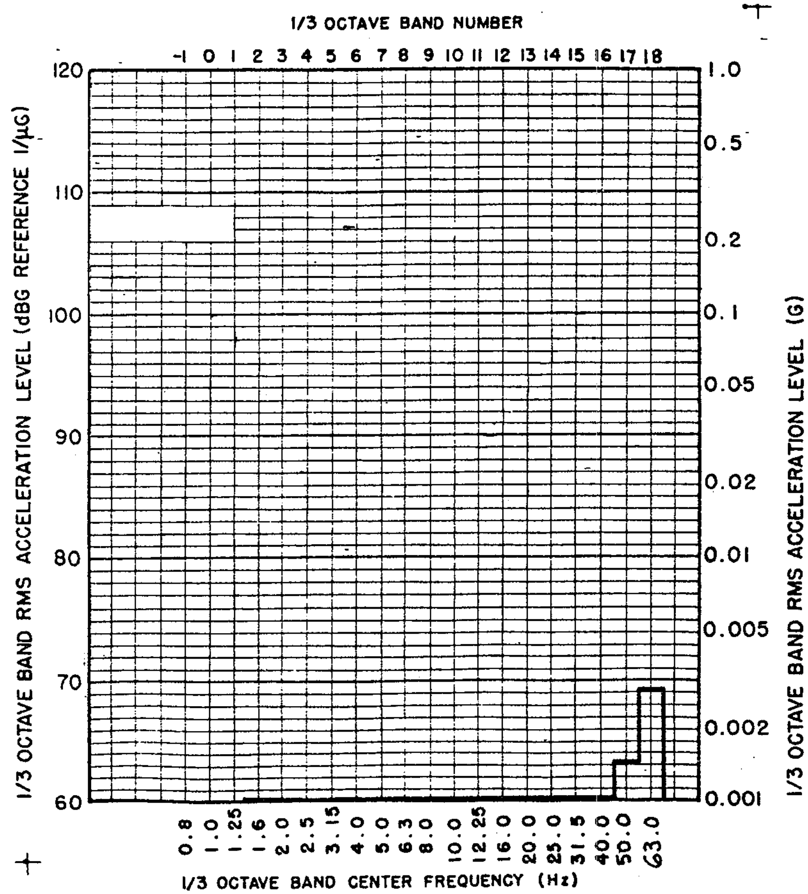


FIGURE VIB10.

TRACTION MOTOR BLOWERS ONLY - MID CAR VERTICAL.

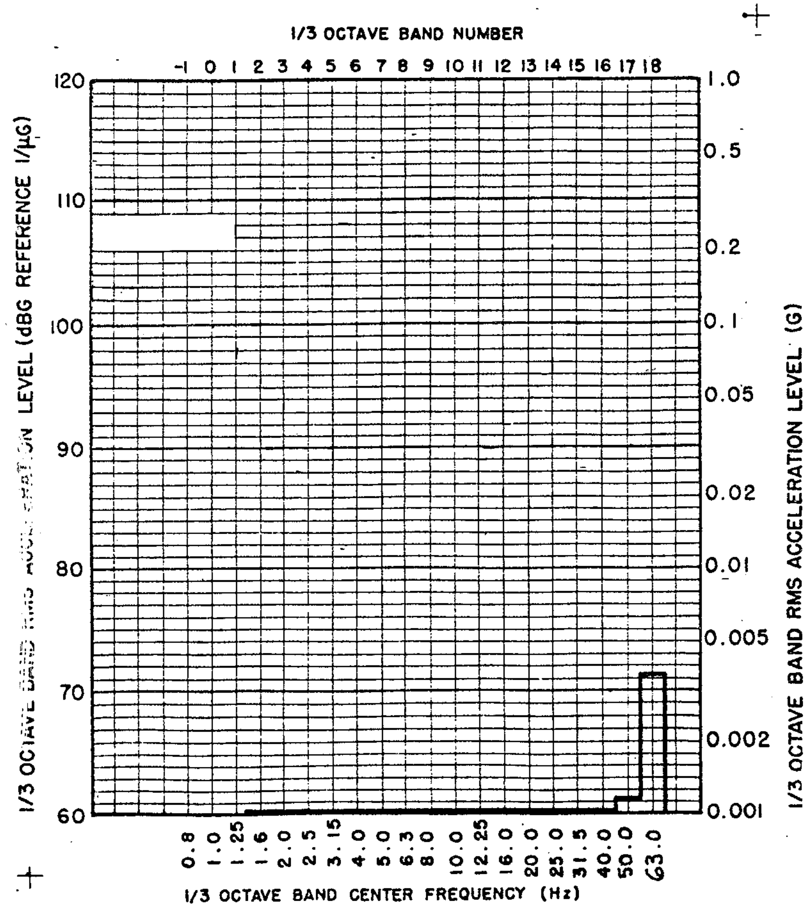


FIGURE VIB11.

TRACTION MOTOR BLOWERS - MID CAR LATERAL.

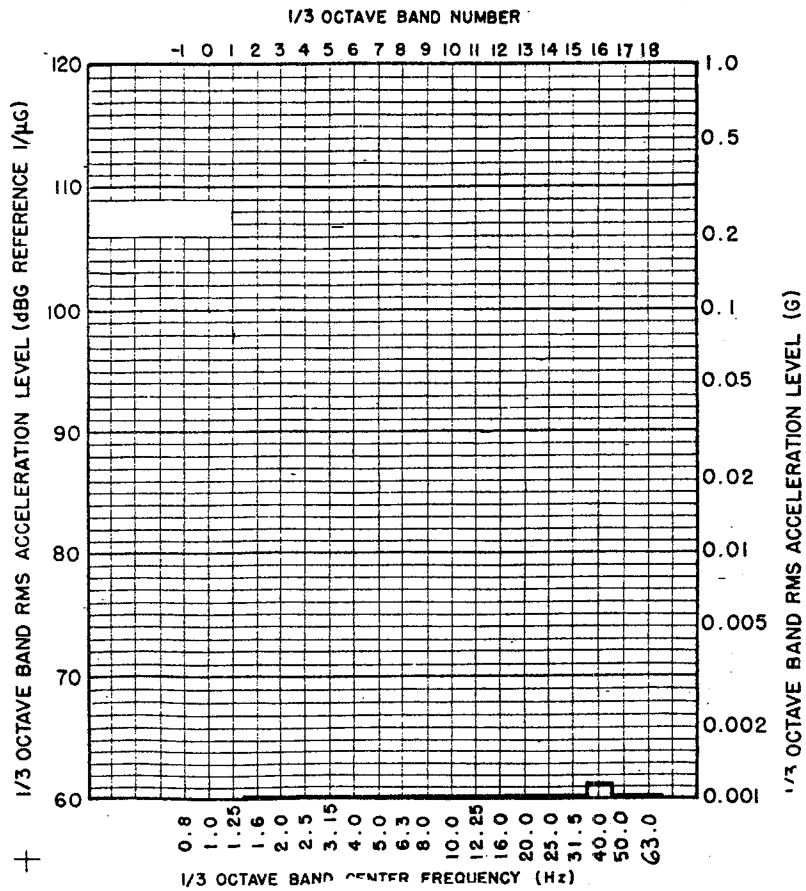


FIGURE VIB12.

TRACTION MOTOR BLOWERS ONLY - 'A' END VERTICAL.

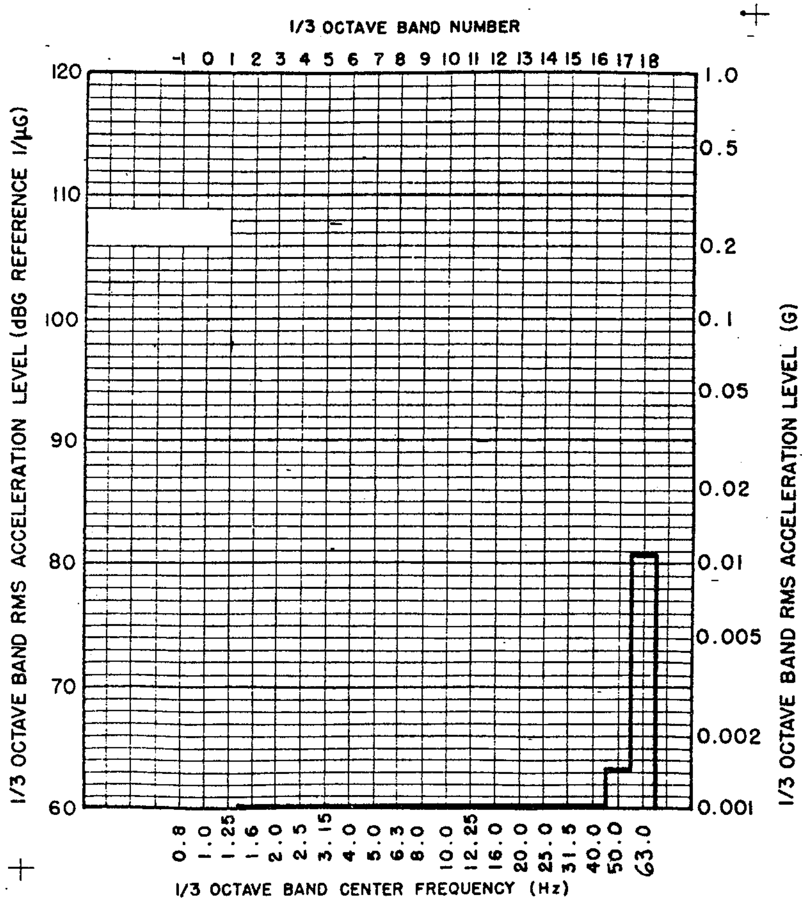


FIGURE VIB13.

TRACTION MOTOR BLOWERS ONLY - 'A' END LATERAL.

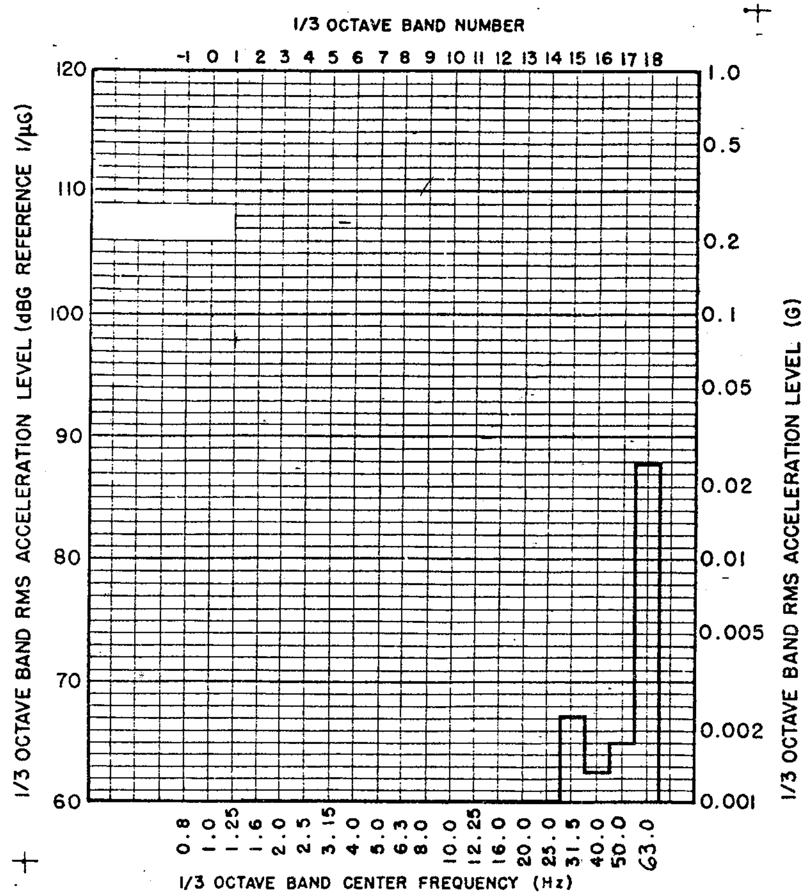


FIGURE VIB14.

ALL AUXILIARIES - 'B' END VERTICAL.

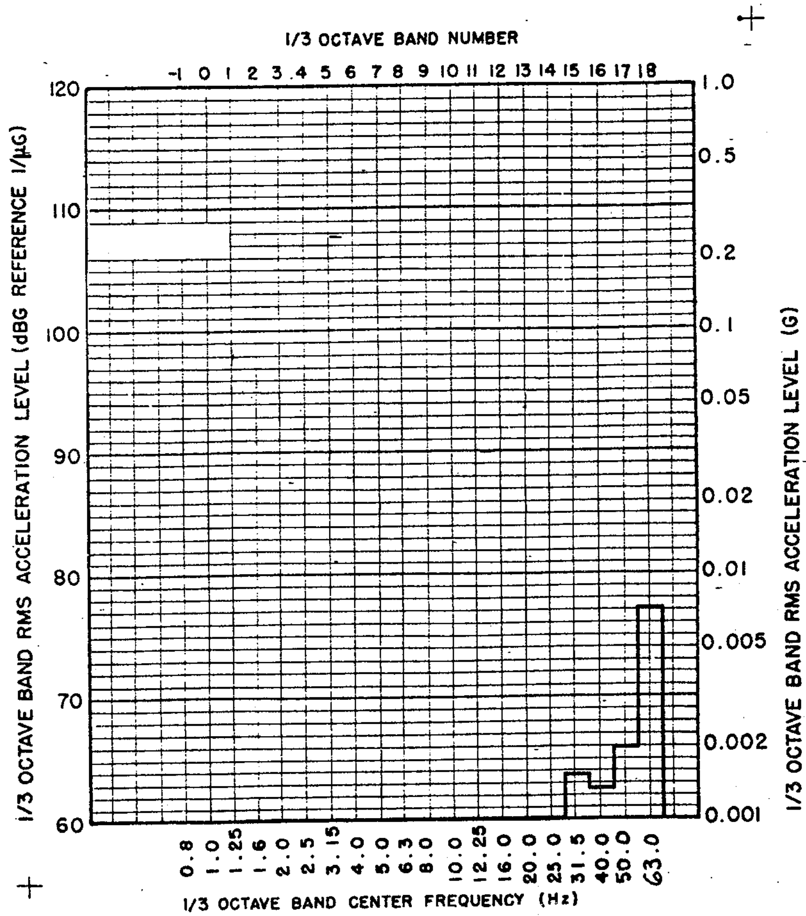


FIGURE VIB15.

ALL AUXILIARIES - 'B' END LATERAL.

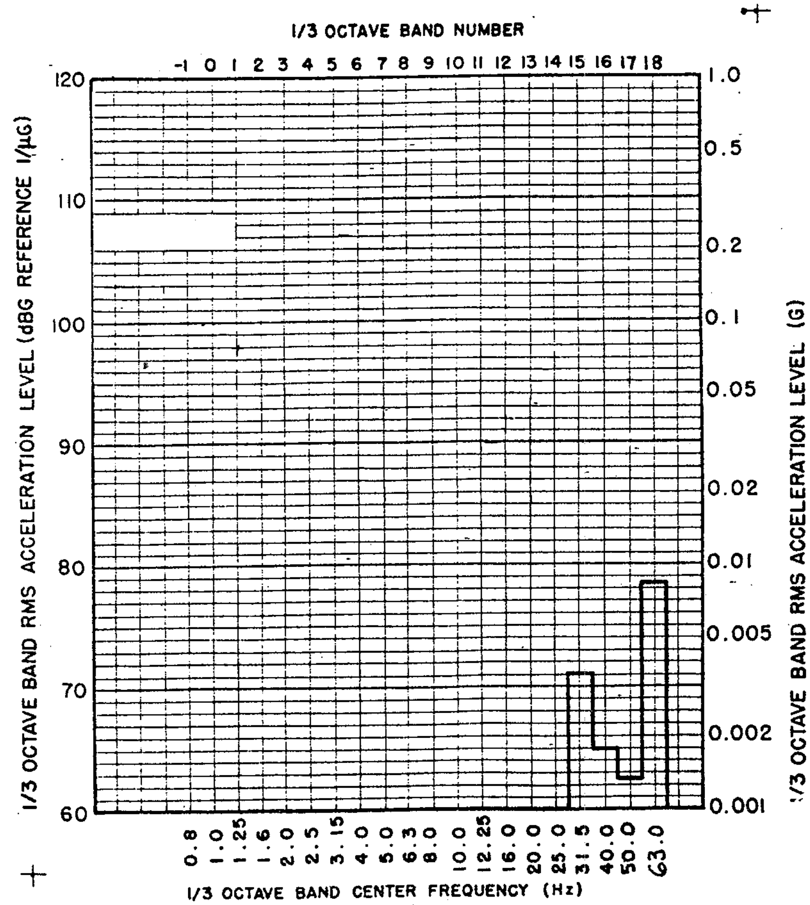


FIGURE VIB16.

ALL AUXILIARIES - MID CAR VERTICAL.

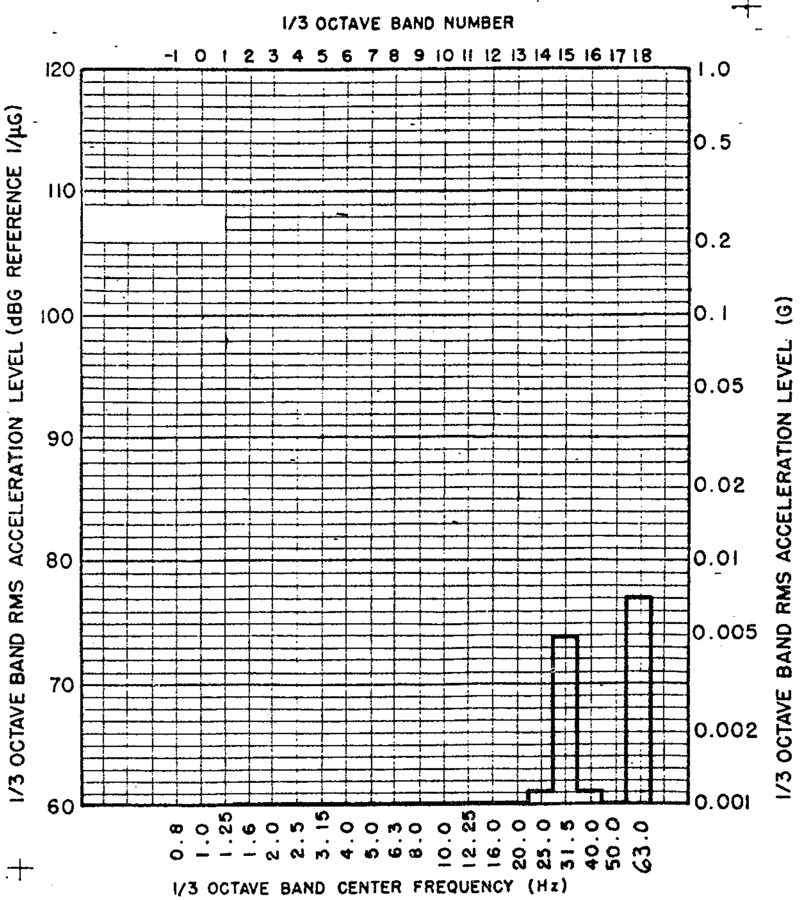


FIGURE VIB17.

ALL AUXILIARIES - MID CAR LATERAL.

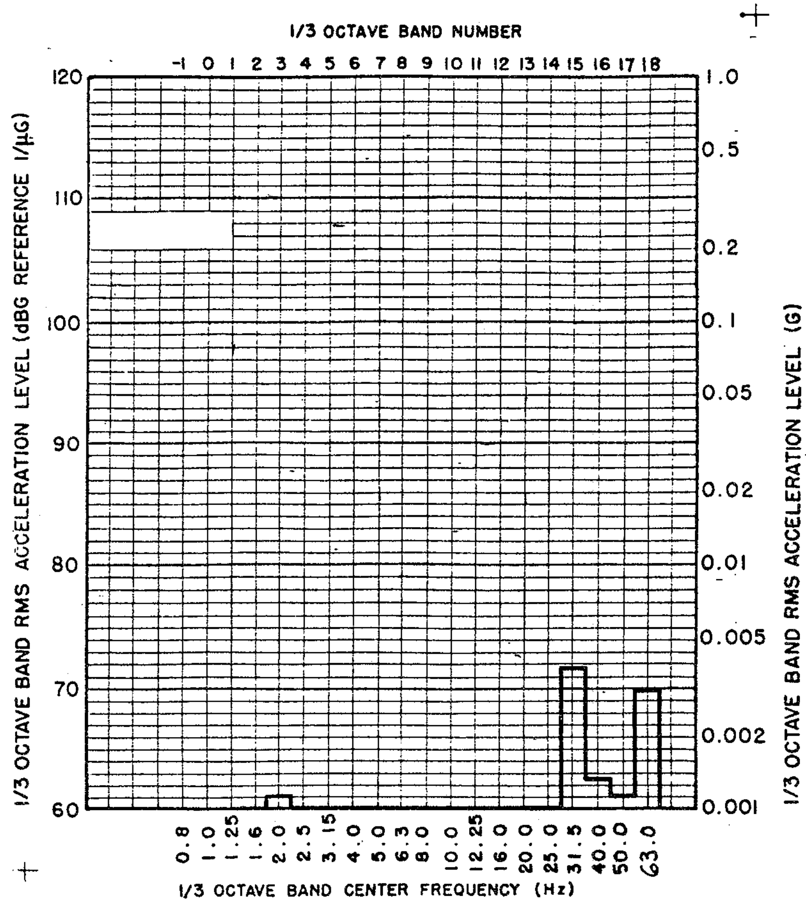


FIGURE VIB18.

ALL AUXILIARIES - 'A' END VERTICAL.

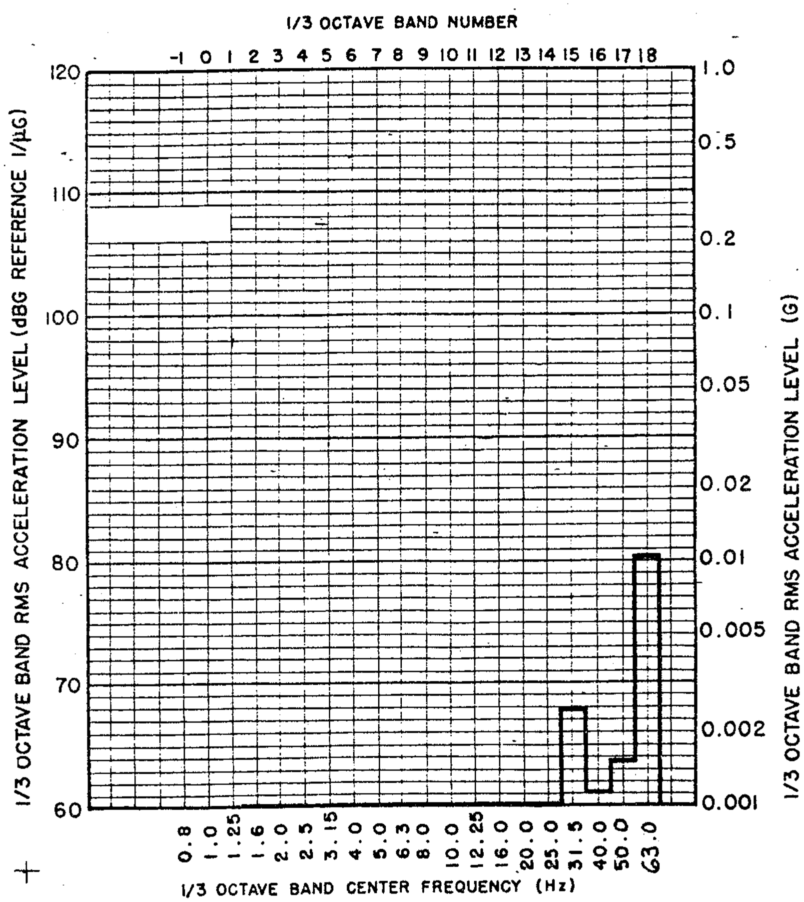


FIGURE VIB19.

ALL AUXILIARIES - 'A' END LATERAL.

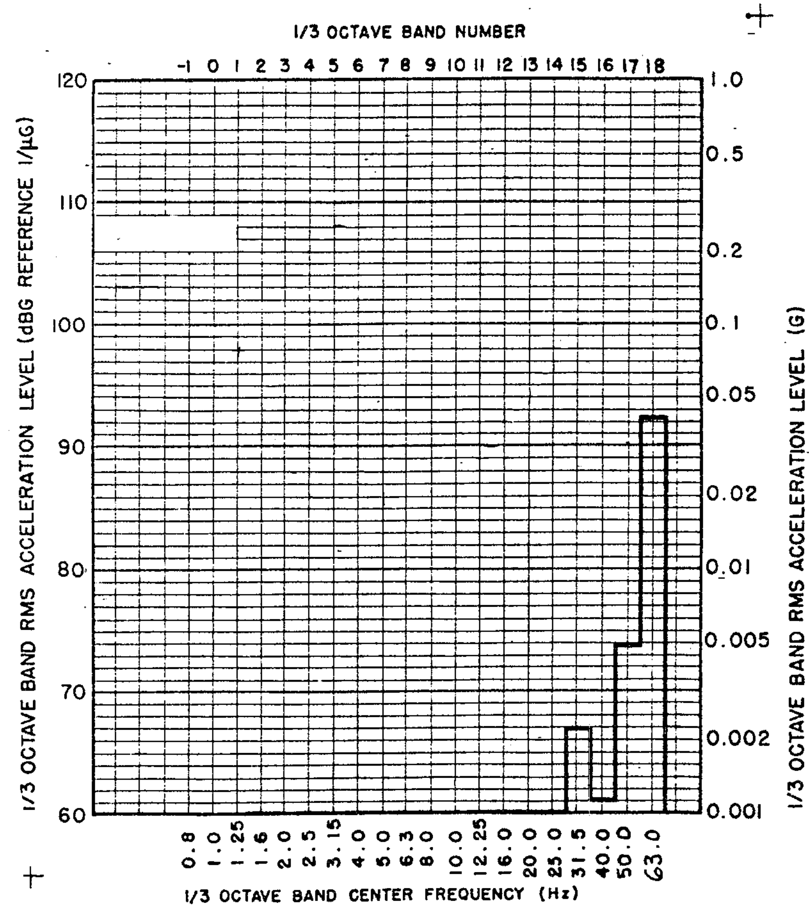


FIGURE VIB20.

637 VOLTS - ALL AUXILIARIES - 'B' END VERTICAL.

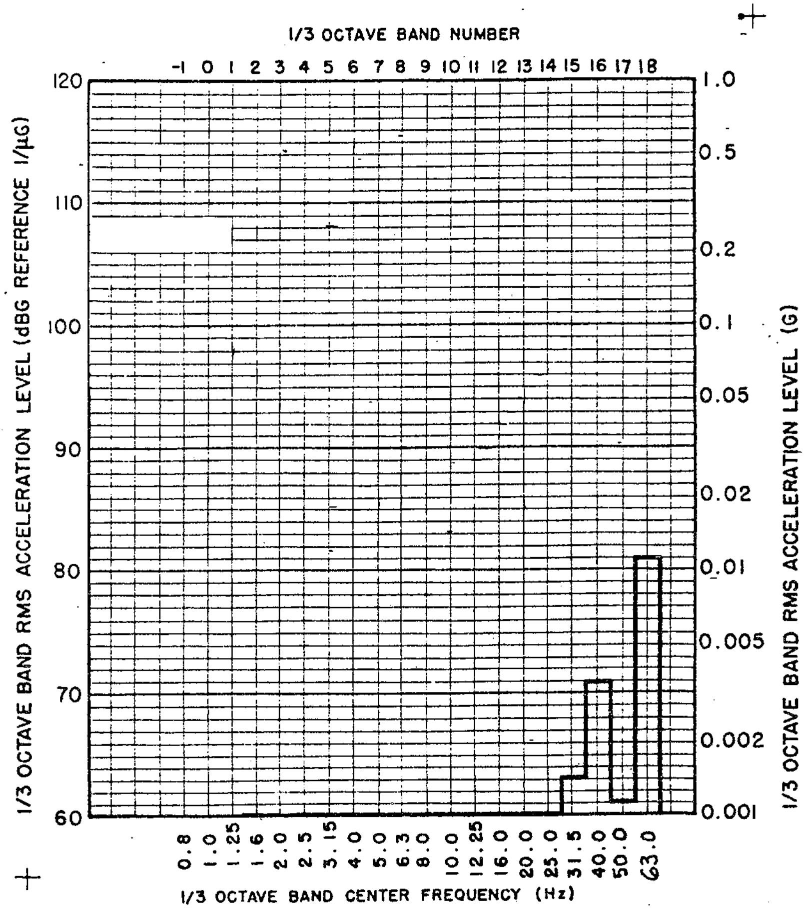


FIGURE VIB21.

736 VOLTS - ALL AUXILIARIES - 'B' END VERTICAL.

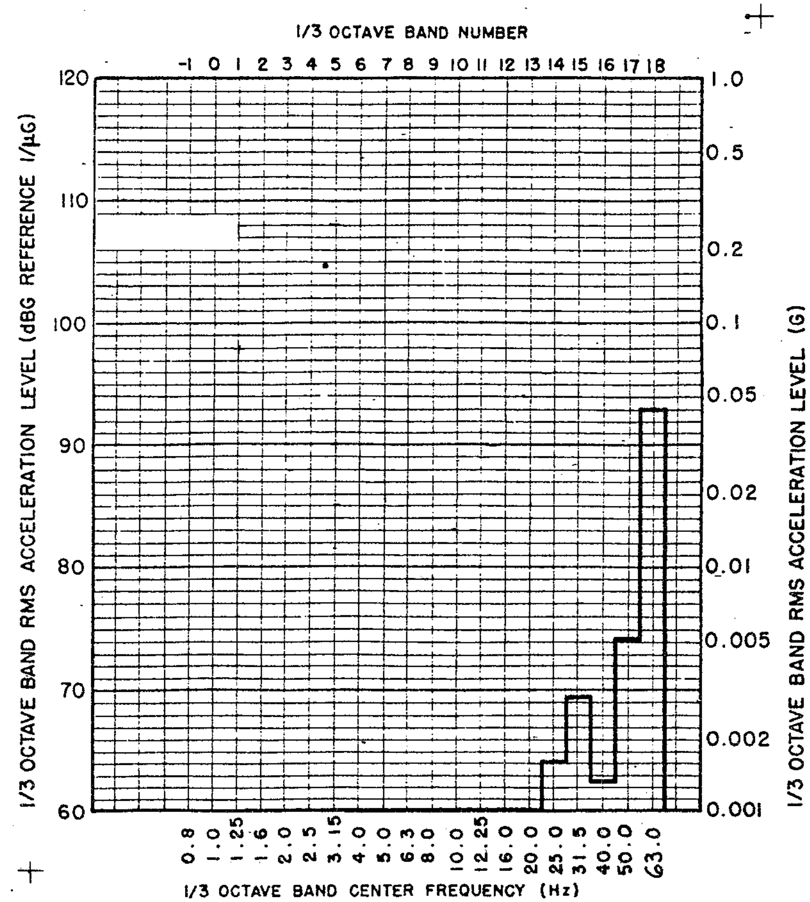


FIGURE VIB22.

ALL AUXILIARIES - IN DOORWAY ON FLOOR - VERTICAL.

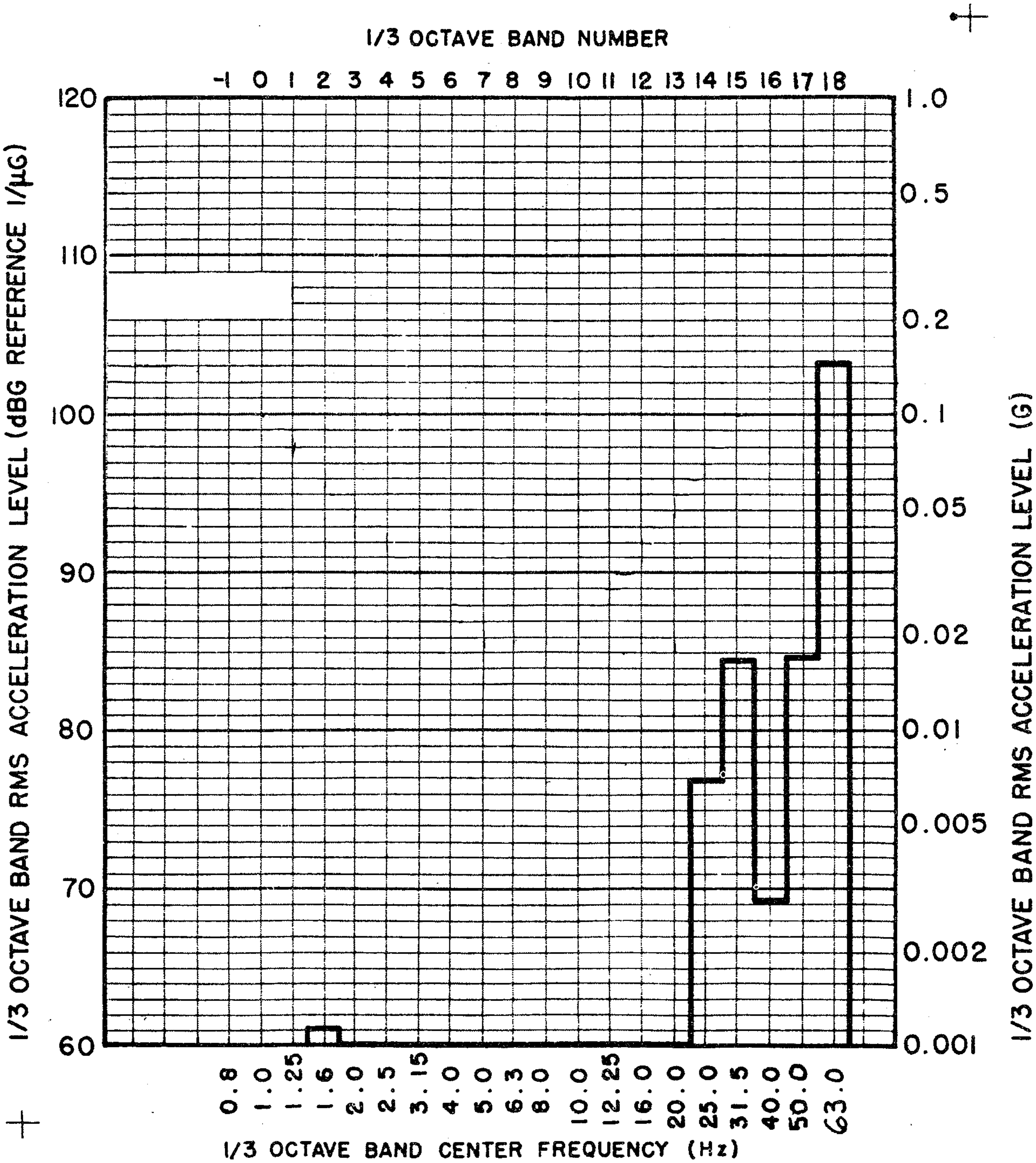


FIGURE VIB23. ALL AUXILIARIES - ON SEAT AT 'B' END VERTICAL.

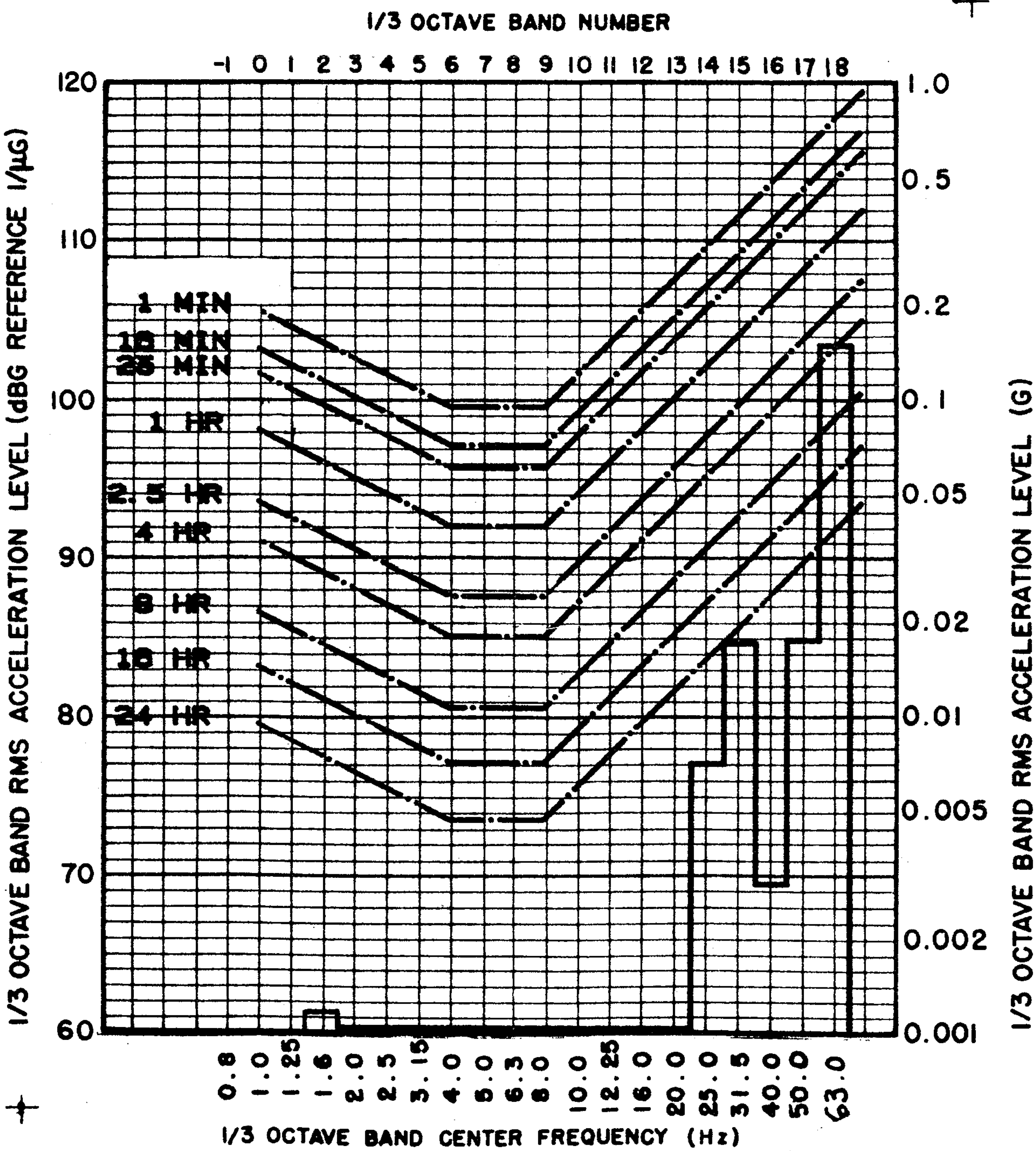
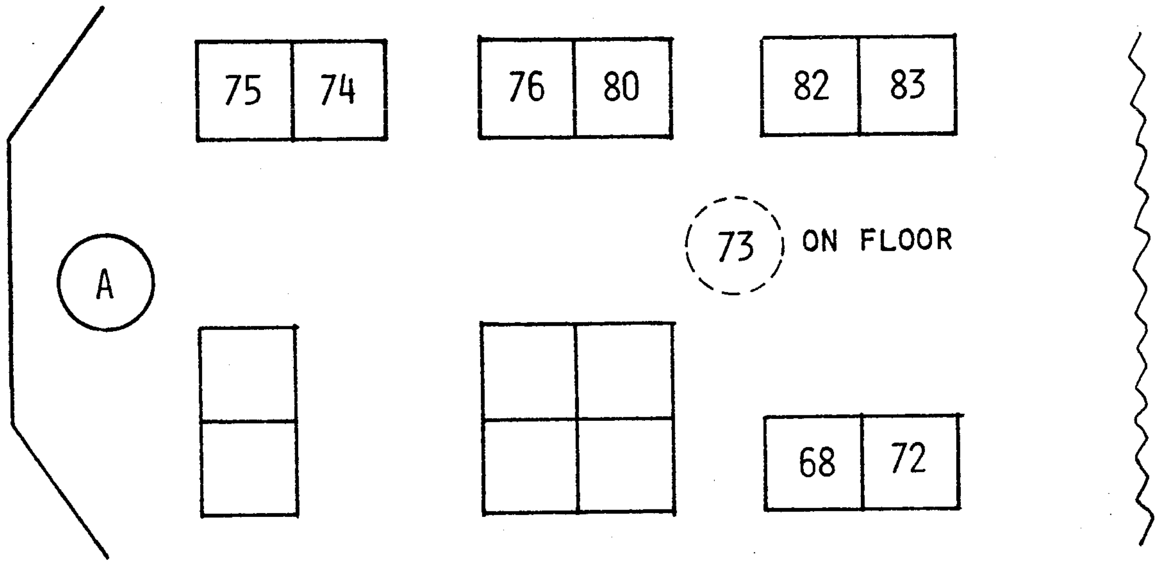


FIGURE VIB24. SEAT VIBRATION COMPARED TO ISO STANDARD.



Levels shown are highest band level in dB G re. 1μ (vertical)

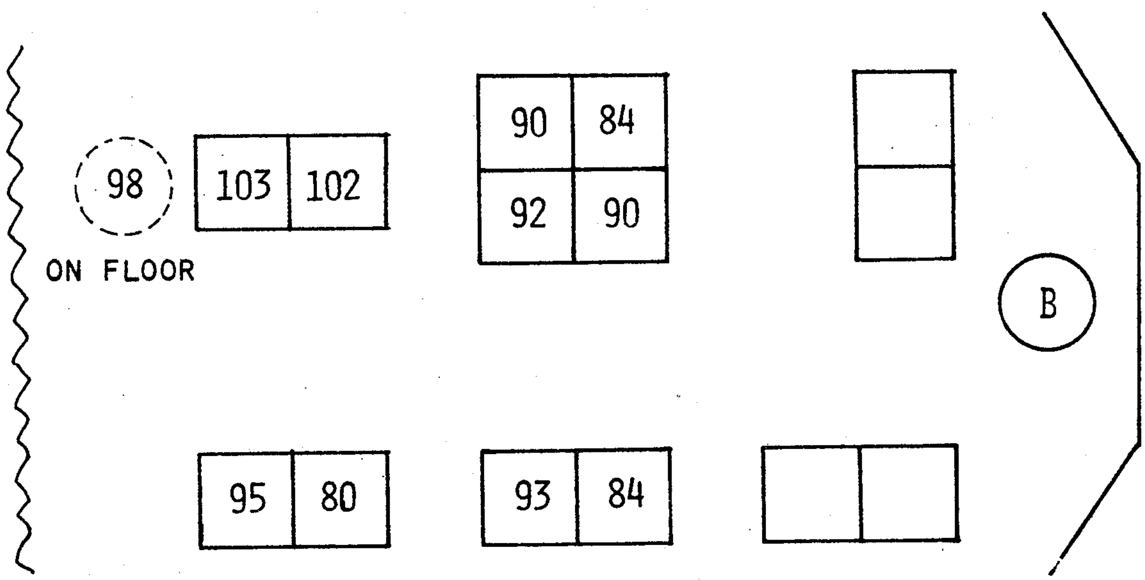


FIGURE VIB25. MAX VIBRATION LEVELS ON SEAT PLAN.

5.7 RIDE QUALITY

5.7.1 Objective

The main objective of the ride quality test was to evaluate the floor vibrations against the vehicle specification. A further objective was to identify any problem areas of the ride during operation of the vehicle. In addition to comparing the ride performance of the vehicle against the specification, the ride of the vehicle was compared against the ISO 2631-1978 Standard, which contains different limits.

The relevant section of the specification is as follows:

Throughout the operational environment, the Light Rail Vehicle shall be designed to be free from objectional vibration and shock. All equipment mounted in the passenger area shall be free from resonance to avoid annoying audio and visual distraction. The ride quality of the vehicle shall be evaluated on test sections of ballasted track with welded, ground rail maintained within the alignment limits as follows:

a)	Gauge	± ¼ inch
b)	Cross level variation (tangent) per 31 feet of track	± ¼ inch
c)	Superelevation per 31 feet of track	± ¼ inch
d)	Horizontal alignment (tangent) mid offset of 62 foot line	± ¼ inch
e)	Horizontal alignment mid ordinate of 62 foot chord	± ¼ inch

The track modulus will be at least 30,000 pounds/inch. This number is intended to be vertical track stiffness. Under these conditions, vertical and horizontal accelerations of the floor structure measured on the vehicle centerline over the trucks and midspan of the carbody sections shall not exceed the acceptable limits.

Measurements shall be made with root-mean-square responding intrumentation having an integration time of one to four seconds and using 1/3 octave bands. Steady-state values apply to average measured values for a 10-second period and shall be less than the limits shown in Figure RQ1 (Figure 3.2.-1 in the specification). Transients shall not exceed 0.15g (104 dB) and apply to any instantaneous reading.

5.7.2 Test Method

The ride quality limits are shown in Figure RQ1. The target section of TTC track used to evaluate the vehicle's ride qualities was located between Station 33 and Station 36. This track contains concrete ties and welded rail, and all track geometry parameters are within FRA Class VI standards.

In the specification, comparisons are limited to measurements on the floor "...on the vehicle centerline over the trucks and at midspan". For this analysis, data were taken at these locations and also on the centerline in the operator's cab.

The last paragraph of Ride Criteria pertaining to the integration times caused some interpretation difficulty for the analyst. The B&K 1/3 octave analyzer was equipped with selectable integration times over a range of 1/32 to 128 seconds, and it was decided to use for steady-state data, an averaging time corresponding to 8 seconds of data. The transient limit of 0.15g (104 dB) was applied to an averaging time of 2 seconds of data.

The ride quality 1/3 octave limits of the specification shown in Figure RQ1 shows a different characteristic for the vertical and lateral directions over some bands with the same limit on others. Both vertical and lateral limits are the same for the 1/3 octave bands of 4, 5, 6.3, and 8 Hz at 86 dBg. The vertical limits have a range between the 1 Hz band to the 31.5 Hz band, but the lateral limits include the extra bands of 1.6 Hz and 40 Hz band. It was assumed that bands outside these are not addressed by the specification.

A standard 1/3 octave format was drawn for the analysis, shown in Figure RQ2. This is the same as the specification, except the Y axis has been extended by 20 dBg downward. This gives a Y axis of between 60 dBg and 120 dBg, a range of 608 dB, the same as that of the 1/3 octave analyzer. The Y axis corresponds to a maximum of 1.0g and a minimum of 0.001g, a range of 1000 to 1. Included on the X axis are the standard band numbers given to the 1/3 octave bands in the 1EC Publication 225 (Ref. 3).

The B&K 1/3 octave analyzer had a low frequency cut-off at the 1.6 Hz band. In order to evaluate the band levels below this frequency, the data were replayed at twice the recorded speed, transposing the frequencies. As a check that the method was giving the correct results, a selected piece of vibration data was played at both the recorded speed and at twice the recorded speed. The integration time for the data played at the recorded speed was set to 8 seconds and for the twice recorded speed at 4 seconds. Thus, in both cases an identical data window was analyzed. The B&K analyzer was controlled by an HP 85 desk-top computer which plotted the two sets of 1/3 octave data in overlay form in Figure RQ2. The two sets of 1/3 octave levels overlay closely between the 1.6 and 40 Hz bands. The plot shows the extended low end, extended by one octave down to the 0.8 Hz band.

Vibration sensing was by accelerometers mounted on the floor. Each accelerometer (of the servo type) was mounted on a substantial base. The base was set on 3 screw feet to give a rock-free platform. The vibration signals, with a conditioned response of DC to 100 Hz, were recorded on a 28-channel FM tape recorder. Each accelerometer has nominal sensitivity of 1 volt per g, with a signal conditioning gain of 10. The playback sensitivity was a nominal 1 volt per g.

The standard accelerometer layout was as follows:

Channel

2	'B' End Truck Centerline Vertical
3	'B' End Truck Centerline Lateral
4	Mid Car Centerline Vertical
5	Mid Car Centerline Lateral
6	Mid Car Left Vertical
7	'A' End Motorman Cab Vertical
12	'A' End Motorman Cab Lateral
24	Vehicle Acceleration Longitudinal

The principle tests were made with a vehicle weight of AW0. In this condition the floor was free of lead ballast and gave the vehicle the correct center of gravity for its weight. The data analysis is restricted to this vehicle weight, with two plots included from AW3 tests for comparison. Subjectively, there was no abnormal vehicle behavior at weights other than AW0, and it is assumed that the vehicle performed in the ride quality sense in a similar manner. However, had it been apparent during vehicle tests at other weights that there was poor vehicle ride, then data would have been recorded and analyzed.

5.7.3 Test Results

5.7.3.1 Worst Speed Tests

The vehicle was very gradually accelerated through the speed range, zero through 50 mph, to detect any speeds at which the ride deteriorated. If a poor ride was noticed, the speed at which it occurred would be included in the constant speed tests to follow. To detect the worst speeds, if any, two methods were used:

1) Subjectively

2) By observing ISO 2631-weighted time history charts

Any observed deterioration of ride on the ISO-weighted charts would be related to an observed roll, pitch, etc., or to a vibration felt through the floor.

There were two types of ISO 2631-weighted charts (Ref. 2):

1) Car Vertical - Weighted with an ISO human longitudinal direction network (Z axis).

2) Car Lateral - Weighted with an ISO human transverse direction network (Y and X axis).

Note that the instrumentation accelerometers' axes refer to car vertical, car lateral, and car longitudinal, but that the ISO standard refers to the axis relative to the human body where the longitudinal axis is through the top of the head (see Figure RQ3). The characteristics of the weighting networks applied to the vertical and lateral signals are shown in Table RQ1.

After the signals were weighted, they were rectified with an RMS circuit that had been specially built to be responsive to low frequency vibration down to 1 Hz.

The rectified signal was fed to a B&K level recorder set to the 'DC Log' scale at a range of 50 dBg.

The worst speed runs were performed twice, the first with the ISO-weighted time history chart weighted for car vertical and the second with the chart weighted for lateral.

Throughout the two test runs, no worse speeds were experienced subjectively or observed on the charts, and it was concluded that there were no worse speeds for the vehicle in the speed range of 0 to 50 mph.

During the tests it was observed that the whole body yaw mode gradually built up in amplitude and was of sporadic nature.

On replay of the data, the same ISO 2631 weighted time histories were produced and these are shown in Figures RQ4 through Figure RQ7. The data were taken from channels 7 and 12, the 'A' end vertical and lateral accelerometer.

It is of interest that the weighted vibration level at 50 mph, in both the car vertical and lateral case, is of the same level (approximately 84 dBg); however, the ISO standard asserts that vibrations in the vertical direction cause less discomfort. In this case, then, the lateral weighted level of 84 dBg is of greater discomfort than the vertical level of 84 dBg.

The tests show that the vehicle is not subject to any worse speeds in the lateral or vertical direction. However, the tests were performed with a car in new condition. It is recommended that the test be expanded to include some runs where the vehicle has been modified with out-of-balance wheel forces or wheel flats to induce worse speeds.

5.7.3.2 Constant Speed Tests

Between Stations 33 to 36 the vehicle was run at constant speeds of 50, 40, and 28 mph. It was clear from the worst speed runs that there were no worse speeds and that the ride gradually decreased in quality as the speed increased to 50 mph. Therefore, as far as the specification was concerned, the 50 mph case would be most critical and this run was compared against the specification boundary.

The 1/3 octave plots, Figures RQ8 through RQ13, show the comparison at 50 mph for the following channels:

Channel		
2	Vertical	'B' End Centerline
3	Lateral	'B' End Centerline
4	Vertical	Mid Car Centerline
5	Lateral	Mid Car Centerline
7	Vertical	Motorman Cab Floor
12	Lateral	Motorman Cab Floor

The data are from Station 33 and have an 8-second time window (4 seconds at twice-speed playback). Clearly, the vehicle easily meets the specification. The data show the presence of a whole body mode in the 1.0 Hz band for lateral and the 1.25 Hz band for vertical.

To obtain a 1/3 octave spectra over a longer time window, the integration time of the analyzer was set so as to collect data between Station 33 to Station 36. The result is shown for the motorman cab vertical and lateral in Figures RQ14 and RQ15, which demonstrate results very similar to those obtained for Station 33.

To obtain the transient data for comparison against the specification, a 2-second time window was selected (1-second at twice replay speed). The analyzer was set in the 'max hold' mode in which the maximum band level from the series of time windows was held and displayed on the screen. The result taken from the accelerometers in the motorman cab is shown in Figures RQ16 and RQ17 for the vertical and lateral directions. On the plots the specification maximum of 104 dBg is shown. Clearly, the car passes this specification, although the track did not contain switches or crossings.

5.7.3.3 1/3 Octave Data at 40 and 28 mph

The 1/3 octave plots for 40 mph and 28 mph taken from the motorman cab are shown in Figures RQ18 through RQ21. As suspected, the levels are lower than the 50 mph case and show very low levels at 28 mph.

5.7.3.4 1/3 Octave Data Taken at 28 mph for a Complete Loop

This test was performed to see if the vehicle was sensitive to a particular type of track section. There are 6 types of track section around the loop, and the vehicle was run around with the paddle pick up cart in tow. Speed was maintained close to 28 mph.

Subjectively, there was no perceptible difference in the ride on any of the 6 track sections; this is supported by the 1/3 octave band levels (Figures RQ22 through RQ33)--again lateral and vertical--for the motorman's cab. The data show that the suspension effectively isolates the car from the track.

5.7.3.5 Comparison of the Vehicle to the Specification at AW2

Figures RQ34 and RQ35 show the vertical and lateral band levels for the 'A' end of the vehicle at 50 mph, and they show the expected similar levels to AW0, again within the specification.

5.7.3.6 Acceleration and Braking Tests

The objective of the test was to see if the vehicle exhibited poor ride quality characteristics when under acceleration or braking. Accelerometer recordings were made for a full power acceleration and full brake in the blended and the friction only mode. The data are presented in ISO 2631-weighted strip chart form in the same style as the worst speed charts.

Figure RQ36 shows the motorman cab vertical and lateral charts. It can be seen from the charts that, during the acceleration, the ride quality followed a similar characteristic as the worst speed charts, with a steady deterioration of ride as speed increased. The propulsion system under full acceleration did not contribute to any deterioration in ride quality and in this respect can be said to be excellent.

The chart records for the brake runs with initial speeds of 50 mph in Figure RQ37 show no deterioration in the ride quality due to braking in either blended or friction mode. Of interest in the deceleration charts is the peak at the end of the brake run, caused by the body pitch induced at the instant the vehicle comes to a halt. This causes a pitching action after the vehicle has stopped. This seems to be a characteristic of this vehicle's suspension.

5.7.3.7 Comparison of the Car Ride Quality to the ISO 2631 Standard

To provide additional information on quality of ride, the data were compared to the ISO 2631 Second Edition, 1981 Standard. This Standard addresses frequencies in the range 1 Hz to 80 Hz and contains a reduced comfort criteria applicable to passengers (derived from studies conducted in the transportation industries), which assesses the effect of vibration on such tasks as eating, reading, or writing. The significant part of the Standard consists of sets of reduced comfort boundary lines associated with time exposure. The Standard is written in the same 1/3 octave band format as the specification.

To show a comparison between the ISO 2631 Standard and the vehicle specification, the two have been overlayed in Figure RQ38 (vertical) and Figure RQ39 (lateral).

The vertical specification shows a similar characteristic to the ISO 2631 4-hour or 2.5-hour exposure line, with some relaxation of limit in the lower frequencies down to 1 Hz. However, the lateral vehicle characteristic is shaped quite differently than the ISO 2631 characteristic, thus the vehicle specification is quite stringent at high frequencies, but in the low frequencies relaxes considerably, down to the ISO 1-minute boundary.

Data for the motorman cab at 50 mph for Station 33 to 36 are shown compared against the vertical and lateral ISO 2631 reduced comfort boundaries in Figures RQ40 and RQ41. In this form the 1/3 octave band analysis shows a different emphasis than against the vehicle specification. Against the vehicle specification, the vertical frequencies around 10 Hz appeared to be the most critical, but when compared to the ISO Standard, the low frequencies at 1 Hz are significant. This is supported by subjective observations on the vehicle, which showed the whole body yaw to be quite noticeable. Note that the set of boundary lines on the ISO Standard for the vehicle lateral case are some 3 dB lower than that for the vertical. This, and the fact that the yaw frequency is at the most sensitive area of the boundary, explains why, when compared against the ISO 2631 Standard, the lateral yaw mode becomes significant.

Although the lateral yaw mode is the most significant as far as the ISO Standard is concerned, it still has not crossed the 1-hour boundary line at 50 mph and, therefore, the comparison still gives the conclusion that the ride is excellent.

5.7.3.8 Summary of Results

The ride quality tests clearly showed that the ride of the vehicle was excellent in all modes of operation. Vibration levels in the vehicle were well below the specification boundaries.

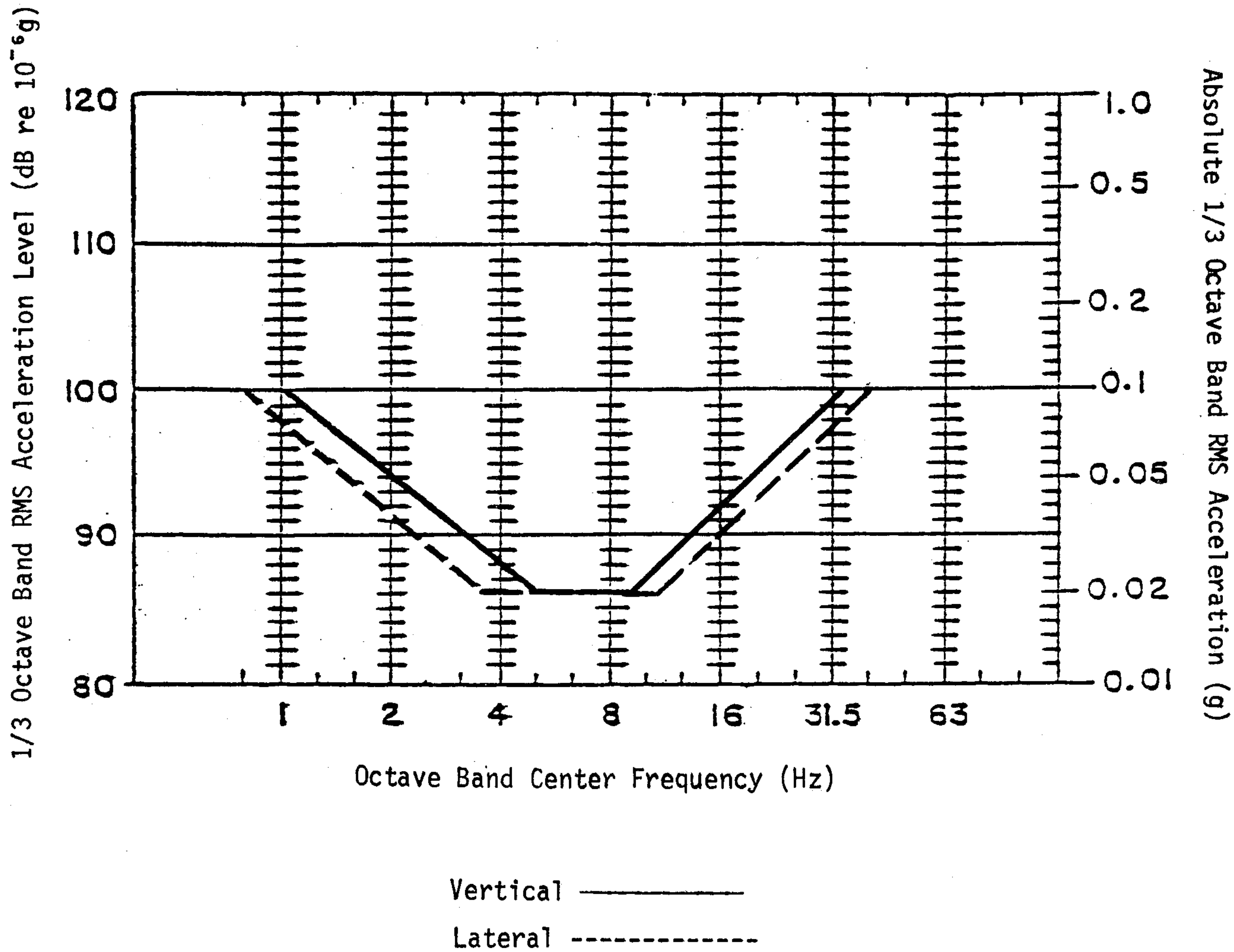
When the ride quality was compared with ISO 2631 1978, 'Guide for the Evaluation of Human Exposure to Whole-body Vibration', again the ride was of excellent quality. The ISO Standard indicated that the most noticeable input of the ride to a passenger was the vehicle yaw mode, which was greatest at the ends of the vehicle, and this was confirmed subjectively.

It is recommended that the ride quality specification be augmented to include failure modes and these be tested. A suggested limit would be the 1-minute reduced comfort boundary of the ISO Standard for a car operating without balance wheels/wheel flats and the 2.5-hour reduced comfort boundary for a vehicle in good condition. This approach would differentiate between vehicles which have different ride quality under less than ideal conditions. The TTC test loop could be improved by the addition of a mile or so of track in a deteriorated condition in order to excite transit cars to a greater extent.

To conclude, within the restraints and limitation of the tests, the ride quality of the vehicle was found to be excellent, both subjectively and from analysis of the data.

TABLE RQ1. RIDE QUALITY VIBRATIONS.

Frequency (center frequency) of third-octave band) Hz	Weighing Factor for longitudinal vibrations (Figure 2a) (applied to car vertical signals)	Weighing Factor for transverse vibrations (Figure 3a) (applied to car lateral signals)
1.0	0.50 = - 6 dB	1.00 = 0 dB
1.25	0.56 = - 5 dB	1.00 = 0 dB
1.6	0.63 = - 4 dB	1.00 = 0 dB
2.0	0.71 = - 3 dB	1.00 = 0 dB
2.5	0.80 = - 2 dB	0.80 = - 2 dB
3.15	0.90 = - 1 dB	0.63 = - 4 dB
4.0	1.00 = 0 dB	0.5 = - 6 dB
5.0	1.00 = 0 dB	0.4 = - 8 dB
6.3	1.00 = 0 dB	0.315 = -10 dB
8.0	1.00 = 0 dB	0.25 = -12 dB
10.0	0.80 = - 2 dB	0.2 = -14 dB
12.5	0.63 = - 4 dB	0.16 = -16 dB
16.0	0.50 = - 6 dB	0.125 = -18 dB
20.0	0.40 = - 8 dB	0.1 = -20 dB
25.0	0.315 = -10 dB	0.08 = -22 dB
31.5	0.25 = -12 dB	0.063 = -24 dB
40.0	0.20 = -14 dB	0.05 = -26 dB
50.0	0.16 = -16 dB	0.04 = -28 dB
63.0	0.125 = -18 dB	0.0315 = -30 dB
80.0	0.10 = -20 dB	0.025 = -32 dB



L (dB re 10^{-6}g) = 20 $\log_{10} \alpha$ + 120, where α is the acceleration in g units.

FIGURE RQ1. RIDE QUALITY LIMITS FROM SPECIFICATION.

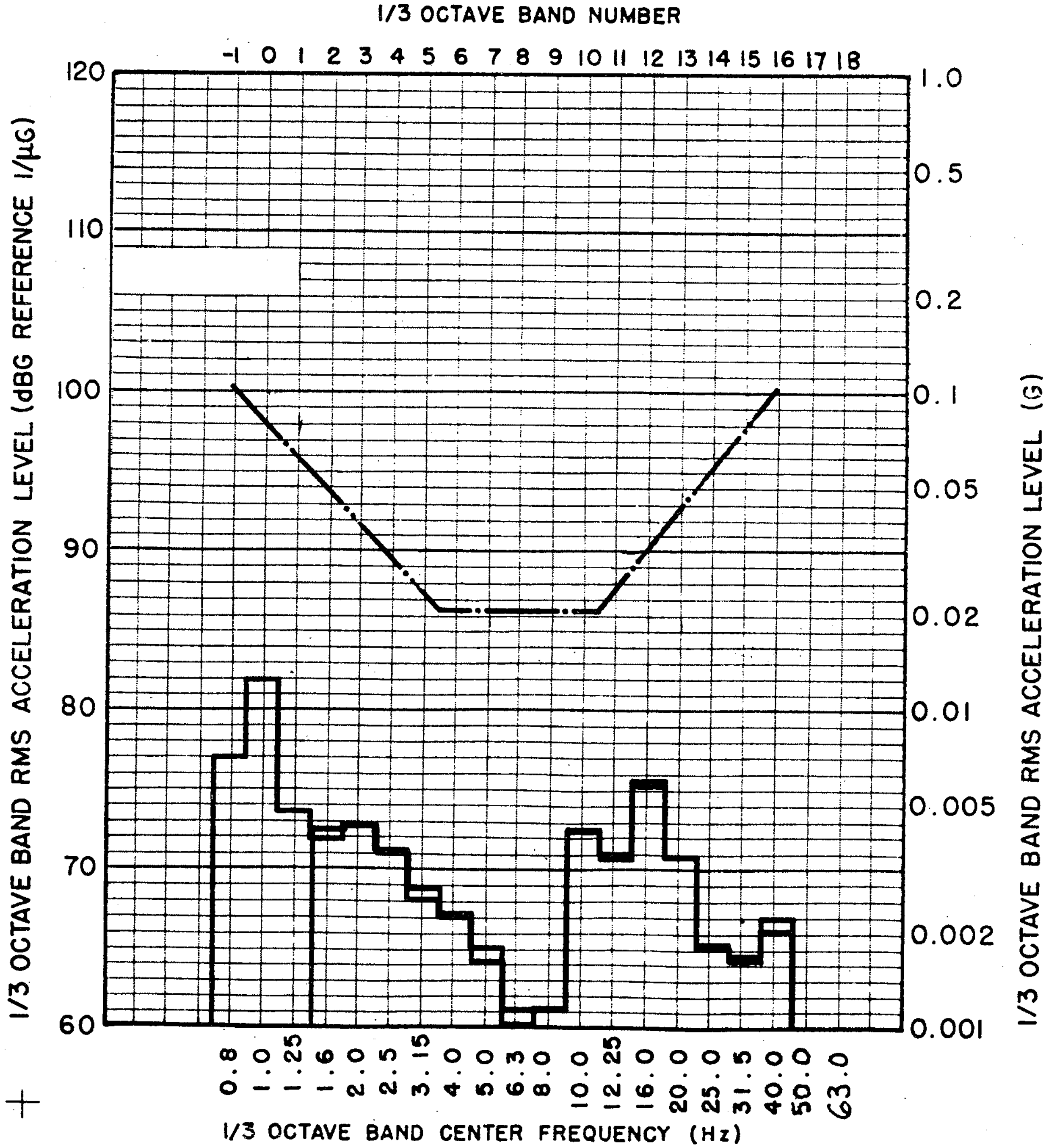
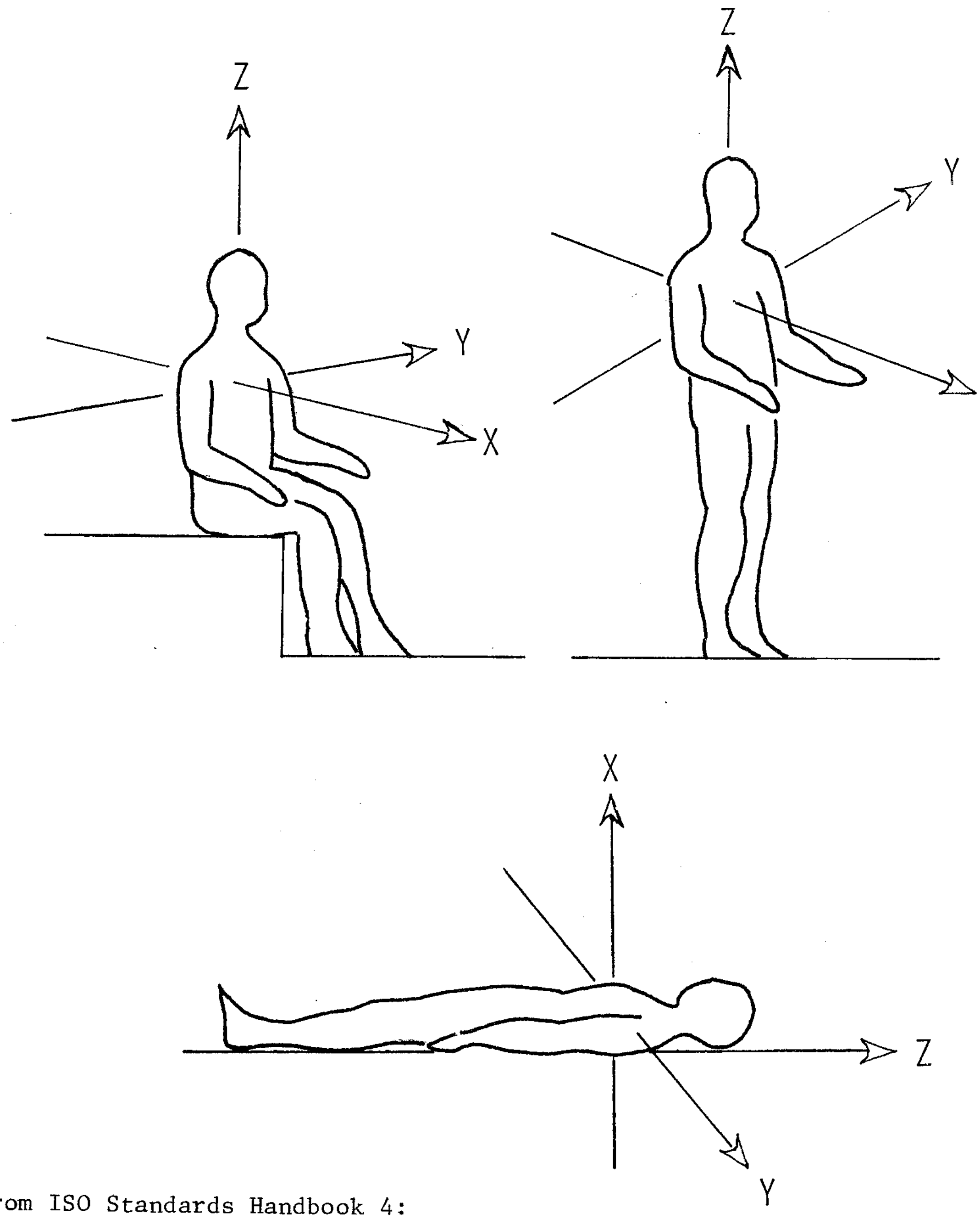


FIGURE FQ2. 1/3 OCTAVE BAND FORMAT WITH NORMAL SPEED AND TWICE SPEED OVERLAY.



(Traced from ISO Standards Handbook 4:
Acoustics, Vibration, and Shock,
International Organization for Standardization, 1980.)

a_x, a_y, a_z = acceleration in the direction of the x, y, z axes.

x axis = back to chest

y axis = right-to-left side

z axis = foot (or buttocks)-to-head

FIGURE RQ3. ISO 2631 HUMAN AXES.

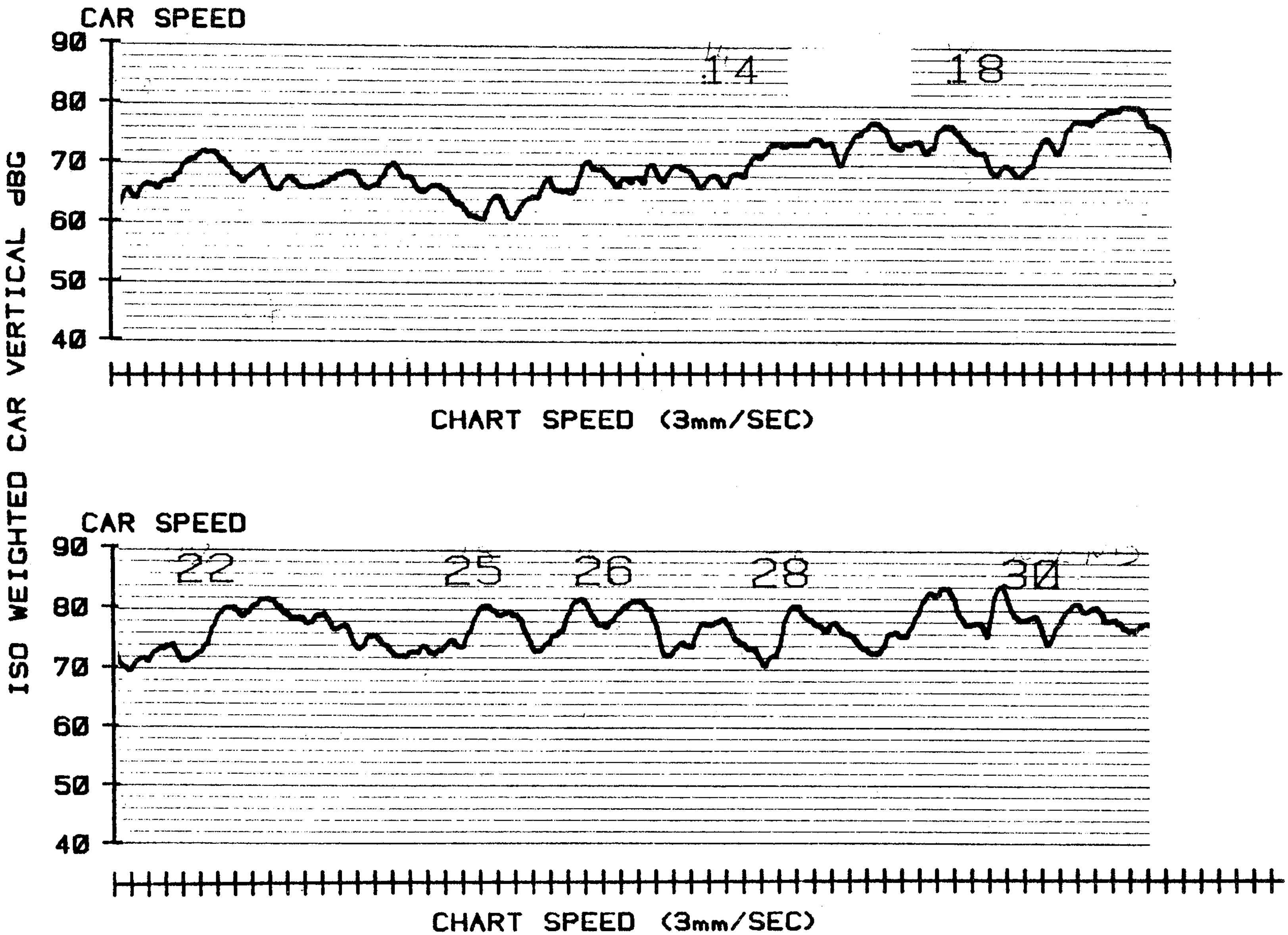


FIGURE RQ4. WORST SPEED ISO WEIGHTED CHART, VERTICAL 0 TO 30 MPH.

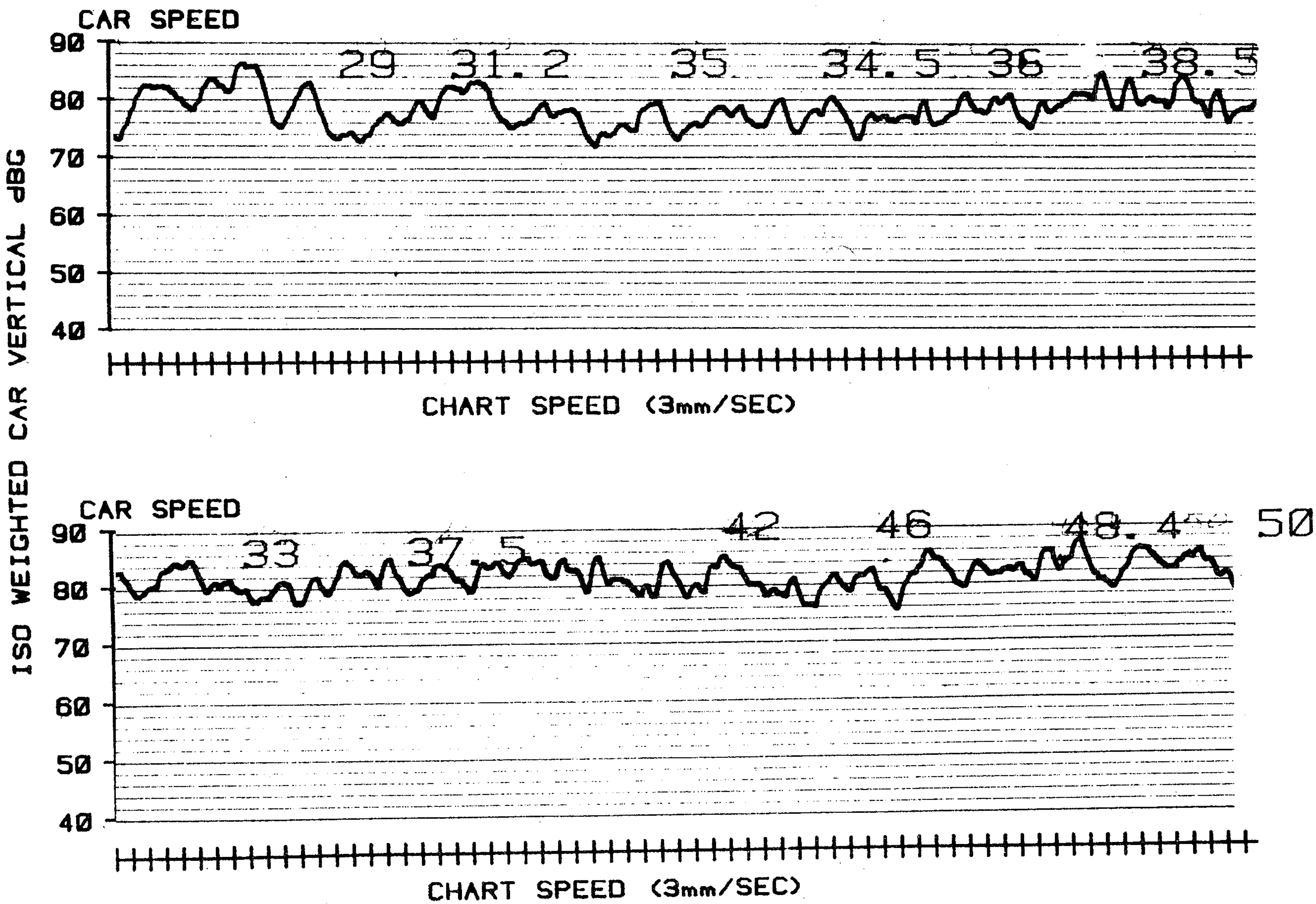


FIGURE RQ5. WORST SPEED ISO WEIGHTED CHART, VERTICAL 30 TO 50 MPH.

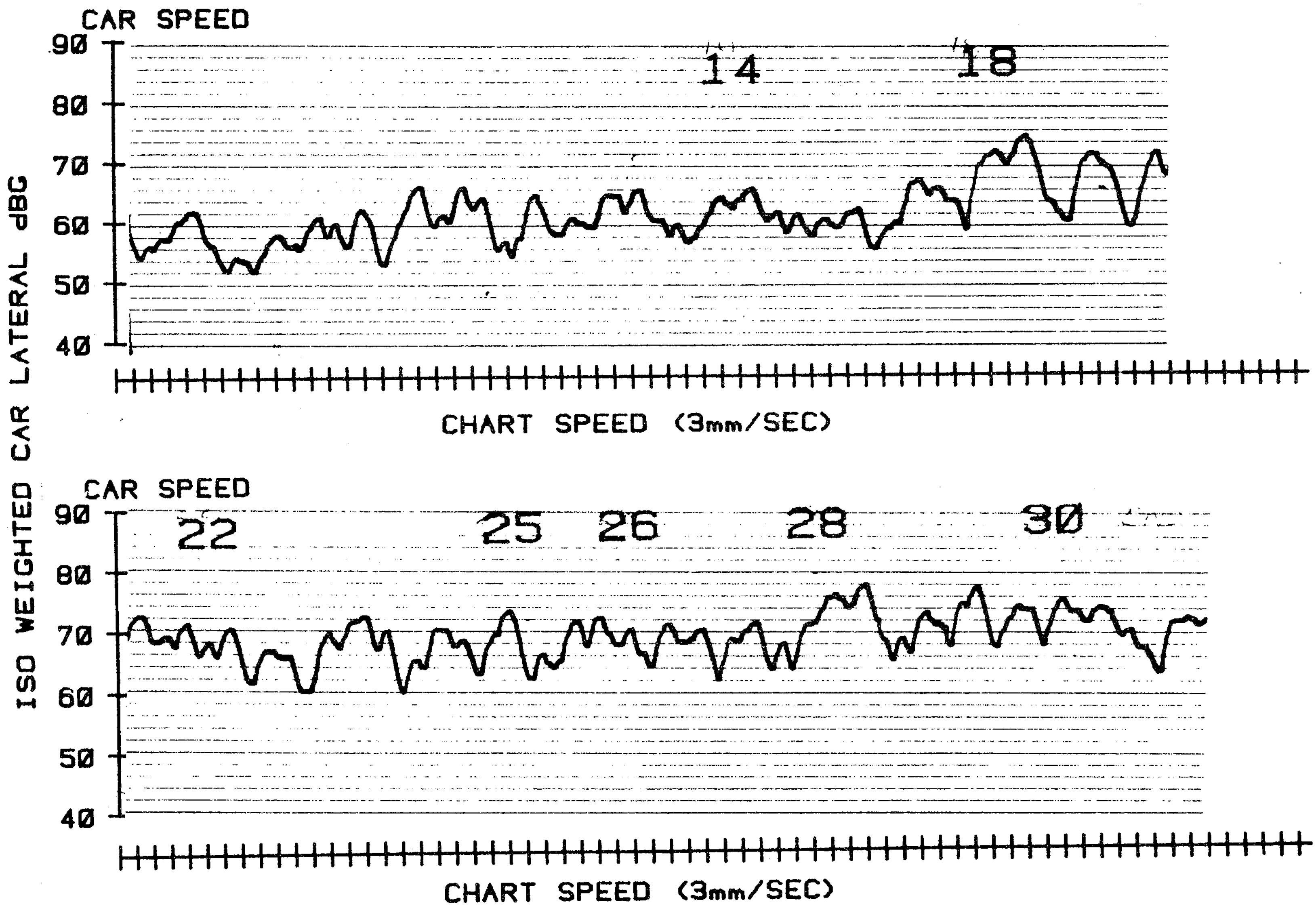


FIGURE RQ6. WORST SPEED ISO WEIGHTED CHART, LATERAL 0 TO 30 MPH.

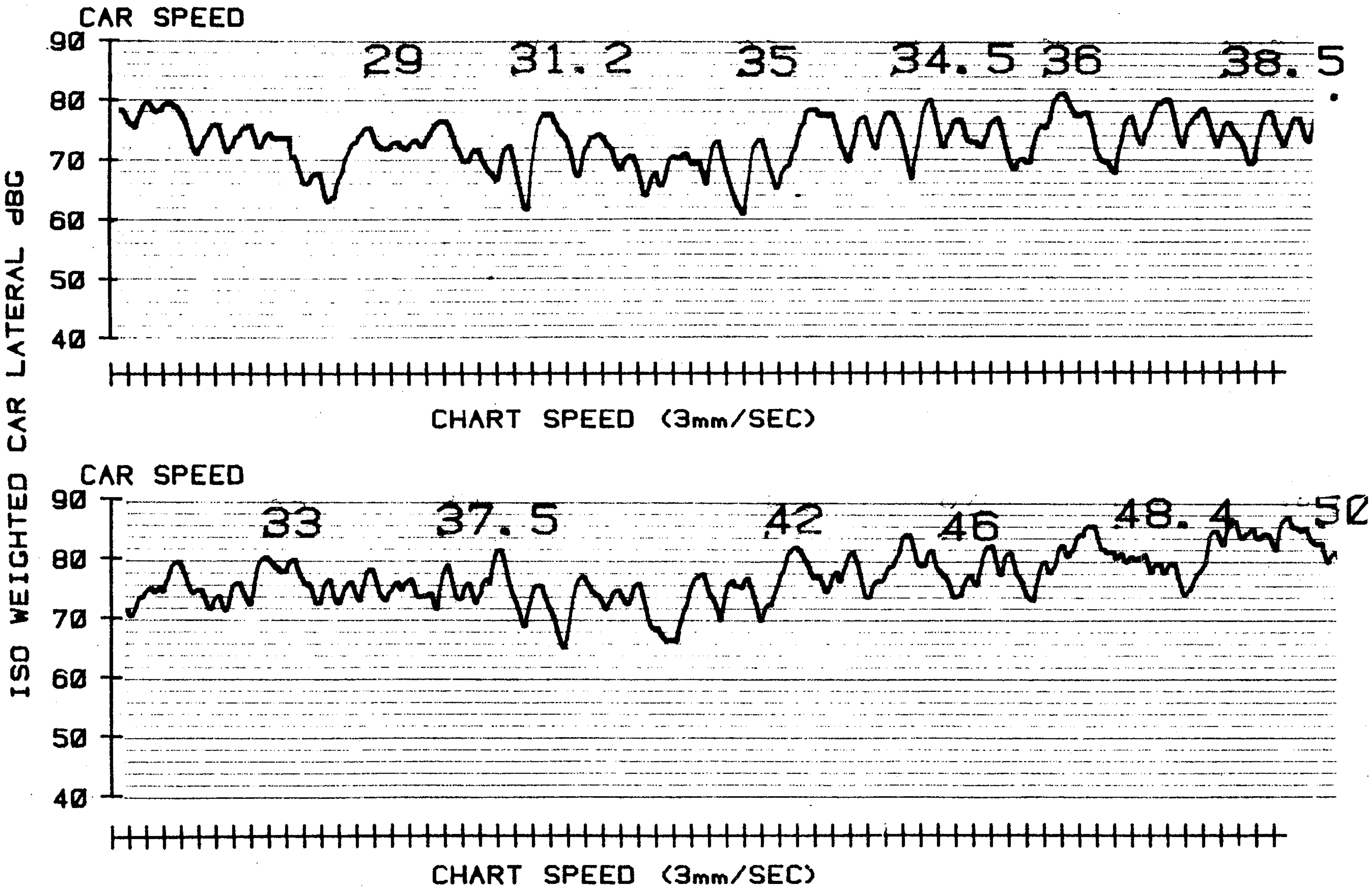


FIGURE RQ7. WORST SPEED ISO WEIGHTED CHART, LATERAL 30 TO 50 MPH.

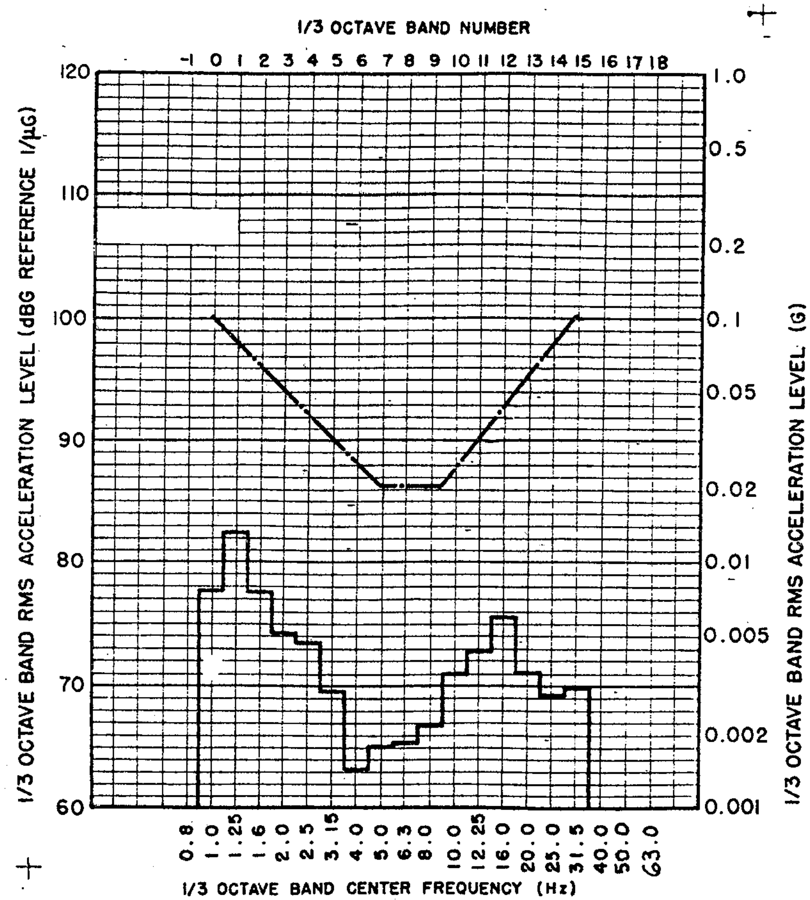


FIGURE RQ8.

50 MPH SPECIFICATION COMPARISON - 'B' END VERTICAL.

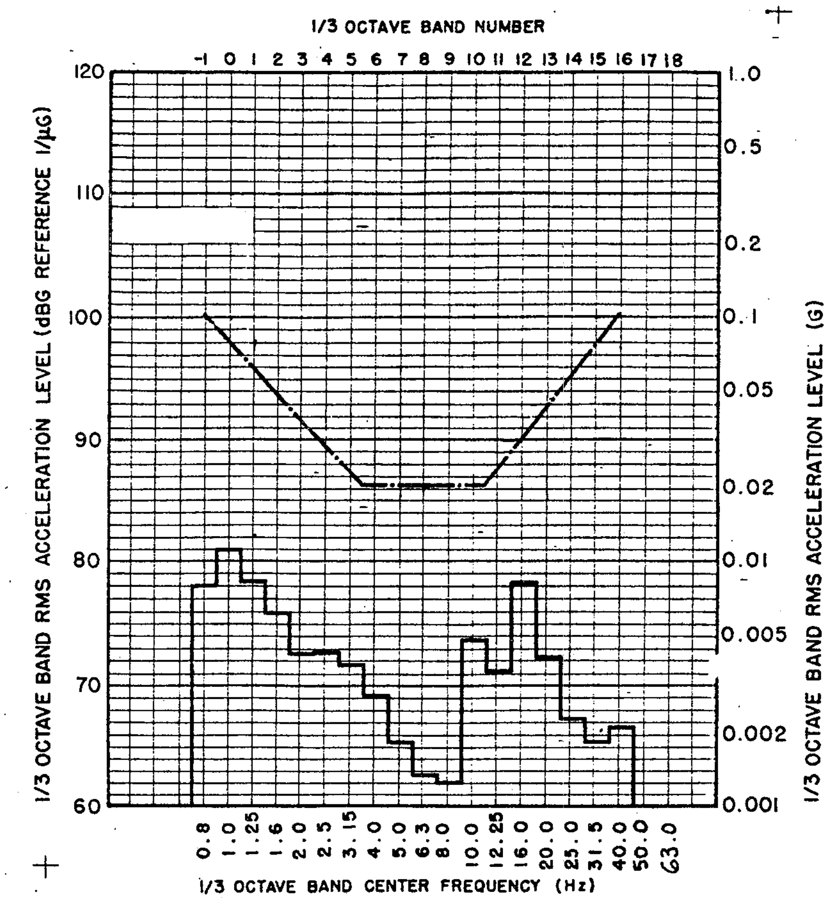


FIGURE RQ9.

50 MPH SPECIFICATION COMPARISON - 'B' END LATERAL.

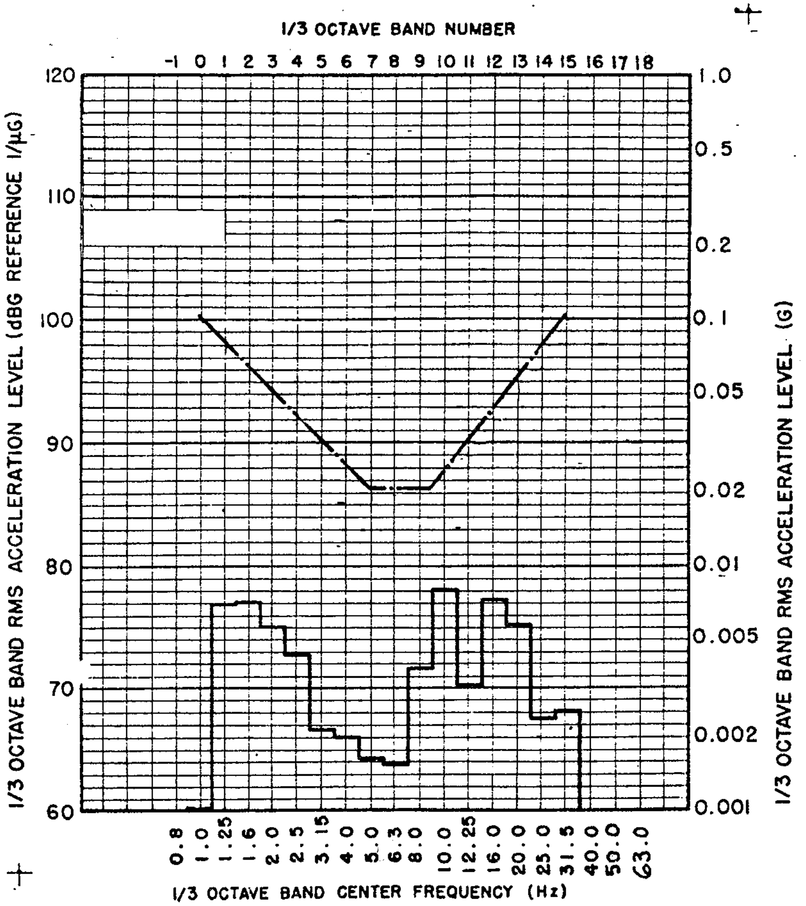


FIGURE RQ10.

50 MPH SPECIFICATION COMPARISON - MID CAR VERTICAL.

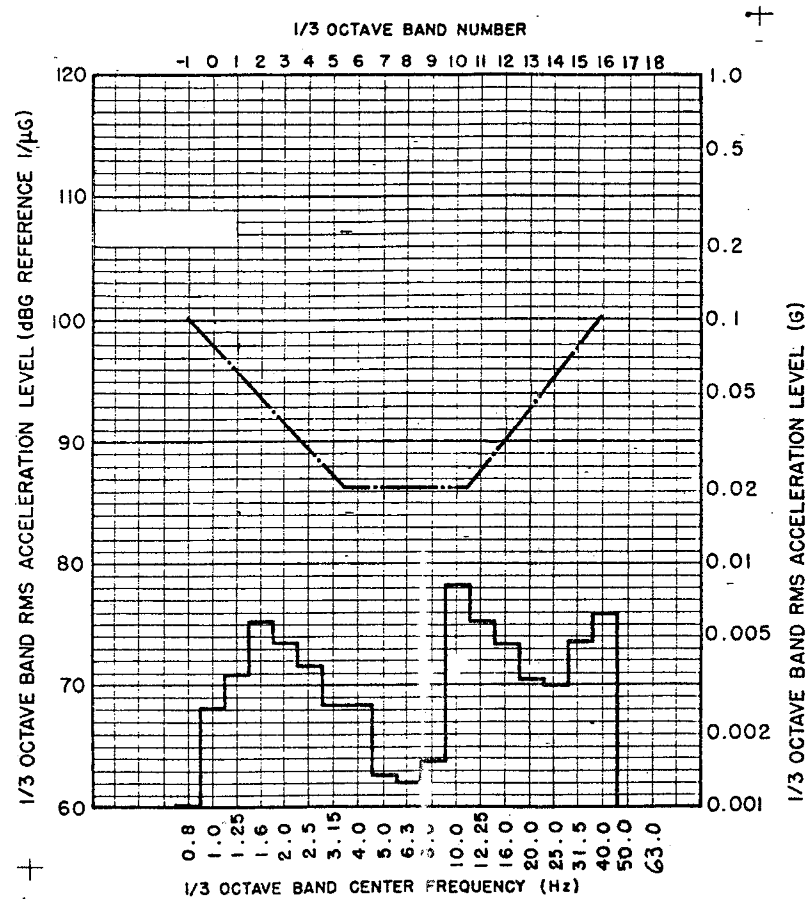


FIGURE RQ11.

50 MPH SPECIFICATION COMPARISON - MID CAR LATERAL.

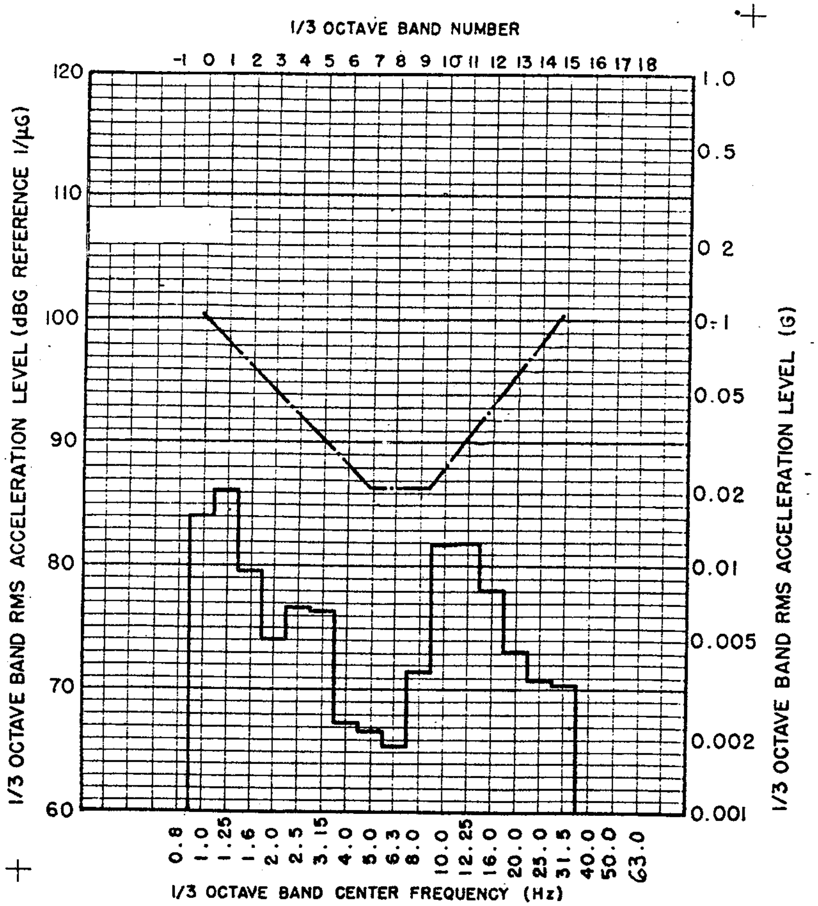


FIGURE RQ12.

50 MPH SPECIFICATION COMPARISON - MOTORMAN CAB VERTICAL.

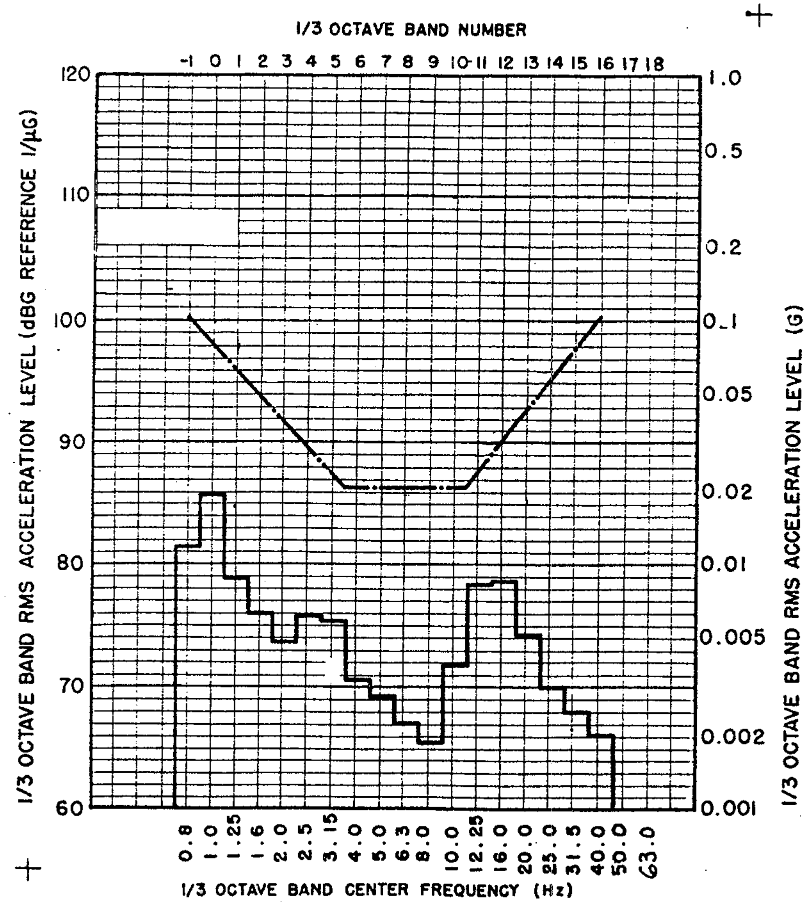


FIGURE RQ13.

50 MPH SPECIFICATION COMPARISON - MOTORMAN CAB LATERAL.

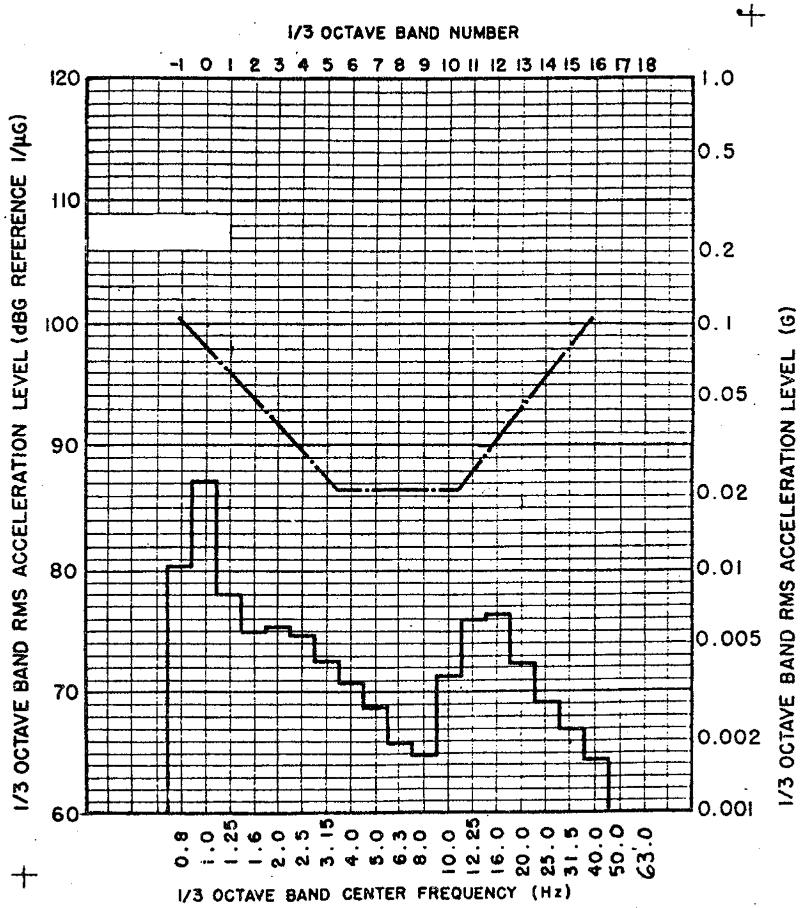


FIGURE RQ14.

50 MPH SPECIFICATION COMPARISON FOR STATION 33 TO 36 - MOTORMAN CAB VERTICAL.

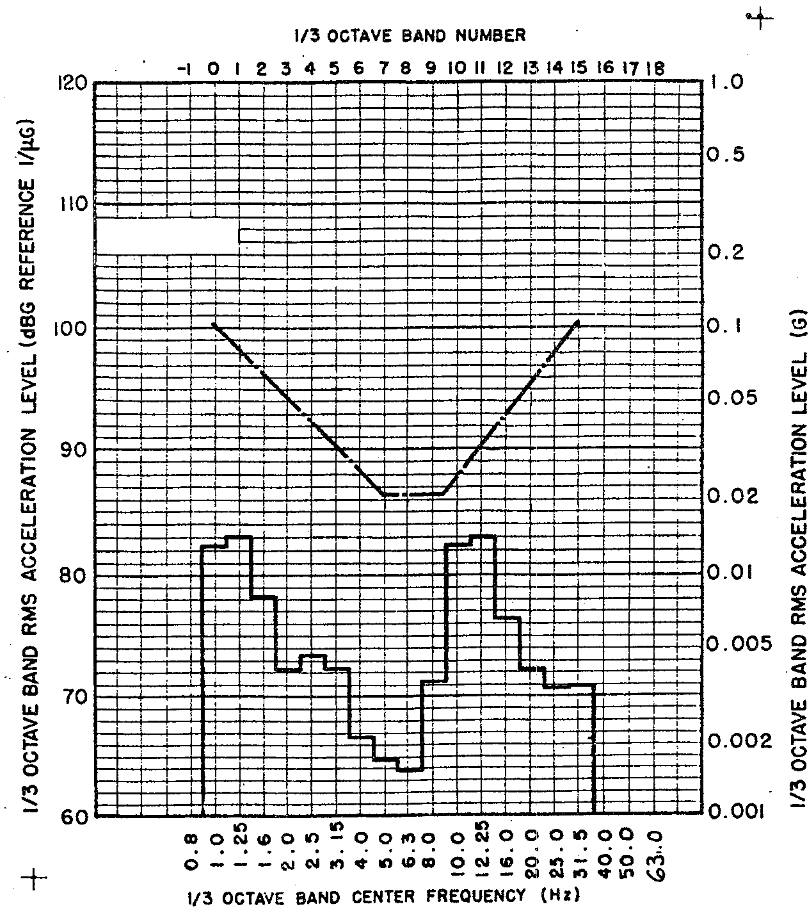


FIGURE RQ15.

50 MPH SPECIFICATION COMPARISON FOR STATION 33 TO 36 - MOTORMAN CAB LATERAL.

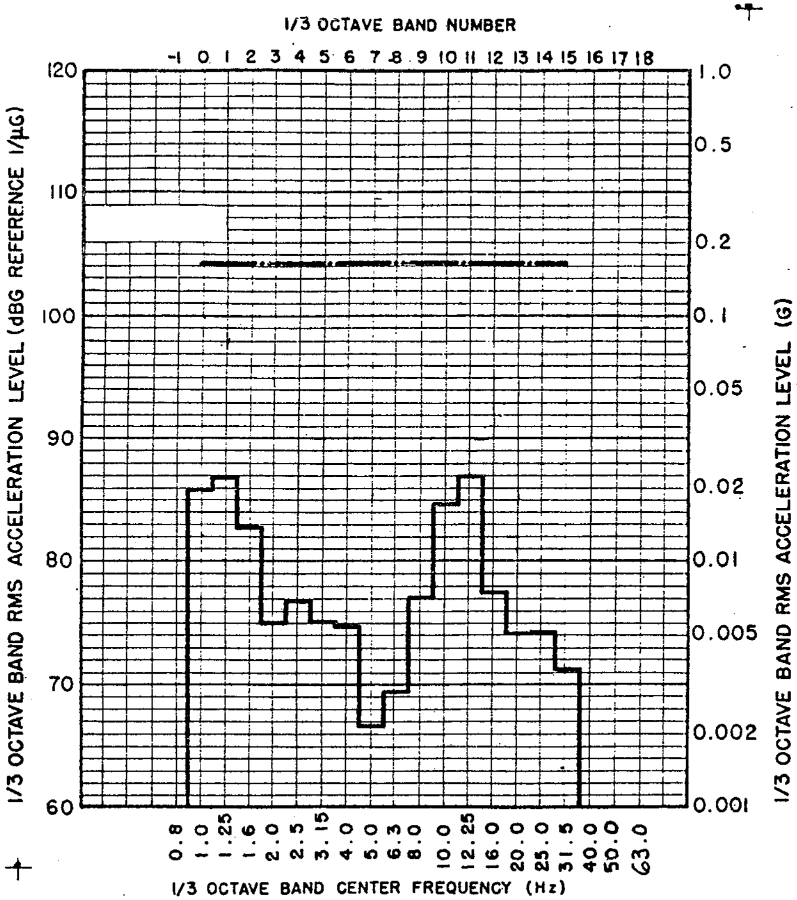


FIGURE RQ16.

50 MPH SPECIFICATION COMPARISON - MAXIMUM BAND LEVELS FOR 2-SECOND TIME WINDOWS, VERTICAL.

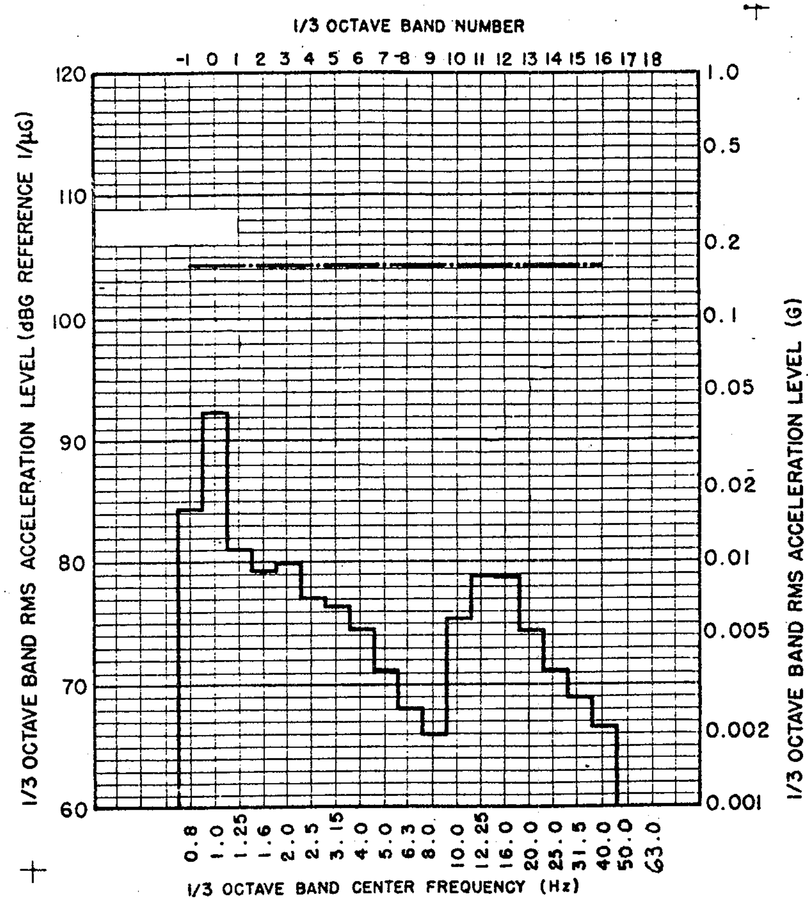


FIGURE RQ17.

50 MPH SPECIFICATION COMPARISON - MAXIMUM BAND LEVELS FOR 2-SECOND TIME WINDOWS, LATERAL.

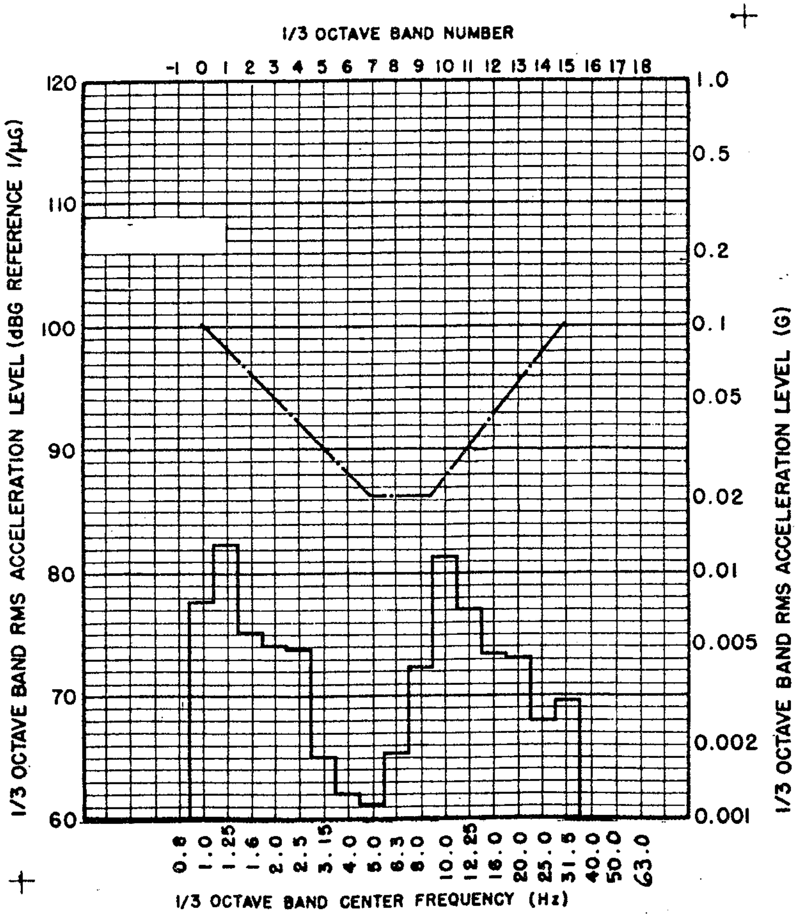


FIGURE RQ18.

1/3 OCTAVE BAND LEVELS AT 40 MPH, VERTICAL.

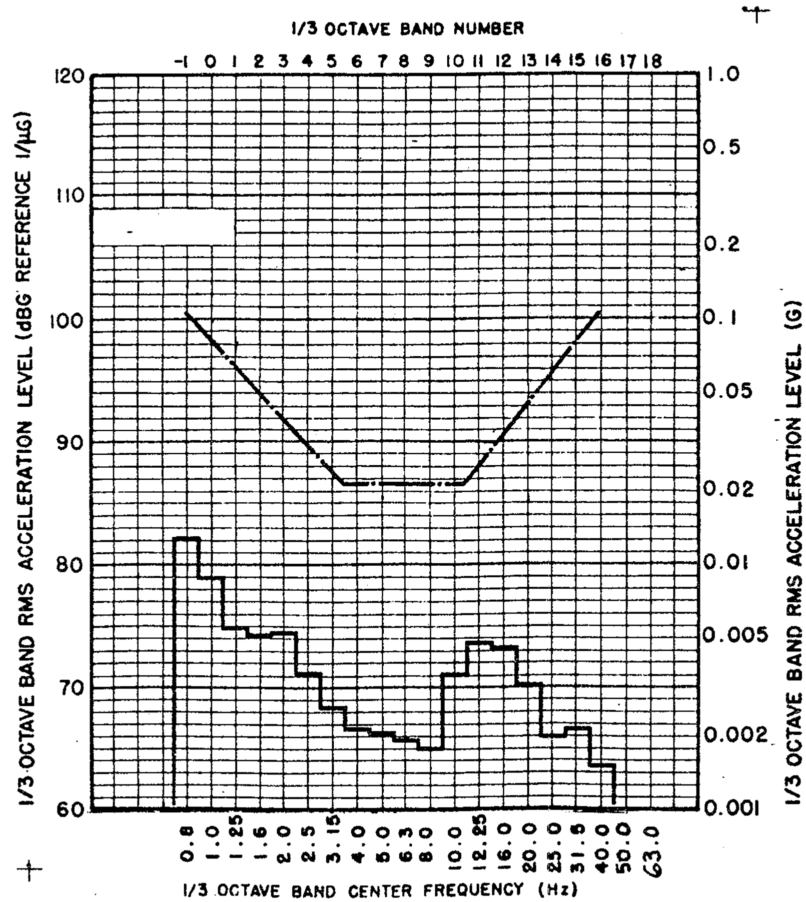


FIGURE RQ19.

1/3 OCTAVE BAND LEVELS AT 40 MPH, LATERAL.

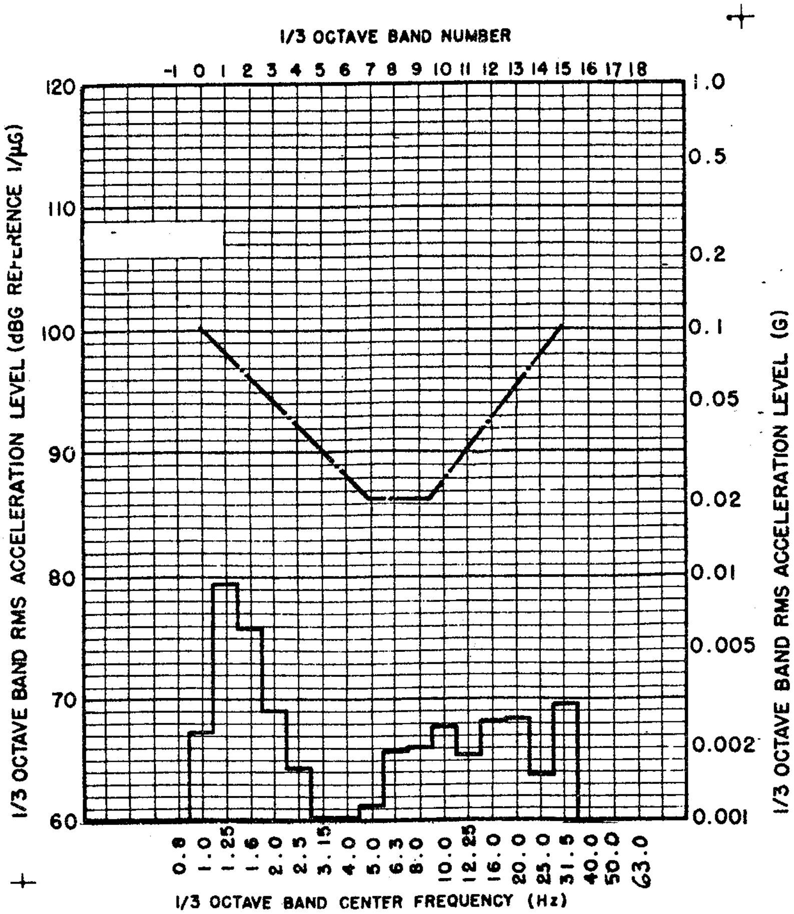


FIGURE RQ20.

1/3 OCTAVE BAND LEVELS AT 28 MPH, VERTICAL.

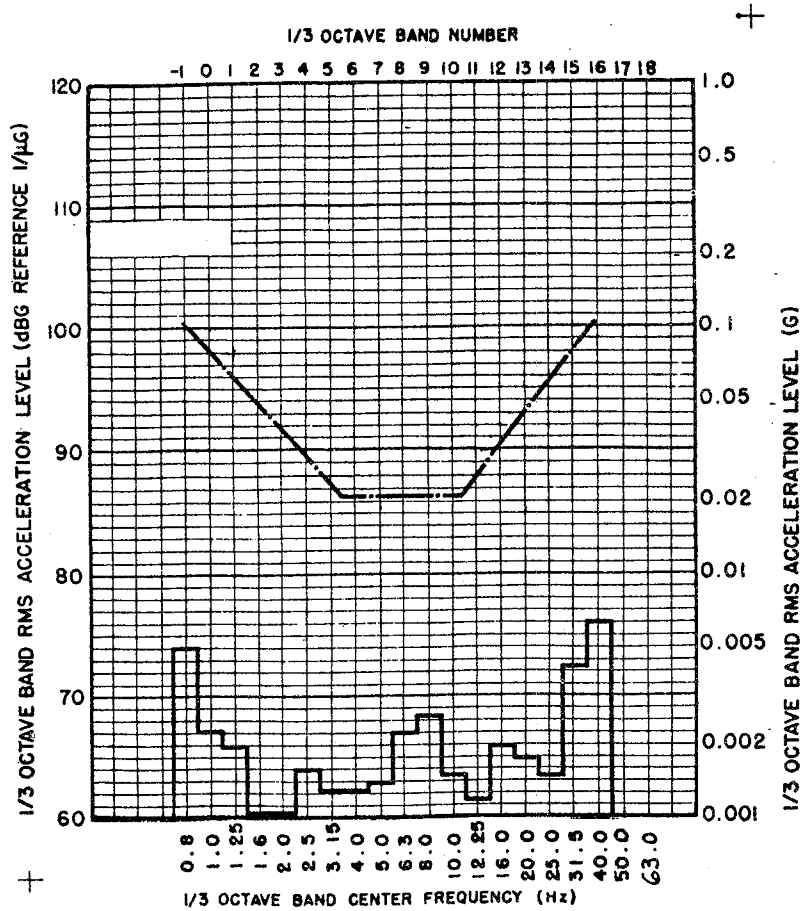


FIGURE RQ21.

1/3 OCTAVE BAND LEVELS AT 28 MPH, LATERAL.

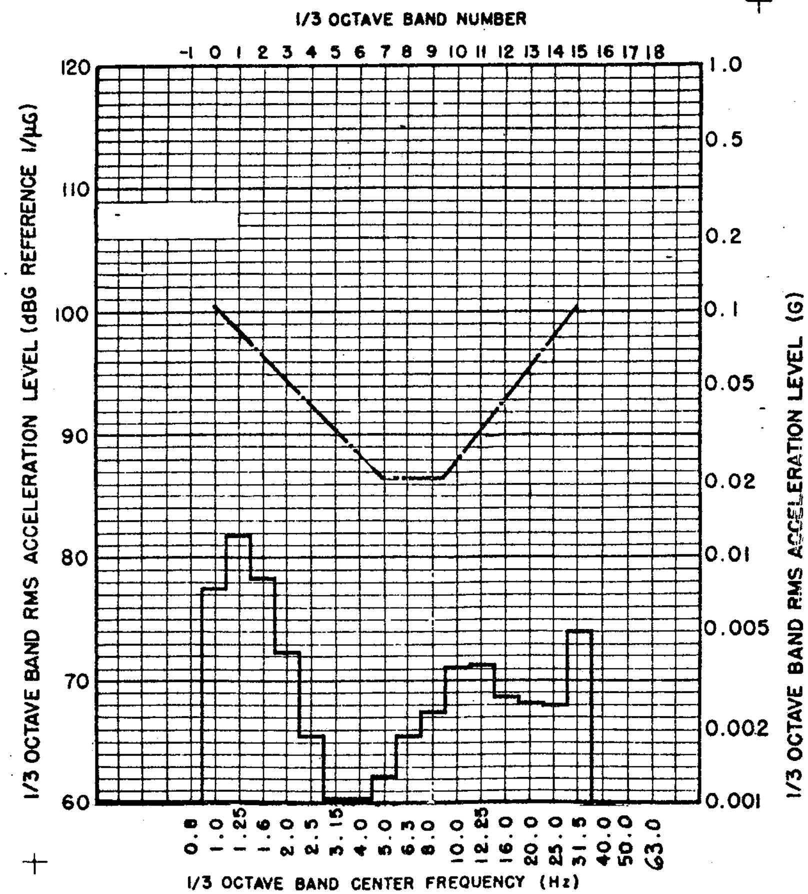


FIGURE RQ22.

SECTION I, VERTICAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

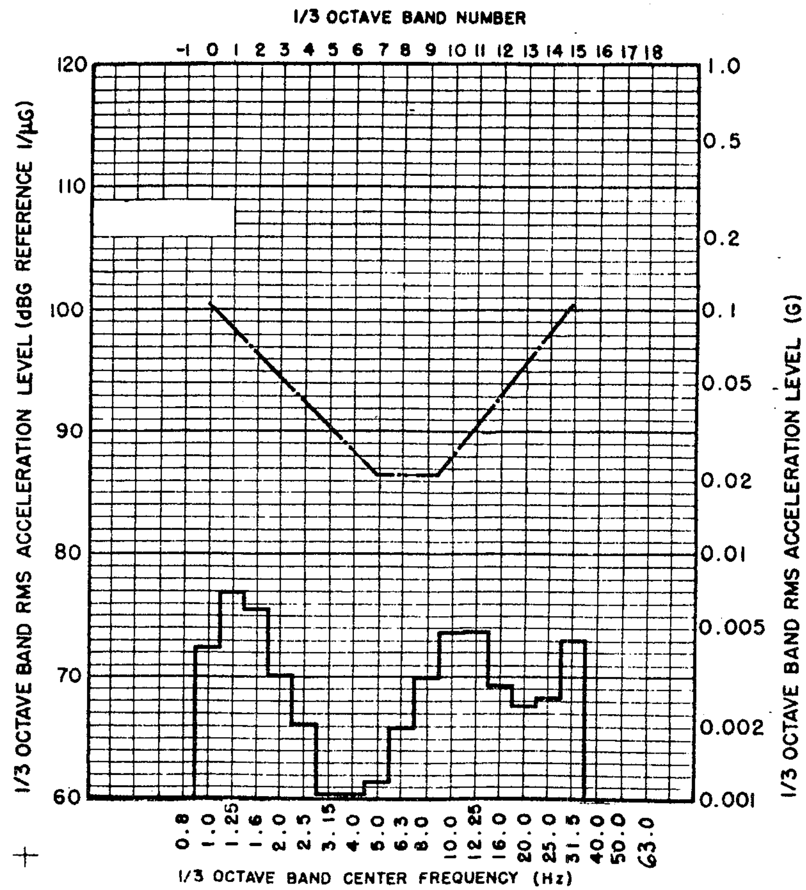


FIGURE RQ23.

SECTION II, VERTICAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

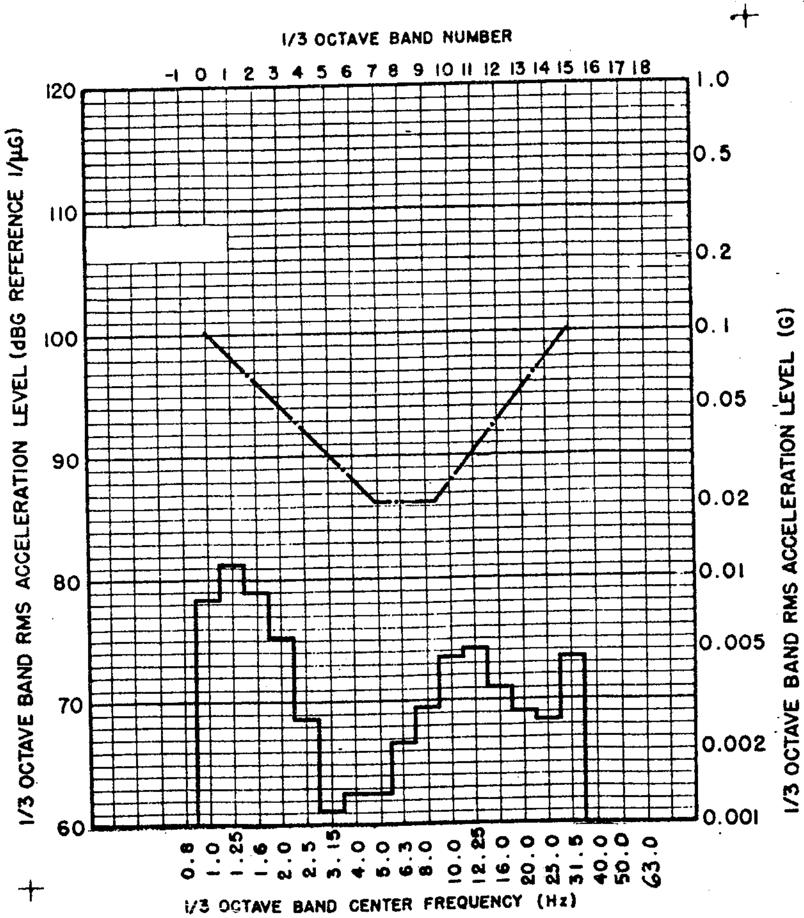


FIGURE RQ24.

SECTION III, VERTICAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

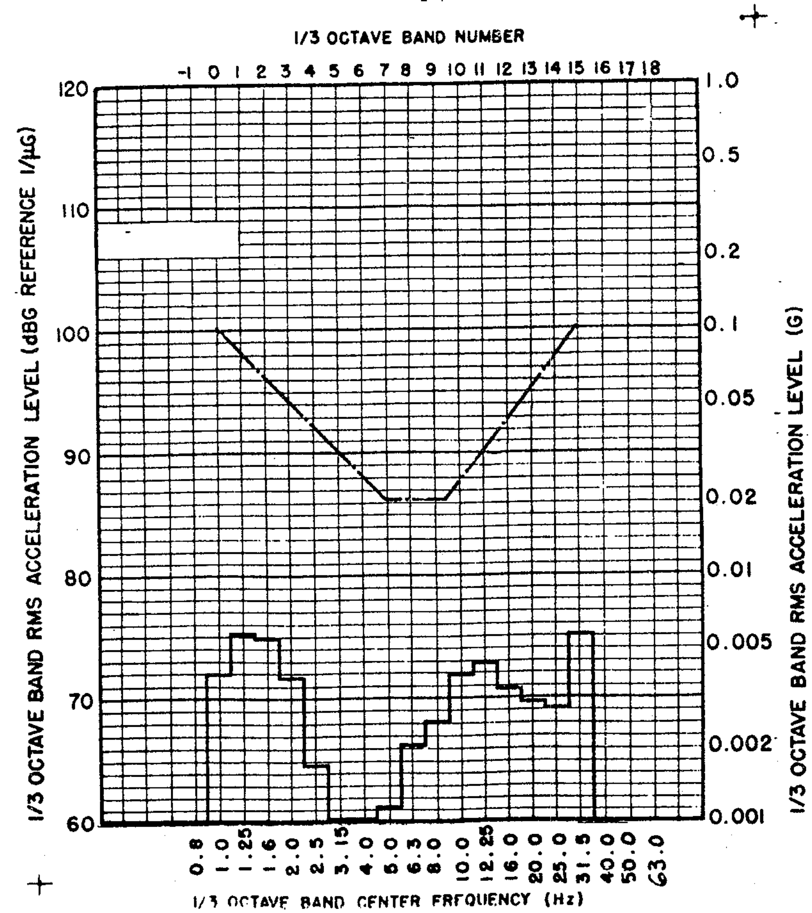


FIGURE RQ25.

SECTION IV, VERTICAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

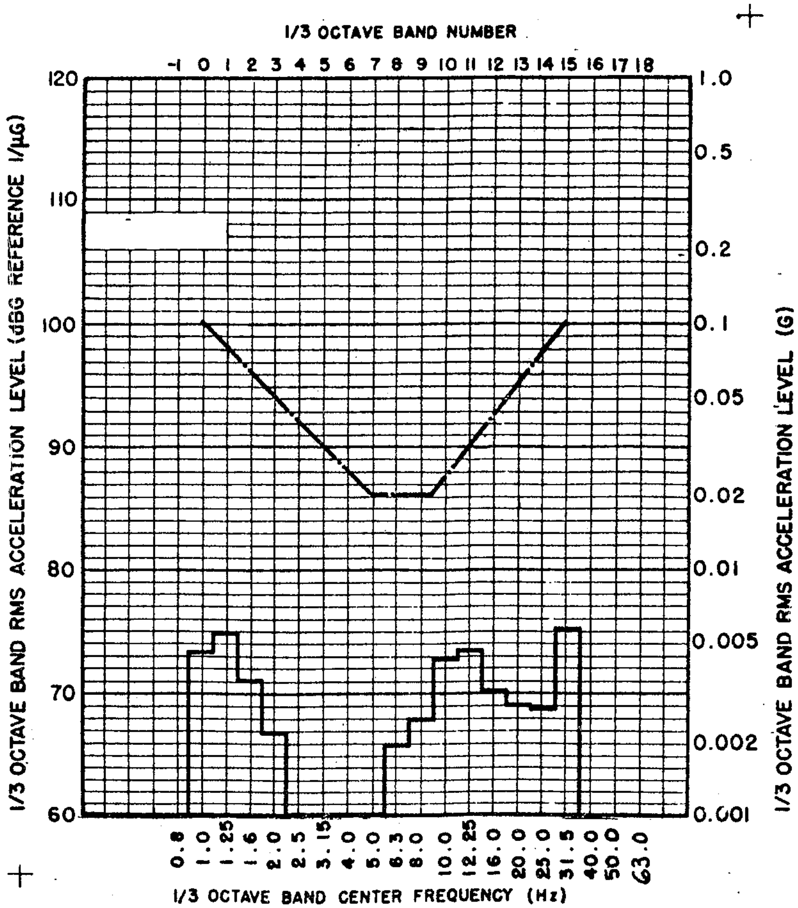


FIGURE RQ26.

SECTION V, VERTICAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

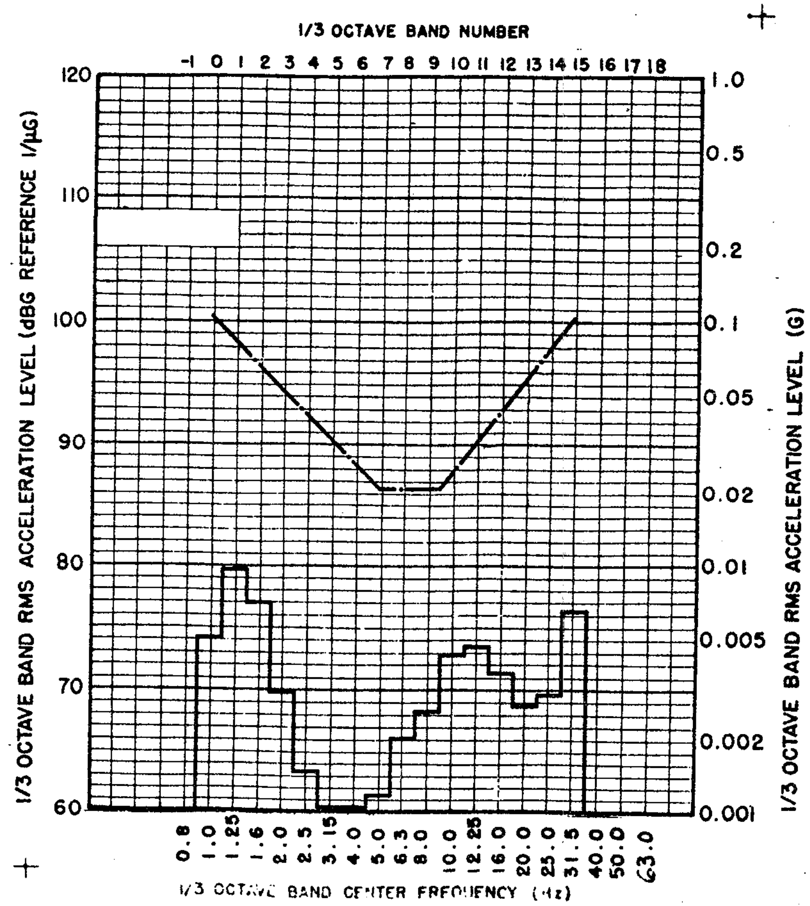


FIGURE RQ27.

SECTION VI, VERTICAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

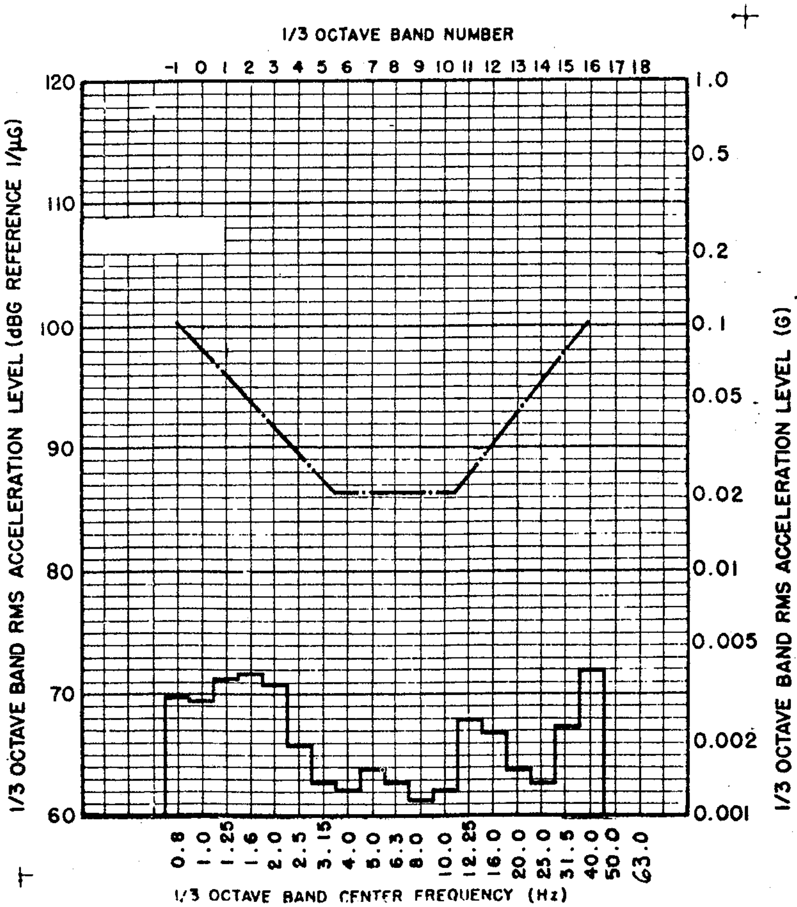


FIGURE RQ28.

SECTION I, LATERAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

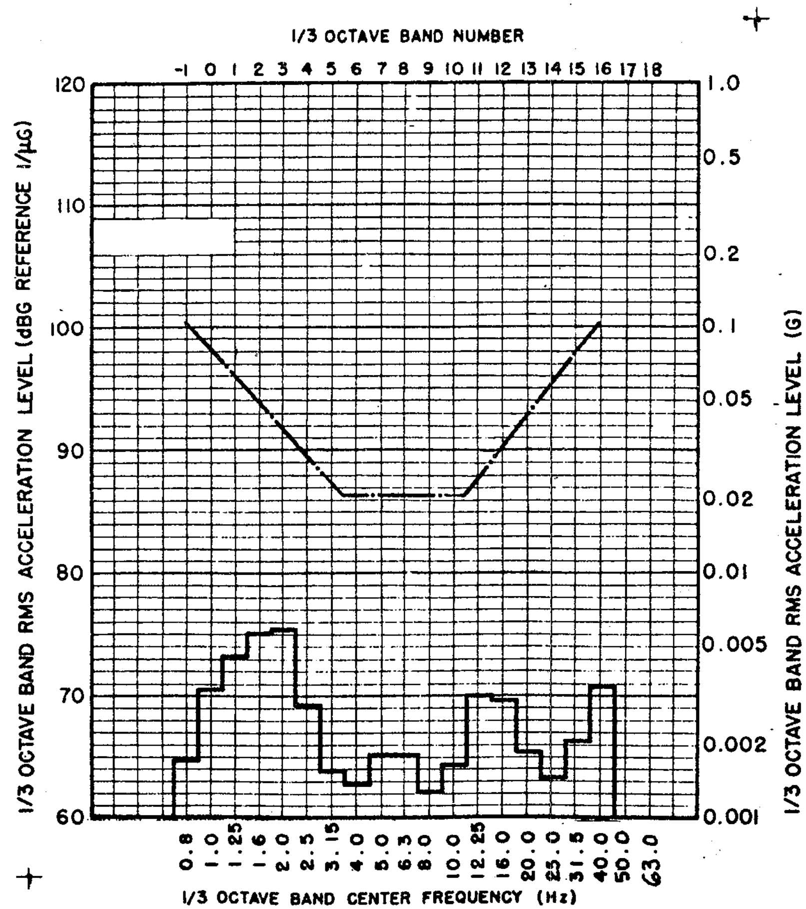


FIGURE RQ29.

SECTION II, LATERAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

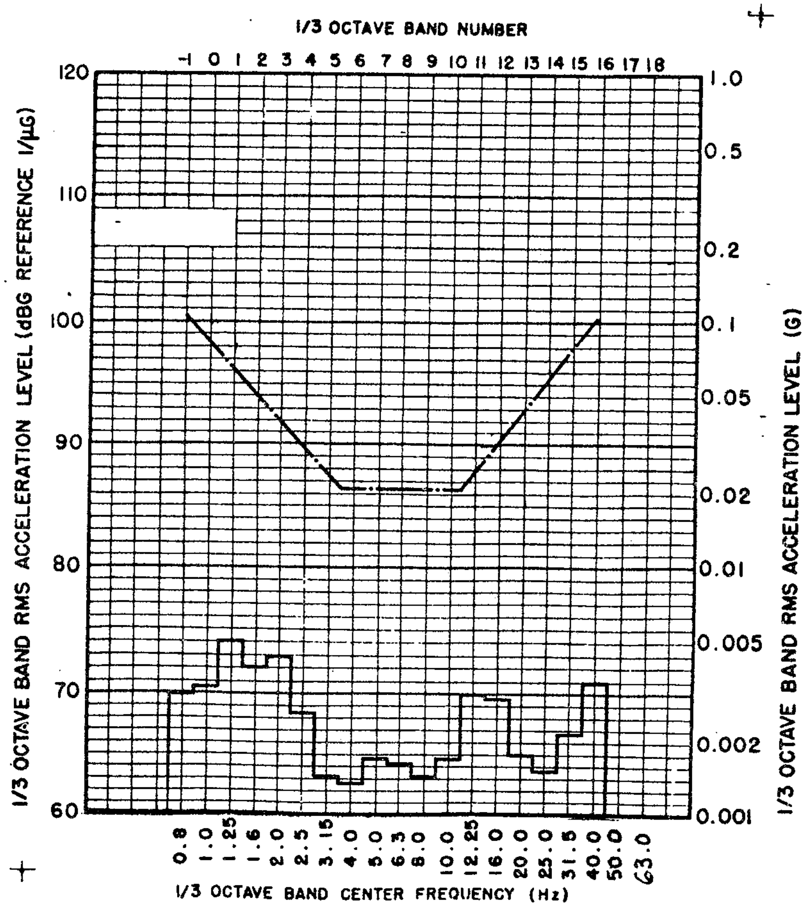


FIGURE RQ30.

SECTION III, LATERAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

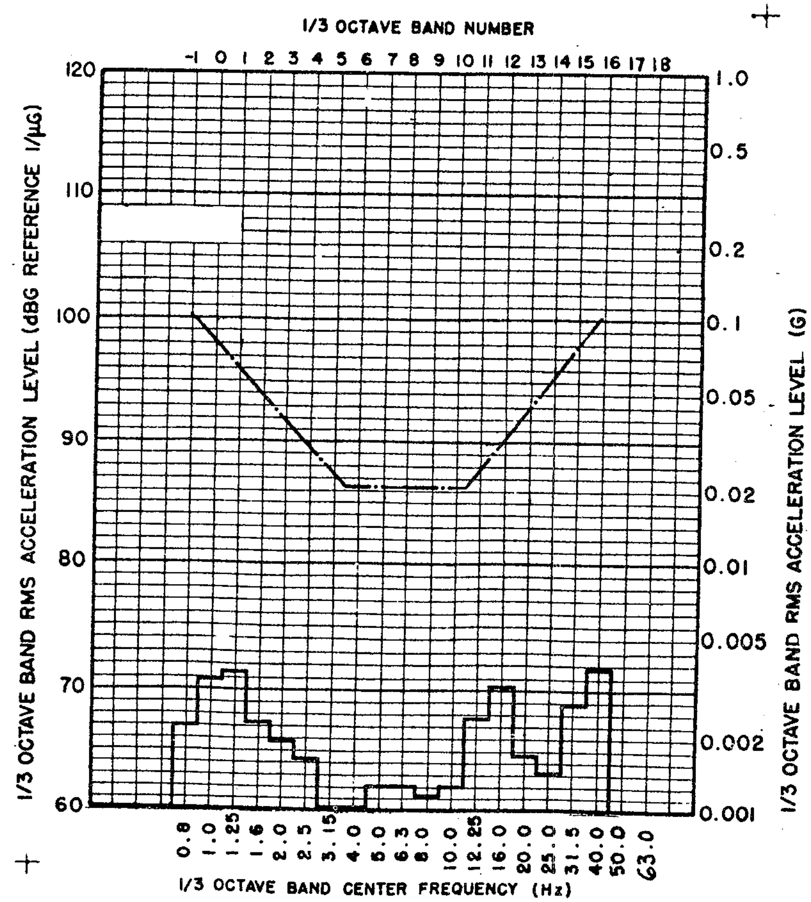


FIGURE RQ31.

SECTION IV, LATERAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

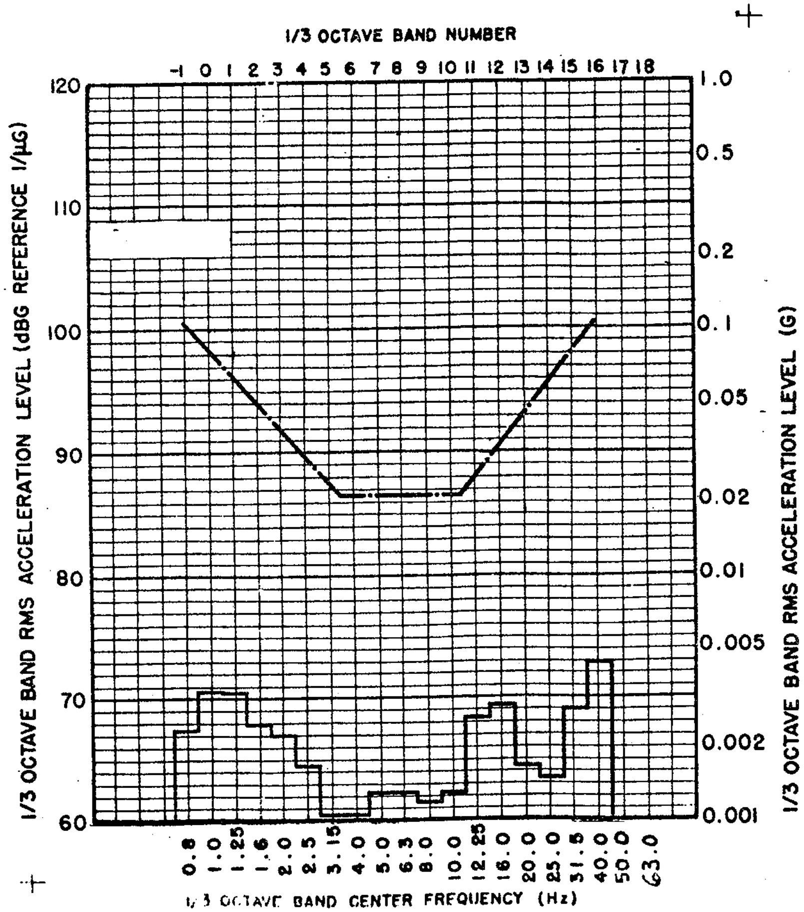


FIGURE RQ32.

SECTION V, LATERAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

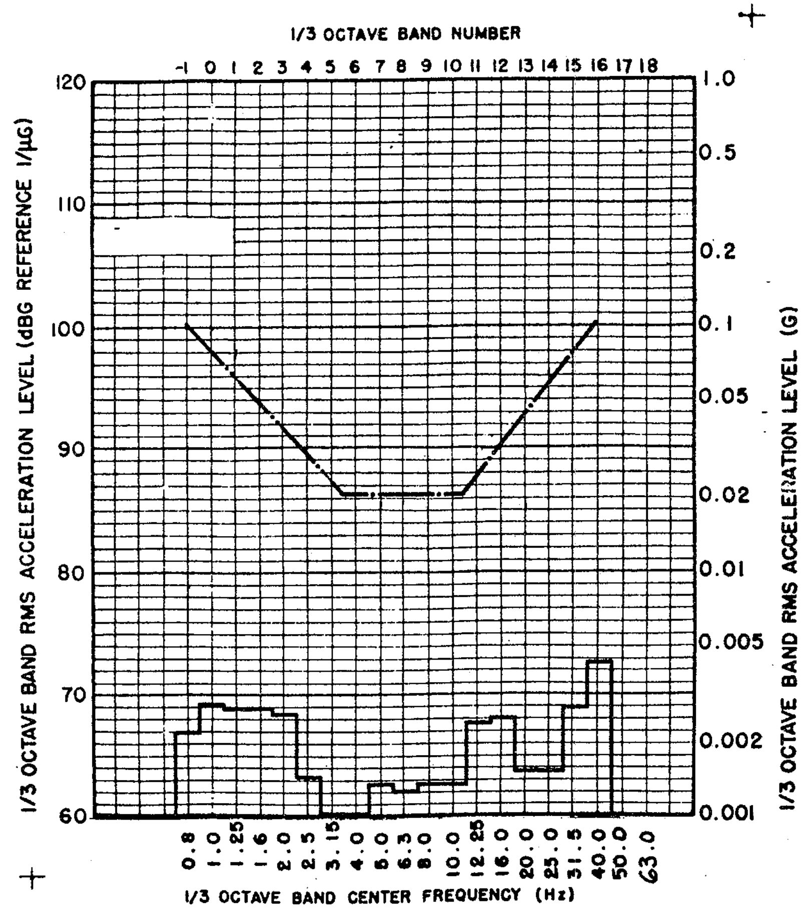


FIGURE RQ33.

SECTION VI, LATERAL 1/3 OCTAVE BAND LEVELS AT 28 MPH.

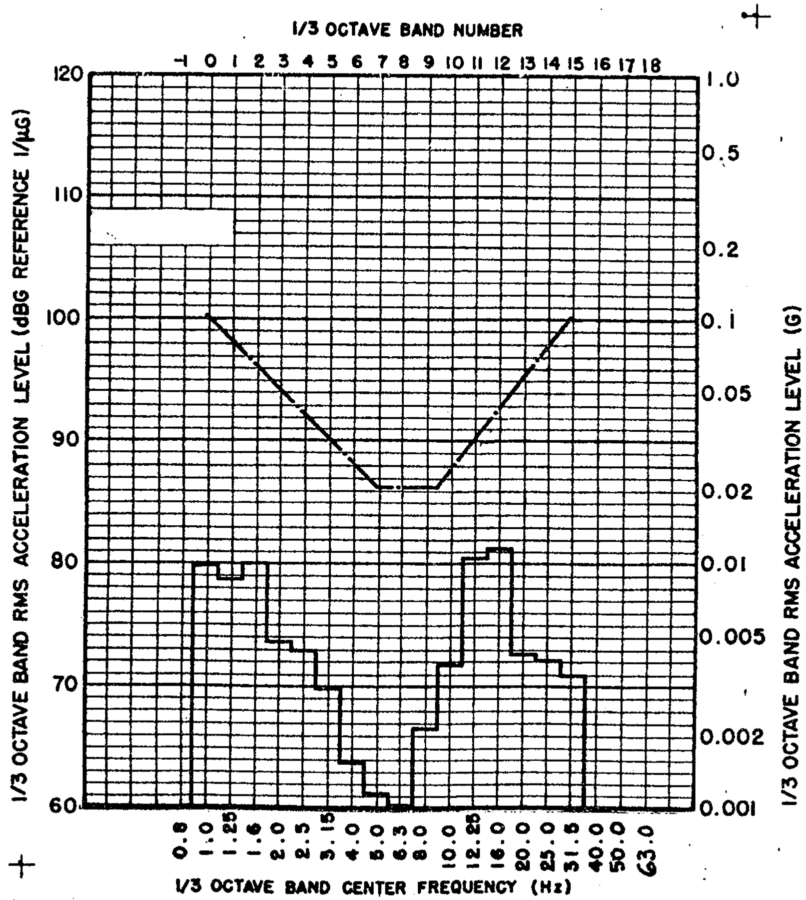


FIGURE RQ34.

VERTICAL 1/3 OCTAVE BAND LEVELS AT 50 MPH AT AW2.

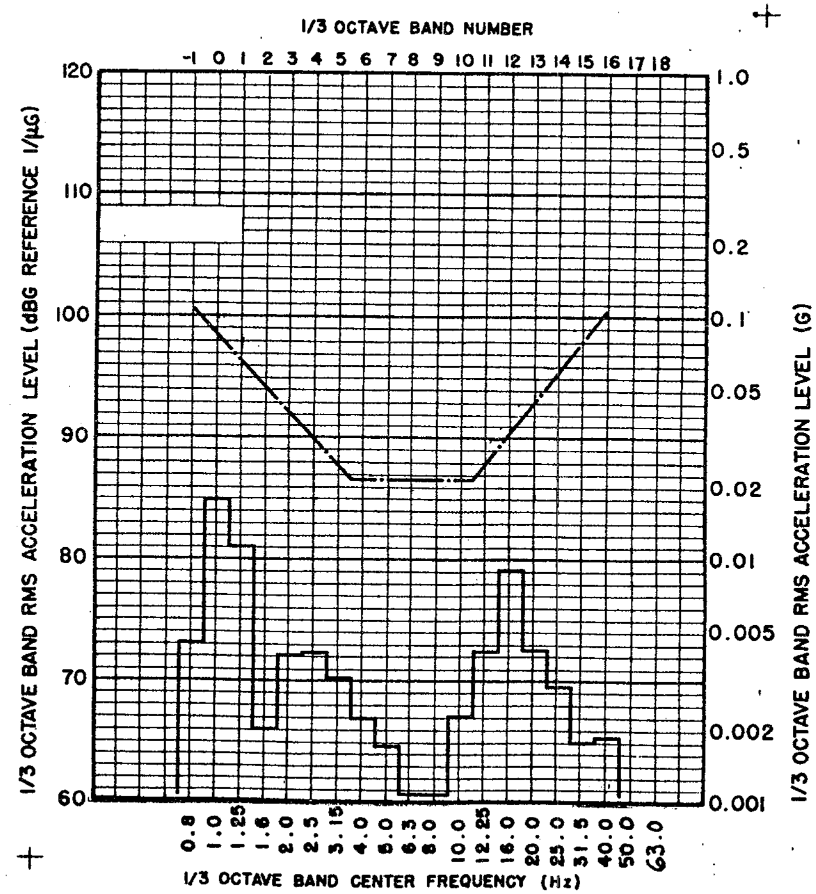


FIGURE RQ35.

VERTICAL 1/3 OCTAVE BAND LEVELS AT 50 MPH AT AW2.

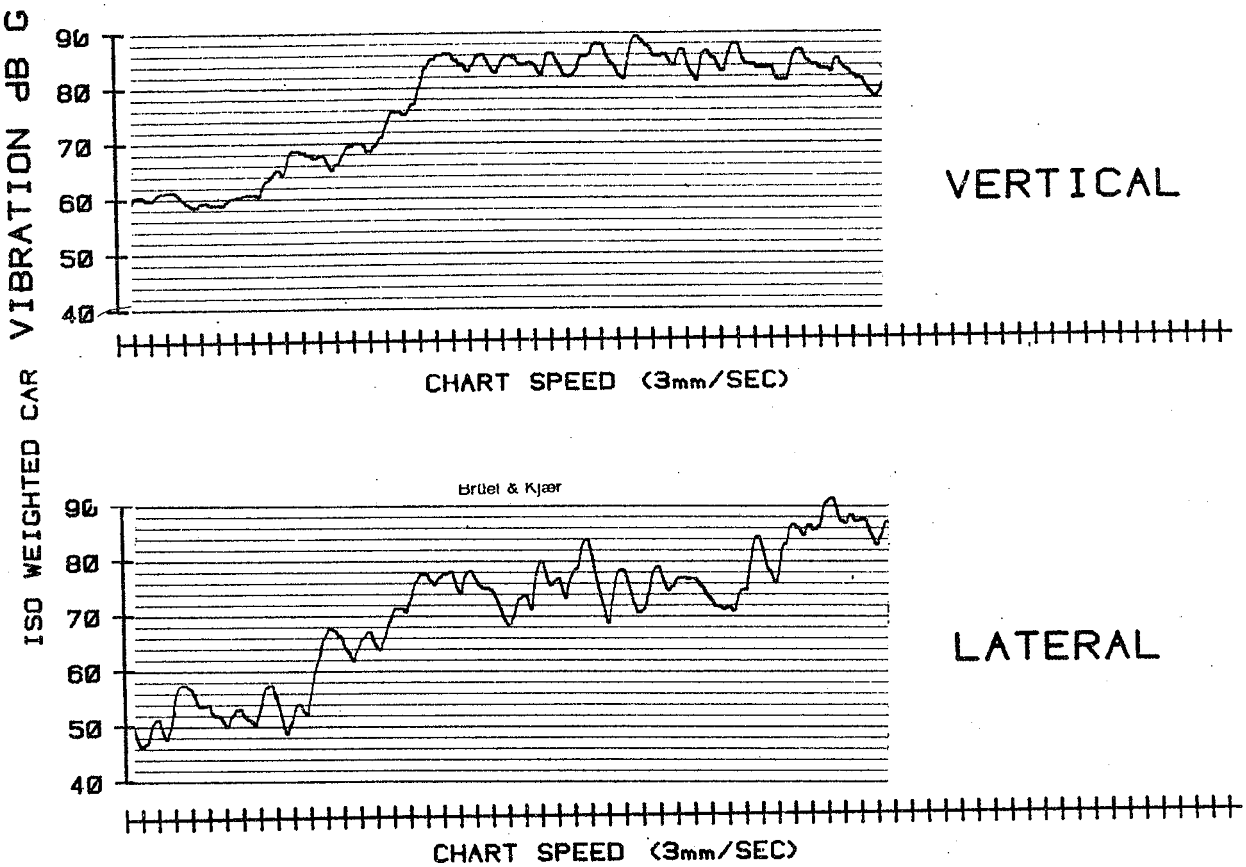


FIGURE RQ36. ACCELERATION, ISO-WEIGHTED, VERTICAL AND LATERAL TIME HISTORIES.

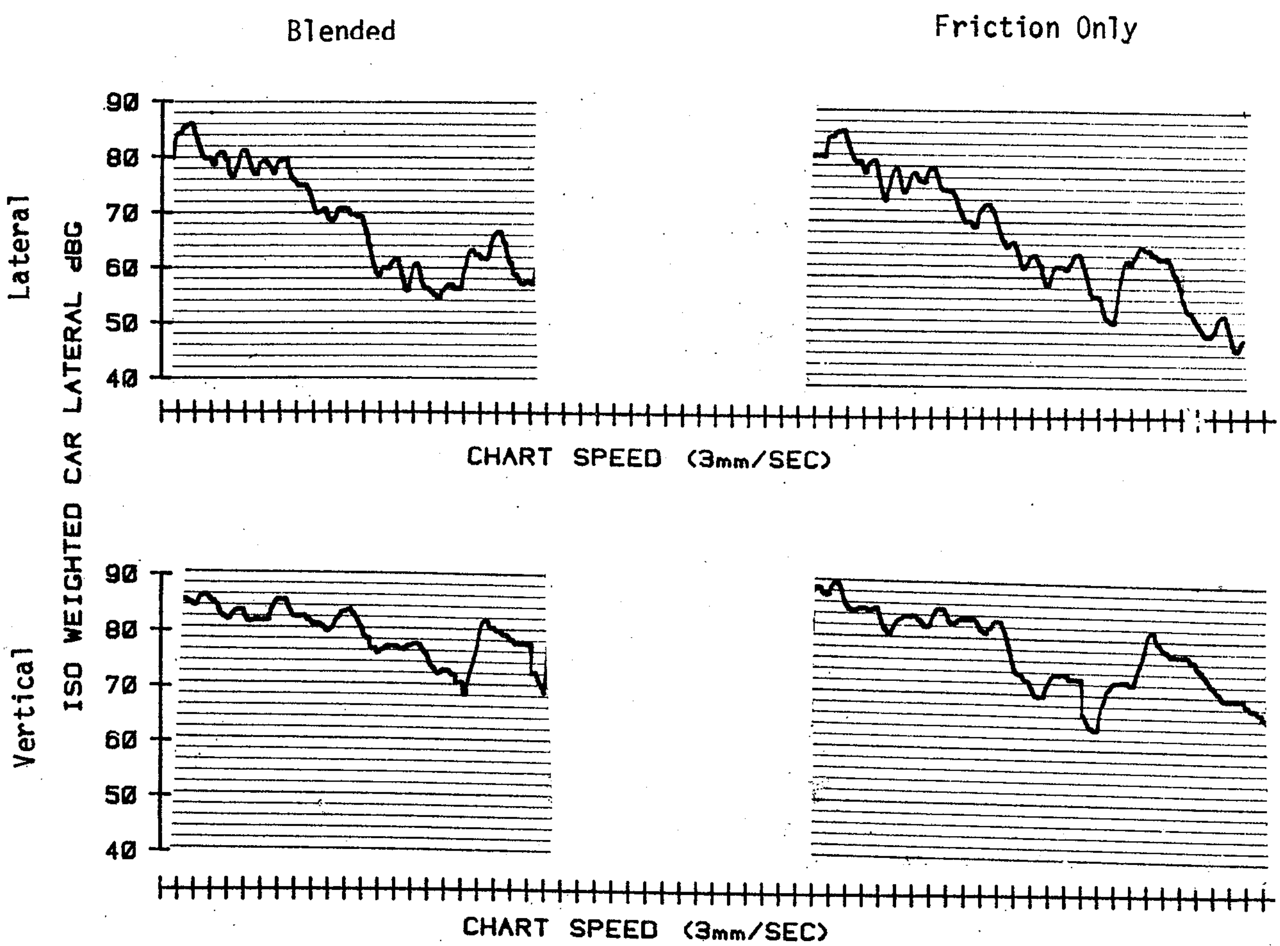


FIGURE RQ37. DECELERATION, ISO-WEIGHTED, VERTICAL AND LATERAL TIME HISTORIES.

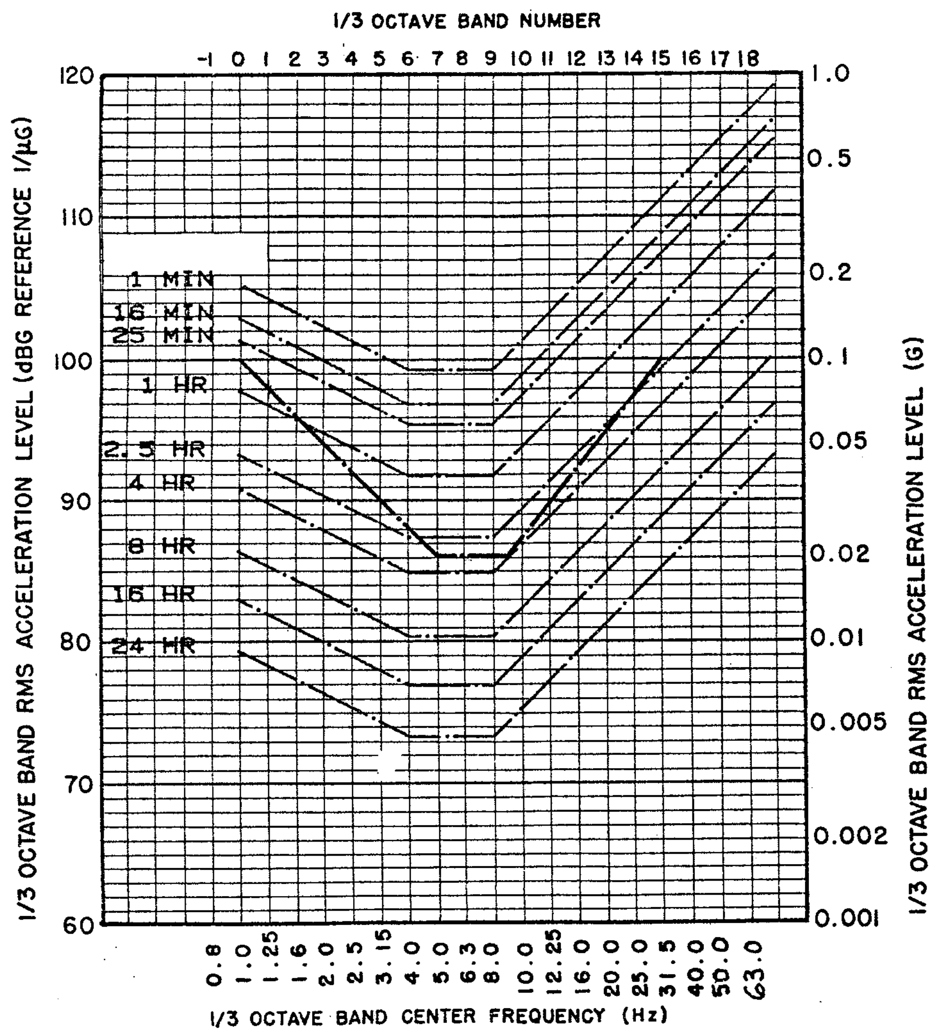


FIGURE RQ38. VERTICAL SPECIFICATION AGAINST ISO 2631 REDUCED COMFORT BOUNDARIES.

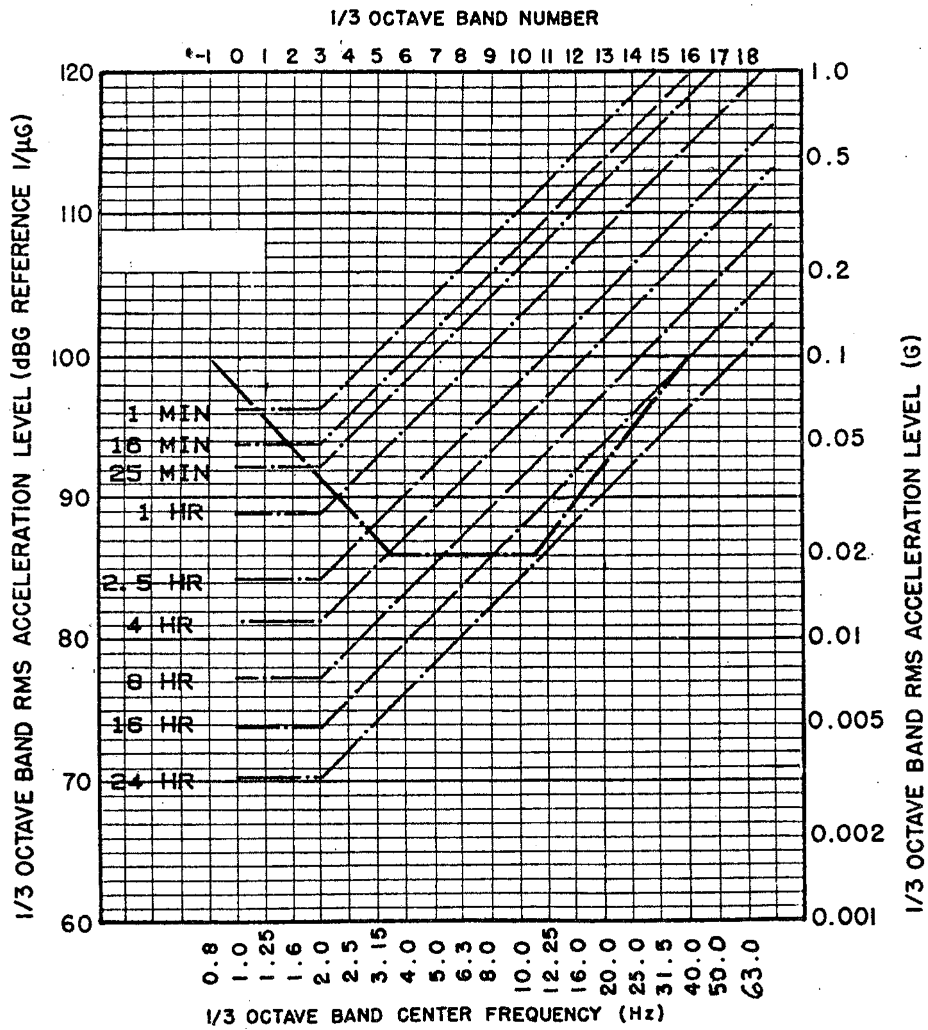


FIGURE RQ39. LATERAL SPECIFICATION AGAINST ISO 2631 REDUCED COMFORT BOUNDARIES.

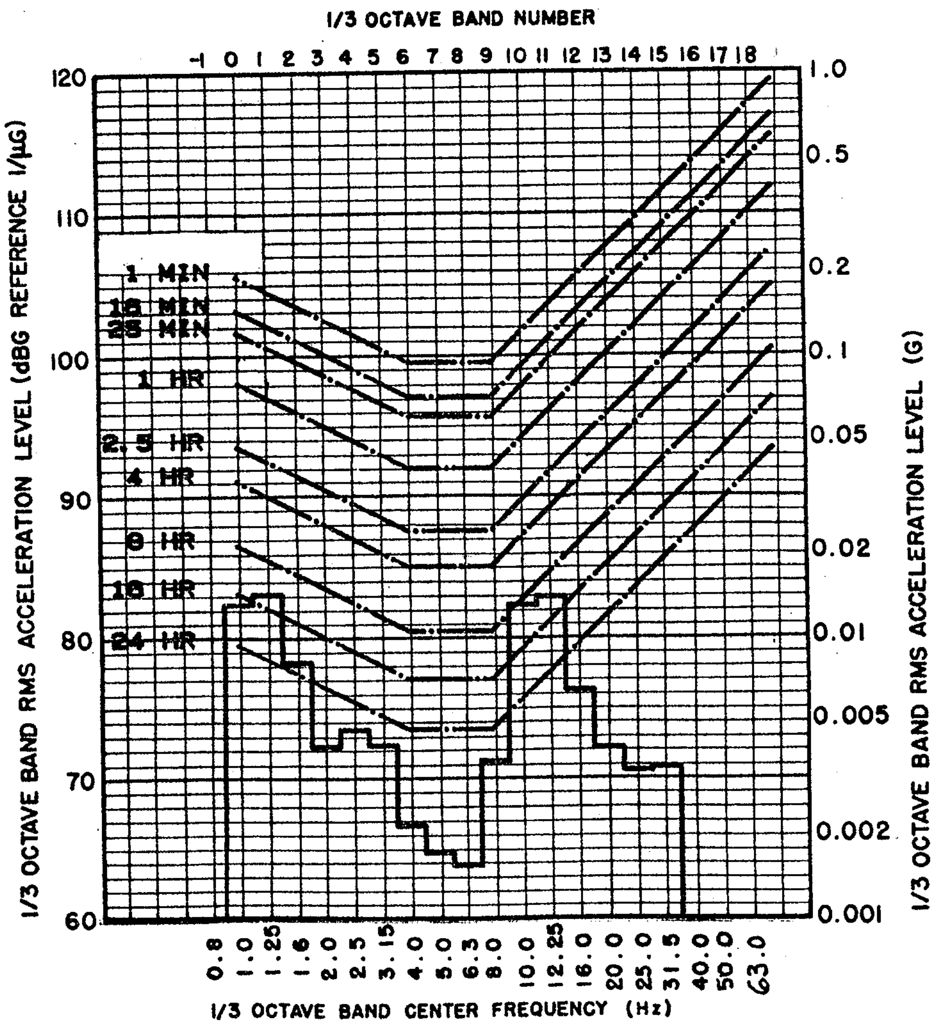


FIGURE RQ40. VERTICAL 1/3 OCTAVE BAND LEVELS AGAINST ISO 2631 BOUNDARIES.

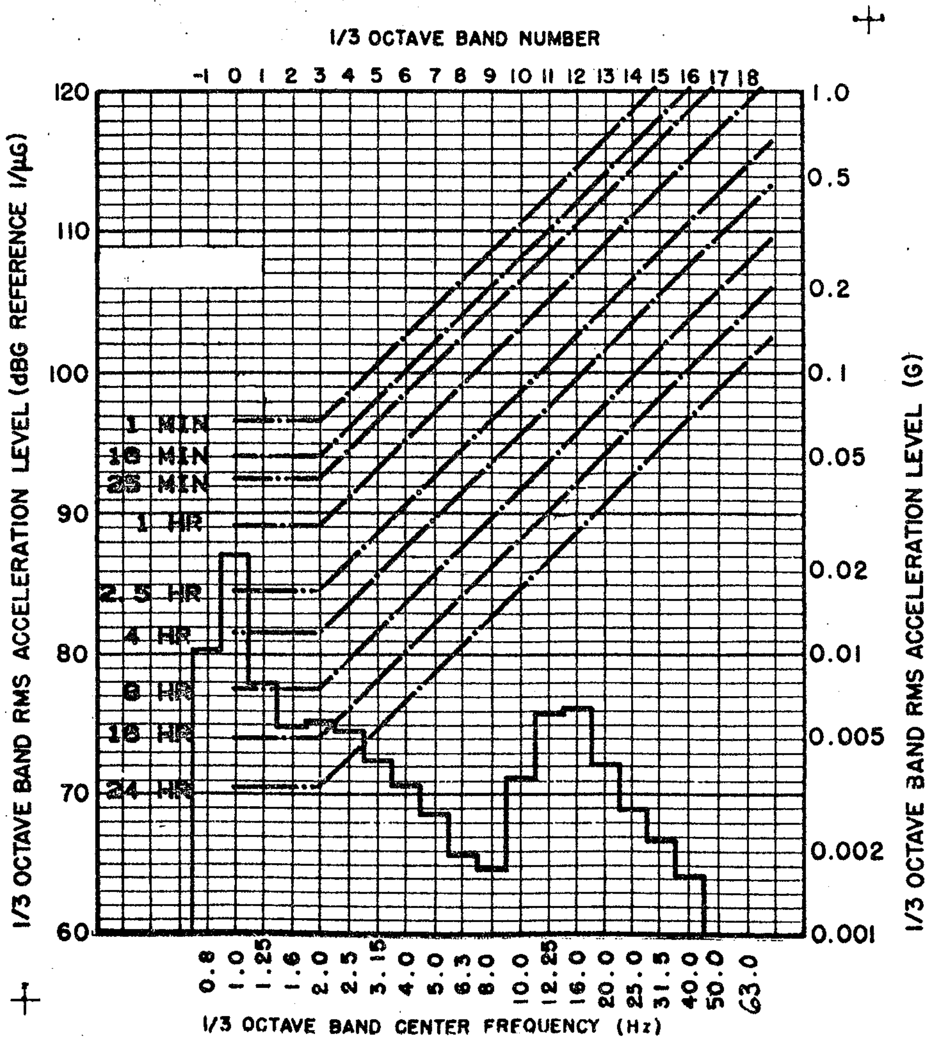


FIGURE RQ41. LATERAL 1/3 OCTAVE BAND LEVELS AGAINST ISO 2631 BOUNDARIES.

5.8 ACOUSTIC PROPERTIES

5.8.1 Objective

Acoustic measurements were made on the vehicle both for wayside and interior locations to obtain data for comparison to the specifications and to characterize the noise environment for a typical passenger.

The specifications are limited by:

Wayside Noise Limits

Average noise values generated by the vehicle operating on tie-and-ballast tangent track--in the open, at 50 mph--shall not exceed 80 dBA measured 50 feet from the track centerline. Track conditions shall be as specified for ride requirements with new ground rail.

Interior Noise Limits:

With all systems simultaneously operating at normal conditions and with the vehicle moving at 50 mph on B&T track in an open area, the interior noise level shall not exceed 72 dBA at any location along the centerline of the vehicle measured at 4 feet above the floor and at least one foot from any surface. With any one system or unit operating in revenue service, the vehicle interior noise shall not exceed 69 dBA at any location along the centerline of the vehicle measured 4 feet from the floor.

5.8.2 Test Method

5.8.2.1 Wayside

The principal piece of equipment was a Bruel and Kjaer type 2209 Impulse Precision Sound Level Meter. Calibration was performed with a B&K Sound Level Calibrator type 4230. This unit was applied directly to the microphone of the sound level meter and provided a 1000 Hz 94 dB ± 0.25 dB sound pressure level. Because of the unique design, the calibrator provided a sound pressure unefected by the ambient atmospheric pressure. This is an important feature for the test track, which has an altitude of approximately 5,000 feet and an air density approximately 0.85 that of sea level.

The vehicle will produce slightly higher sound pressure levels when it operates at sea level because of the greater atmospheric pressure. For such noise sources as wheel on rail, the sea level values will be approximately 1 dB higher. This is based on Figure N1, which gives correction values for sound pressure levels produced from a point source in a free field.

Noise levels produced from units such as air conditioning blowers and traction motor blowers, which are themselves effected by the density of air flowing through them, are harder to correct since the correction would be dependent on the motor/blower characteristics.

The sound signal was weighted in the B&K 2209 sound level meter with the 'A'-weighted frequency weighting prior to being recorded on a NAGRA IV-SJ two-channel recorder. This frequency weighting was used since it is the weighting detailed in the specification and also because it reduced the dynamic range of the signal.

Sound pressure time histories were produced by replaying the 'A'-weighted signal to a B&K type 2306 level recorder, and frequency analysis was performed on a B&K type 2131 1/3 octave digital frequency analyzer from the recorded 'A'-weighted signal.

5.8.2.2 Interior Noise - Stationary

With the vehicle stationary and with no lead ballast on the floor, the major auxiliary systems were operated in sequence and sound recordings were made from a microphone placed at 5 foot intervals down the centerline of the vehicle and 4 feet above the floor. The microphone, connected to the B&K 2209 sound level recorder, was handheld and pointed to the floor.

The sound level meter was set to 'A' weighting and this weighted signal was recorded onto a NAGRA IV SJ recorder.

On replay, the signal was fed to a B&K 2306 level recorder set in the 'AC Log' mode, 'slow' pen, and the 'A'-weighted levels were stripped out. In addition, the signal was fed to a B&K 1/3 octave analyzer.

5.8.2.3 Interior Noise - Moving

With the same equipment as was used for the stationary vehicle, 'A'-weighted sound recordings were made on the NAGRA IV SJ. It was thought that the 'A' weighting network would reduce the dynamic range of the signal and prevent saturation of the NAGRA IV-SJ front end by infra-sound frequencies caused by turbulent air flow past doors and windows. Subsequent playback did show that some saturation did occur in places on the recording. These were occasional broken areas of a few milliseconds in duration. This did not occur on a previous transit test, where an external high pass filter was used to remove infrasound frequencies and, therefore, this external filter practice should be used for future tests. The 'A'-weighting network appears not to be sufficient to prevent the phenomenon. However, due to the limited extent of the "broken" signal, it was thought the tape was suitable for analysis.

5.8.3 <u>Test Results</u>

5.8.3.1 Wayside

Figure N2 shows a 50 mph pass by 'A'-weighted sound pressure time history taken at Station 33.7 on the test track. The time history was produced on a B&K type 2306 strip recorder with the pen writing speed set to 40 mm/sec. This corresponds to a sound level meter speed of "slow." The measurement site was chosen because it satisfied the specification requirement of essentially a free field environment. The track type was 119 lb/yd welded rail on concrete ties, tangent track with zero grade.

The pass-by data show a maximum level of 76 dBA "slow" for both counterclockwise vehicle travel and clockwise travel. This satisfies the specification requirement even when the altitude correction of 1 dB is added. The microphone used was a B&K type 4134 with the diaphragm in the horizontal plane. This was chosen because of its suitability for moving sound sources. The microphone was tripod mounted clear of any reflective objects at a height of 5 feet above the rail head, approximately 7.5 feet above the ground and 50 feet from the centerline of the track.

The location had good ambient characteristics. Figure N3 shows the low ambient level between 30 and 40 dBA; this is approximately 40 dB below the maximum level at pass-by. The "spikes" on the strip chart are from crickets.

Pass-by runs were made of the same site for two other speeds of 28 and 15 mph. The time histories are shown in Figures N4 and N5. This gives the pass-by maximum levels for AW0 as:

	CCW	CW
50 mph	76 dBA	76 dBA
28 mph	71 dBA	70 dBA
15 mph	68 dBA	64 dBA

These levels could be considered the minimum the vehicle will produce since it was running in light condition with optimum tracks and wheels.

The data show the expected similar levels for both clockwise and counterclockwise running.

A welded repair on the head of the outside rail caused "rabbit ears" on the "fast" pen speed characteristic, as shown in Figure N6. The general sound level is the same as produced at the smooth site, but the irregularity caused short peaks some 3 dB higher. The irregularity was slightly off center of the microphone which resulted in a non-symmetrical characteristic. This could be considered to be the AW0 characteristic for a less than ideal track.

Testing was also performed at a weight of AW2 but conditions for this test were not as ideal because:

1. The microphone was located near the track irregularity.

2. The vehicle had wheel flats.

Figure N7 shows a pass-by at 50 mph where it could be concluded that without the "rabbit ears", the maximum level would have been close to 78 dBA, still within the specification. Also, on the same figure is a "coast-by" where the vehicle came by running on a dead-rail. The signature is almost identical.

This gives the indication that the pass-by level is not influenced by auxiliary or power equipment.

Figure N8 shows data taken on the outside of the oval. Here the track irregularity is on the same side as the microphone and the rabbit ears are expectedly higher. However, the overall characteristic is the same, showing that the acoustic envelope of the vehicle is symmetrical. Also shown in the figure is a 15 mph pass-by which shows evidence of the wheel flats.

It can be concluded from the AW2 tests that, had the tests been performed under the same conditions as the AW0 tests, the car would have produced levels slightly higher but still within specification maximum of 80 dBA.

Figure N9 shows data produced from a track-brake and a friction only deceleration from 15 mph with the vehicle coming to rest approximately in the area of the microphone. The signature shows a slight brake squeal up to 72 dBA for the friction brake and, in general, a quiet brake operation for both the track and friction brake.

With the microphone at 50 feet from the track and the vehicle immediately opposite it, the vehicle was run both with all and partial auxiliaries to find the stationary levels produced. These were:

Traction Motor Blowers, Convertor, and A/C	56 dBA
Traction Motor Blowers and Convertor without A/C	55 dBA
Air Compressor and Converter	46 dBA
Convertor Only	34 dBA
All Systems	56 dBA

The 'A' weighted 1/3 octave band levels for the "all on" case are shown in Figure N10. The spectra show the 400 Hz band to be most significant, with a uniform distribution of energy.

5.8.3.2 Interior Noise - Stationary

Table N1 shows the 'A'-weighted sound pressure levels for traction motor blowers, air conditioning, and air compressor operating independently and also for all systems. The levels show that for the microphone 4 feet from the floor, the traction motors gave similar sound levels throughout the vehicle at around 61 dBA. The air conditioning level was of the same order at the 'A' end, with an increase up to 66 dBA at the 'B' end. Air compressor noise was considerably lower, 53 dBA at the 'A' end and down to 39 dBA at the 'B' end. With all systems on a maximum of 68 dBA at the 'B' end was produced.

TABLE N1. INTERIOR NOISE LEVELS - VEHICLE STATIONARY.

MODE	1	'A' End 2	3	4	5	6	7	8	9	'B' End 10	11	12
Traction Motor Blowers Only	60	61	62	62	60	61	59	62	63	62	61	61
Air Conditioning Only	61	62	61	61	61	63	64	65	64	65	65	66
Air Compressor Only	53	52	48	45	50	42	42	41	40	39	39	39
All Systems	63	62	65	64	65	64	66	65	66	68	67	68

The table clearly shows compliance with the specification, however, the noise characteristic contained in the ventilation mode was objectionable.

The 1/3 octave band levels for the auxiliaries are shown in Figures N11 through N22. They are shown for 'A' end, mid car, and 'B' end for the same modes as Table N1. Figures N11 through N13 are for traction motor blowers only, Figures N14 through N16 are for air conditioning only, Figures N17 through N19 are for air compressor only, and Figures N20 through N22 are for all systems on. The 1/3 octave levels shown are from 'A'-weighted signals and indicate which frequencies are significant to the loudness of the sound. The traction produced salient bands at 400 Hz and 63 Hz and the air conditioning 200 Hz. The spectra show a broad band nature with no high frequency tones evident.

5.8.3.3 Interior Noise - Moving

Table N2 shows the 'A'-weighted sound levels corresponding to a microphone height of 4 feet above the floor, horizontal plane, and pointing at the floor for various locations and modes of operation.

TABLE N2. INTERIOR NOISE LEVELS AT VARIOUS VEHICLE SPEEDS.

50 mph	CW	'A' end cab	58 dBA
50 mph	CCW	'A' end cab	55 dBA
50 mph	CW	'A' end truck	58 dBA
50 mph	CCW	Mid car, Air conditioning off	65 dBA
50 mph	CCW	Mid car	66 dBA
40 mph	CCW	Mid car, All on	66 dBA
20 mph	CW	Mid car, All on	66 dBA
10 mph	CW	Mid car, All on	56 dBA
50 mph	CW	Mid car, Pantograph down	62 dBA

The table shows that the levels are well within the specification maximum of 72 dBA. At the mid car location there is no variation of sound pressure level with speed because of the masking effect of the auxiliaries. These levels were taken with the vehicle running at constant speed with only sufficient power applied to sustain the speed.

A run was made with the pantograph down, with the vehicle in a no power mode. This produced a 62 dBA level at a speed of 50 mph, showing that for the moving vehicle the air conditioning is significant in masking the track noise.

Figure N23 shows the 'A' weighted level during a 100% blended brake and a 100% friction only brake. The sound level pressure remains constant throughout the event, showing effective masking. Subjectively, there were no noticeable changes in the acoustic environment during these modes.

Figure N24 shows a 100% acceleration for both a "soft" supply and a "hard" computer controlled power supply. The "soft" supply shows a slight lowering of level because the auxiliaries reduce their speed as the vehicle draws power. The "hard" supply shows a more steady level.

The 1/3 octave band levels taken at 50 mph in the mid car are shown in Figure N25. The band levels for the same location and speed (but with the air conditioning off) are shown in Figure N26. The band levels for a coast run with the pantograph down are shown in Figure N27. These figures show how for the mid car location the running noise of the car is masked by the air conditioning.

During a 100% acceleration run, a 2 second window of data was taken a few seconds after the car moved away from rest. Figure N28 shows the 1/3 octave spectra associated with the full power operation of the car.

5.8.3.4 Discussion and Conclusions of Results

The wayside data showed that the vehicle, with a level of 76 dBA, was within 80 dBA at 50 mph.

The data showed that at 28 mph, the level was 71 dBA.

The pass-by noise on tangent track contained no wheel squeal, indicating the trucks were running true.

With a vehicle weight of AW2 and moderate wheel flats, the pass-by level was 80 dBA.

The vehicle produced no objectionable noise in any of the power/brake modes with only a slight degree of disc squeal.

The interior noise data with the vehicle stationary showed the vehicle to be within specification of 69 dBA for any one system operating. The vehicle was also within the specification limit of 72 dBA when moving at all speeds up to 50 mph.

There were no rattles produced by any of the vehicle fixtures, except that the doors vibrated occasionally when the vehicle was operating at speed with a strong cross wind.

The interior noise was dominated by the air conditioning, which provided masking of the power system and track noise. The interior noise levels contained no objectionable squeals in any mode of operation except the ventilation mode.

Noise characteristics tested at the TTC will be slightly different at sea level because of the effect of the TTC's altitude. In general, levels at sea level will be slightly higher (1 dB). The high altitude will also effect the performance of blowers, etc.

In conclusion, the measured acoustic properties of the vehicle were within the specifications and, subjectively, the vehicle also showed excellent acoustic characteristics.

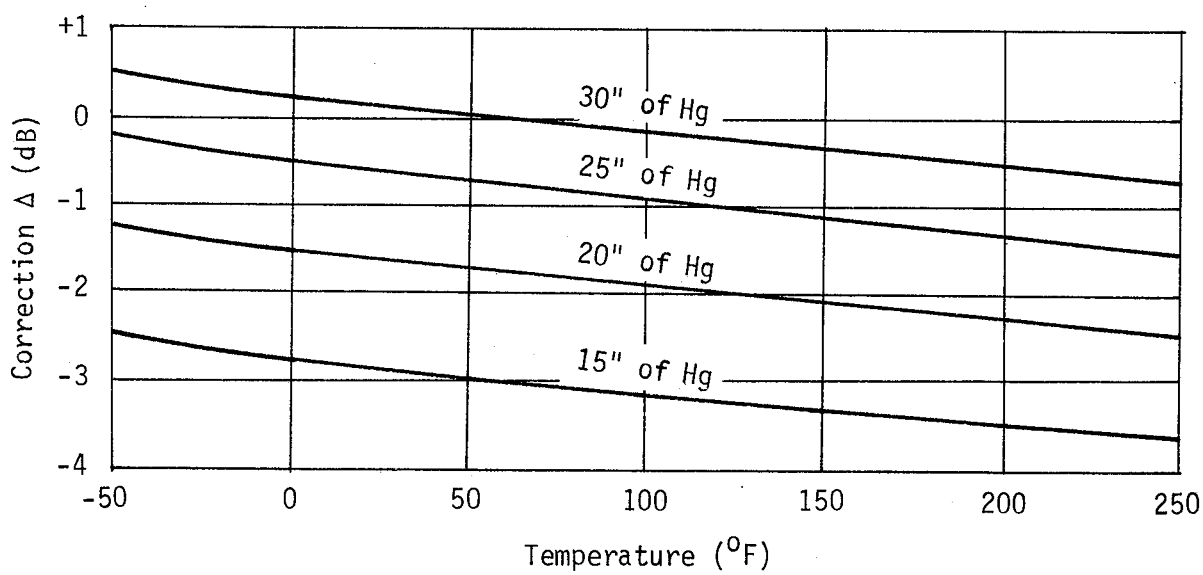
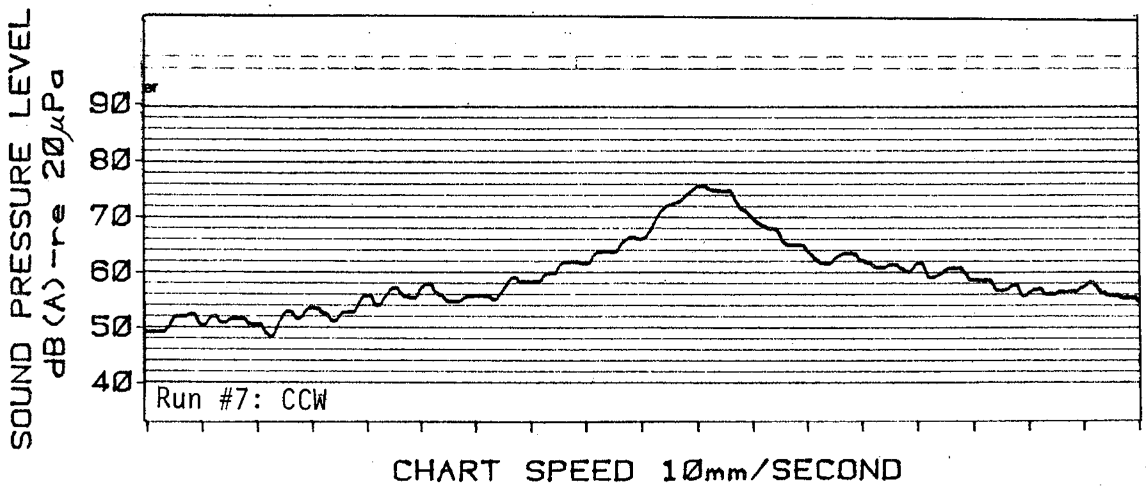


FIGURE N1. CORRECTIONS FOR NON-STANDARD AIR.



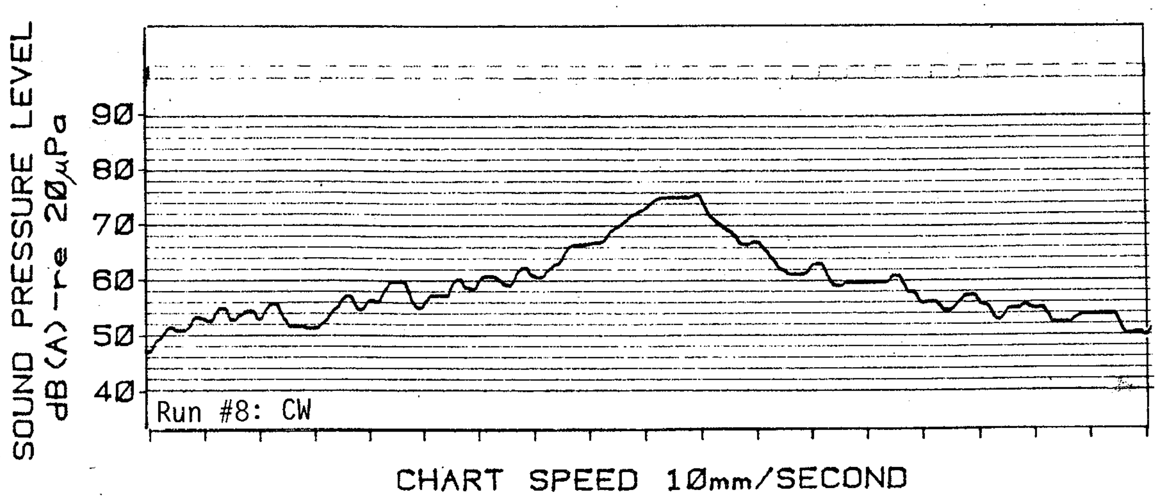


FIGURE N2. 50 MPH PASS BY - SLOW PEN SPEED, CCW AND CW.

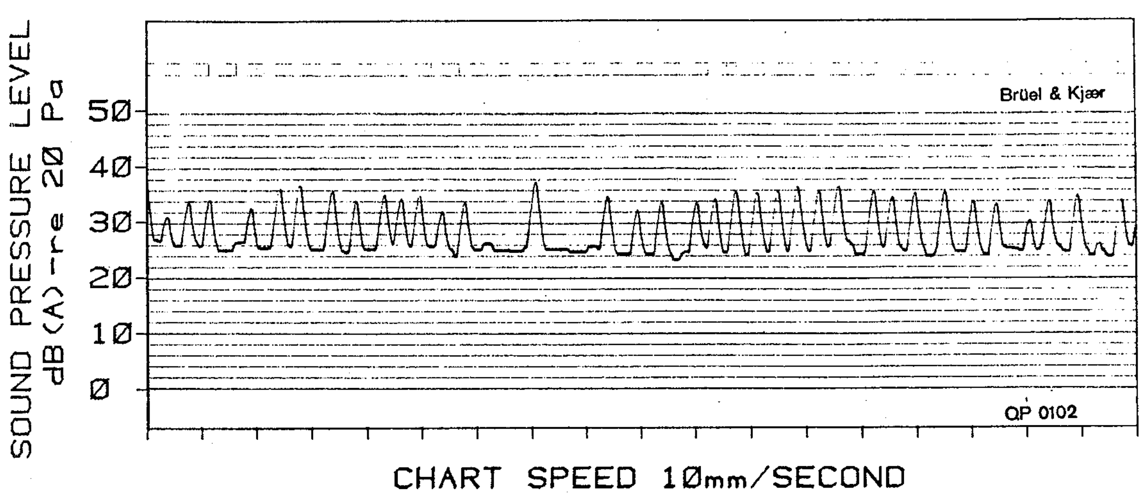


FIGURE N3. PASS BY SITE AMBIENT LEVEL.

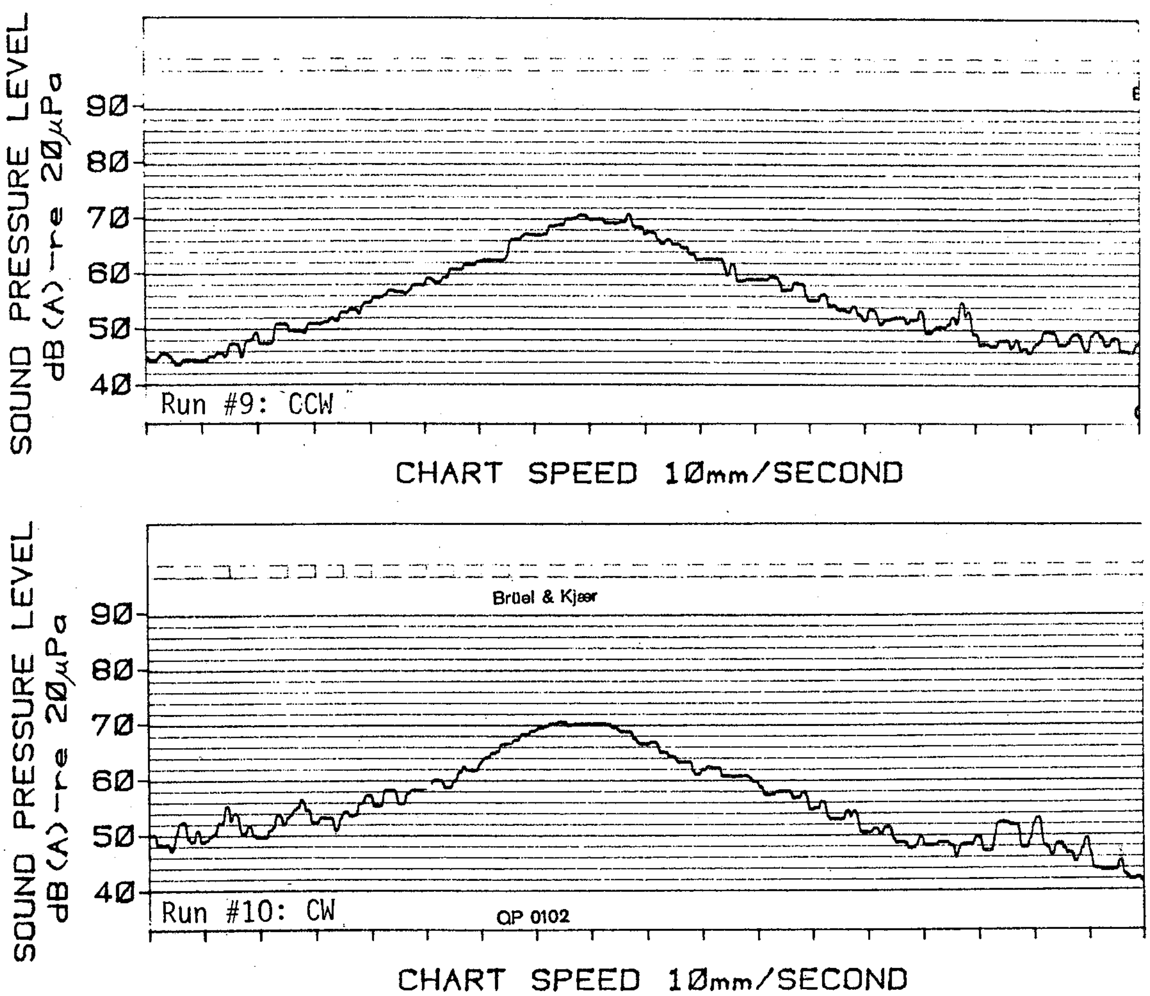
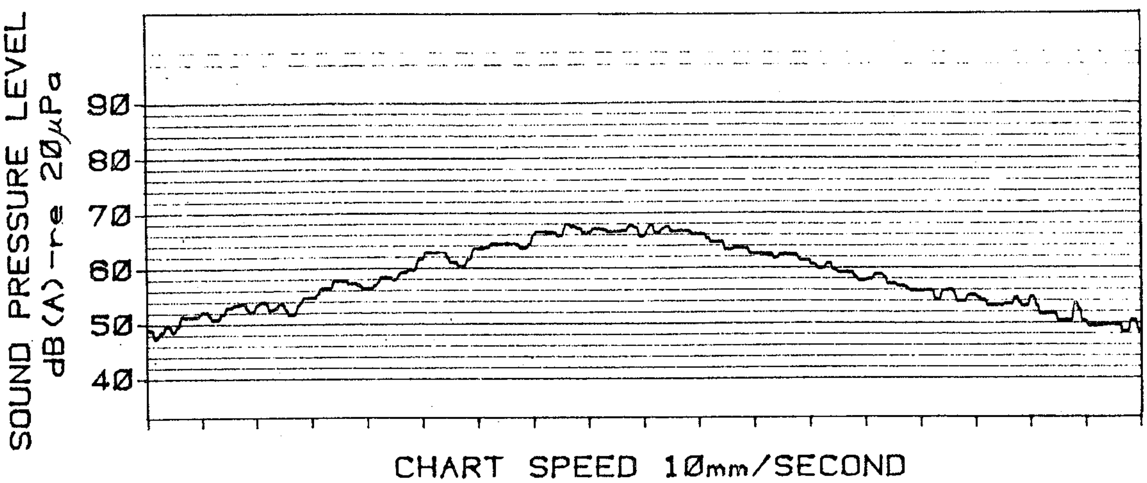


FIGURE N4. 28 MPH PASS BY - FAST PEN SPEED, CCW AND CW.



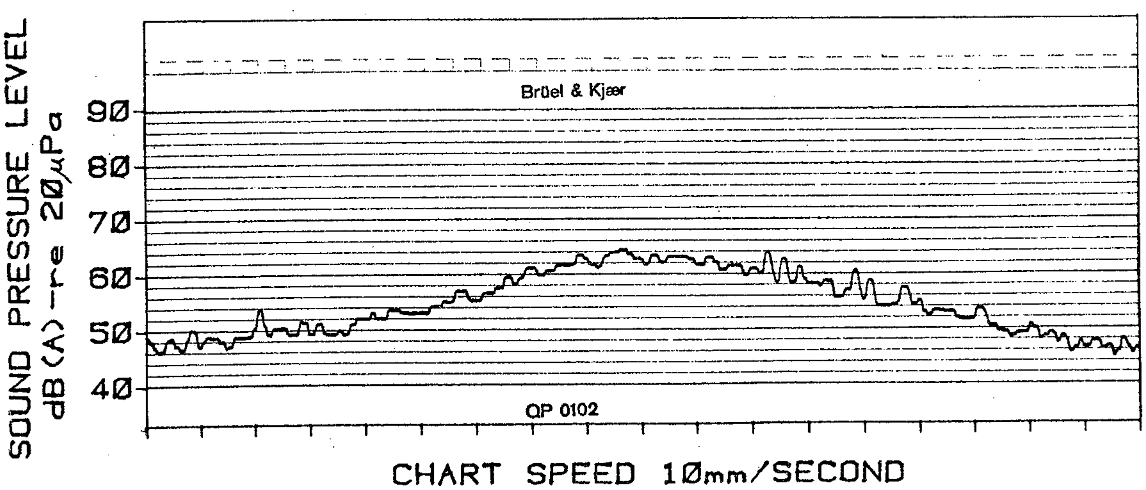
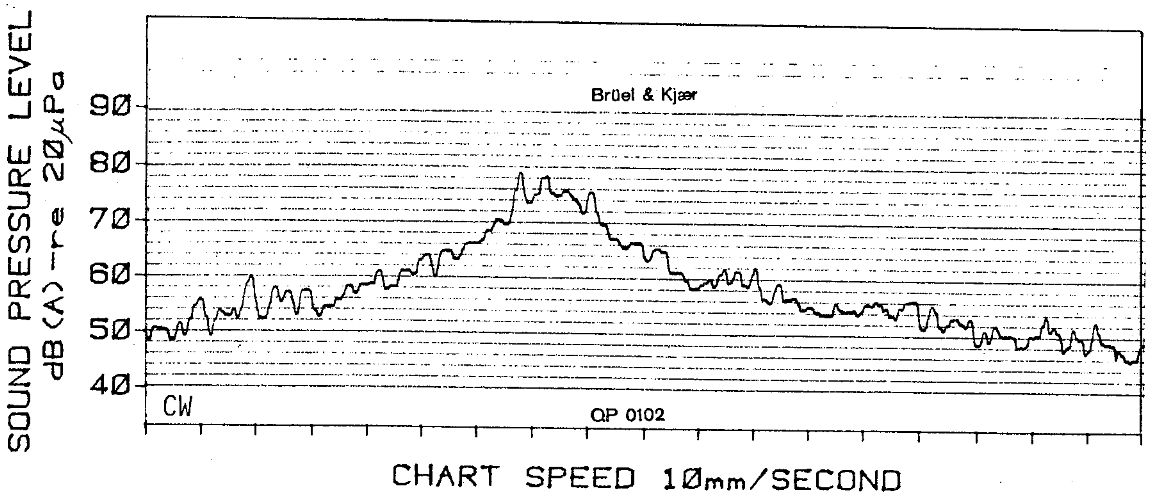


FIGURE N5. 15 MPH PASS BY - FAST PEN SPEED.



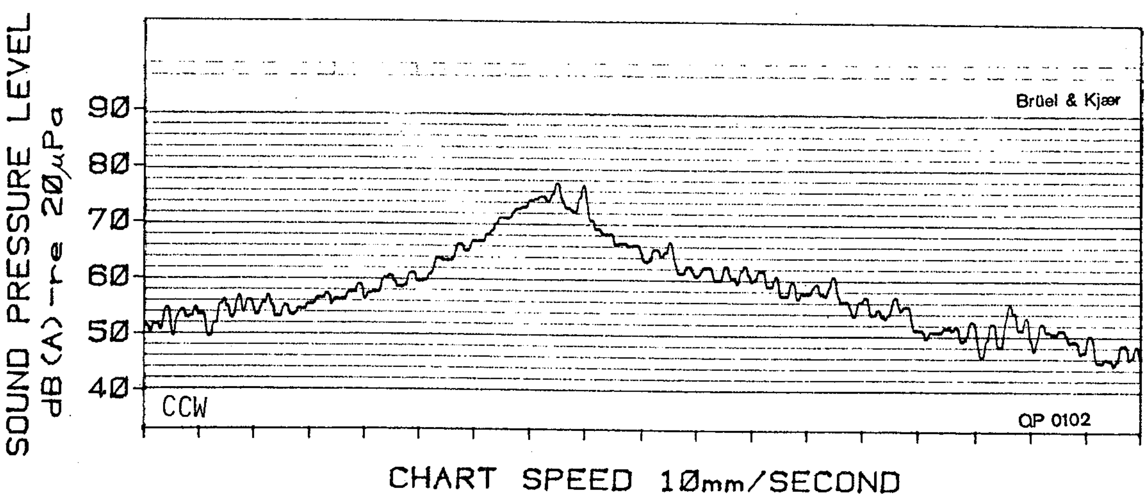
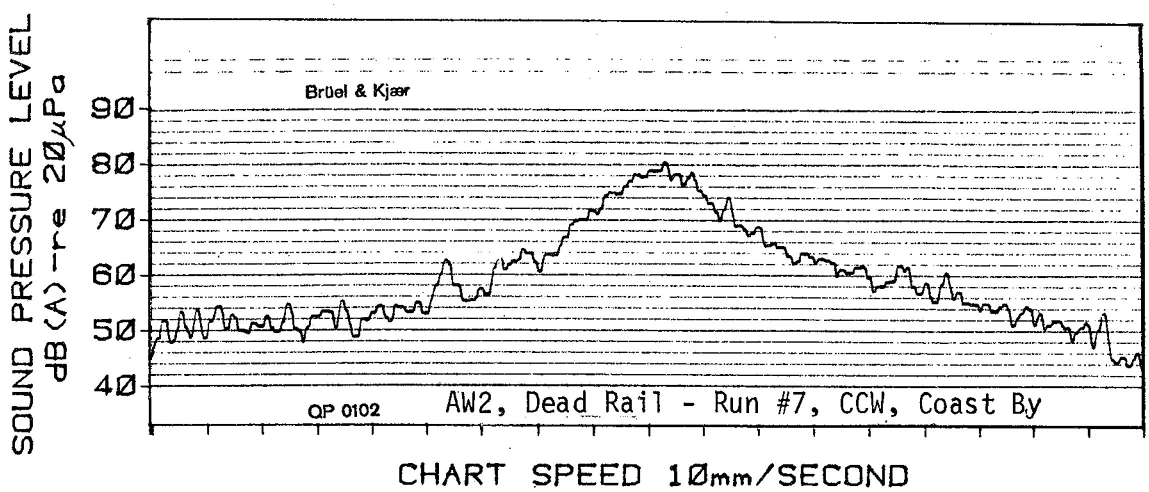


FIGURE N6. 50 MPH PASS BY OVER RAIL IRREGULARITY.



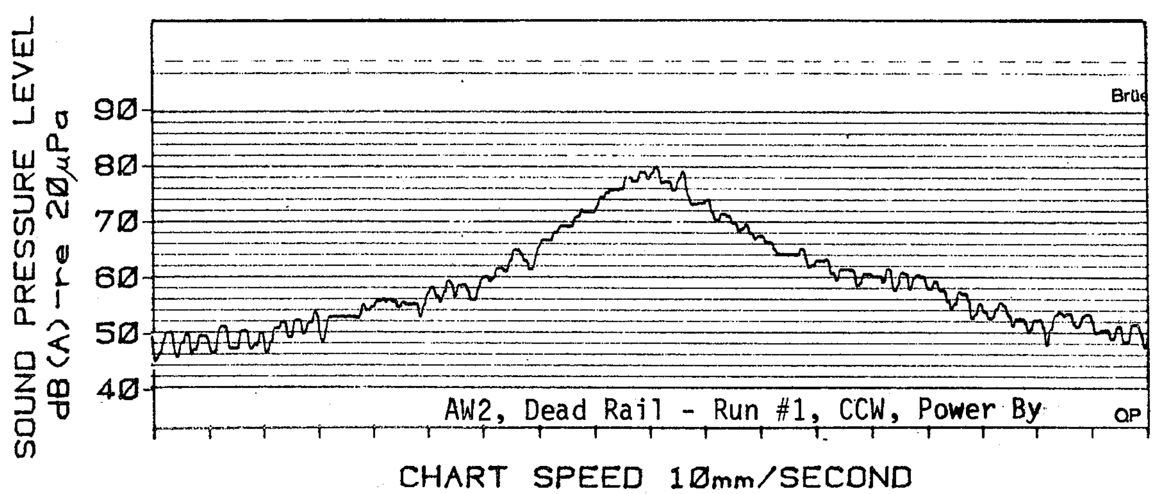
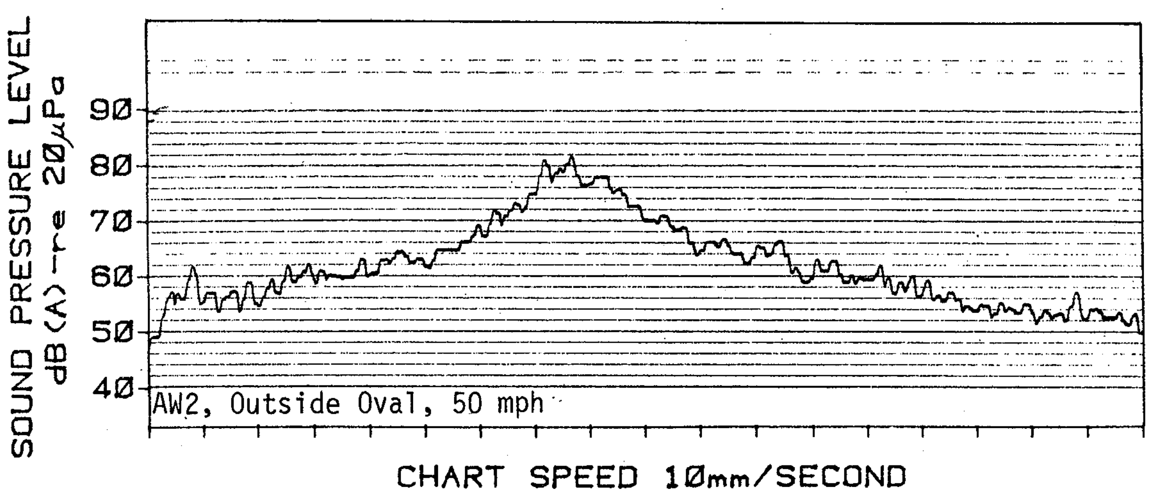


FIGURE N7. 50 MPH PASS BY AT AW2, WHEEL FLATS AND RAIL IRREGULARITY.



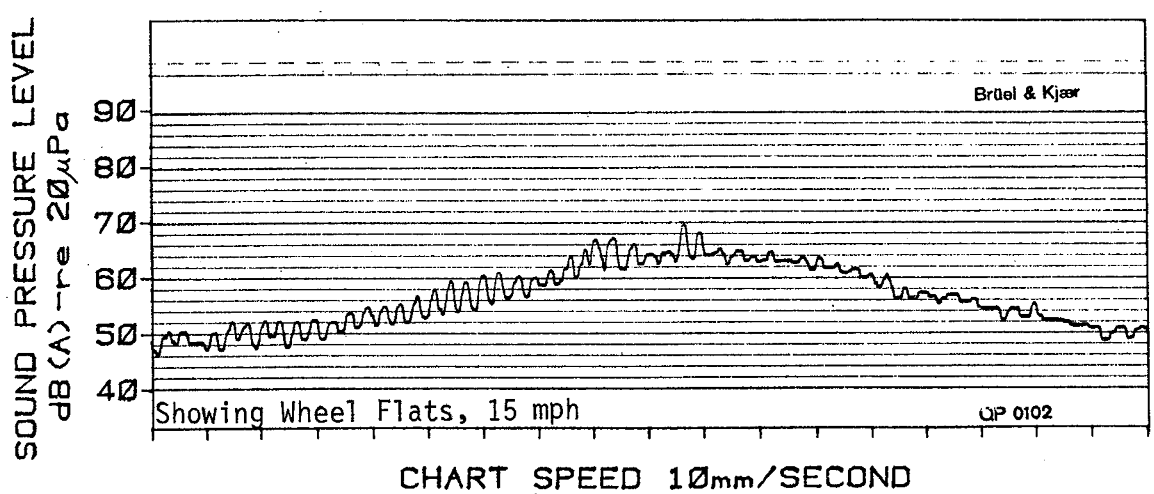
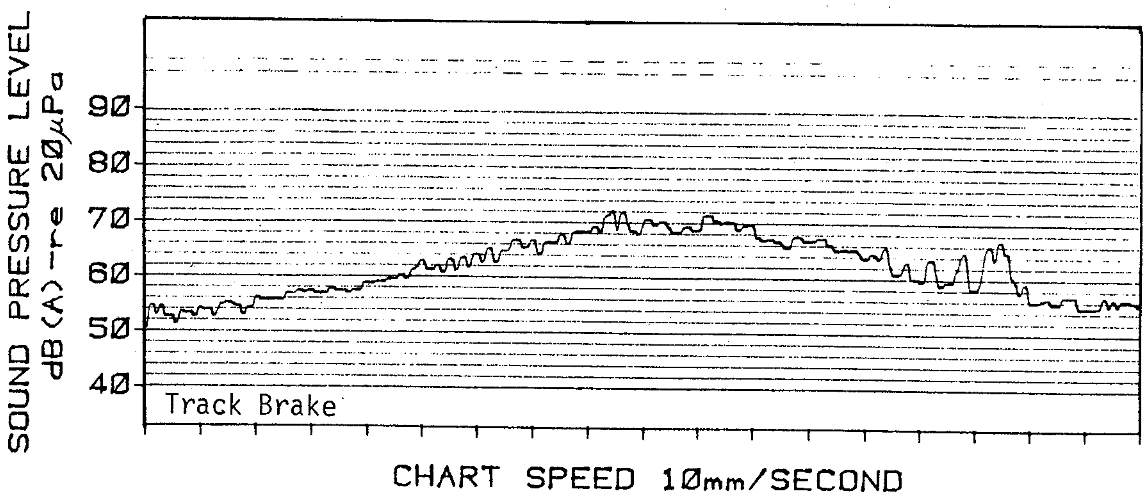


FIGURE N8. 50 MPH PASS BY, MICROPHONE ON OUTSIDE OF THE OVAL.



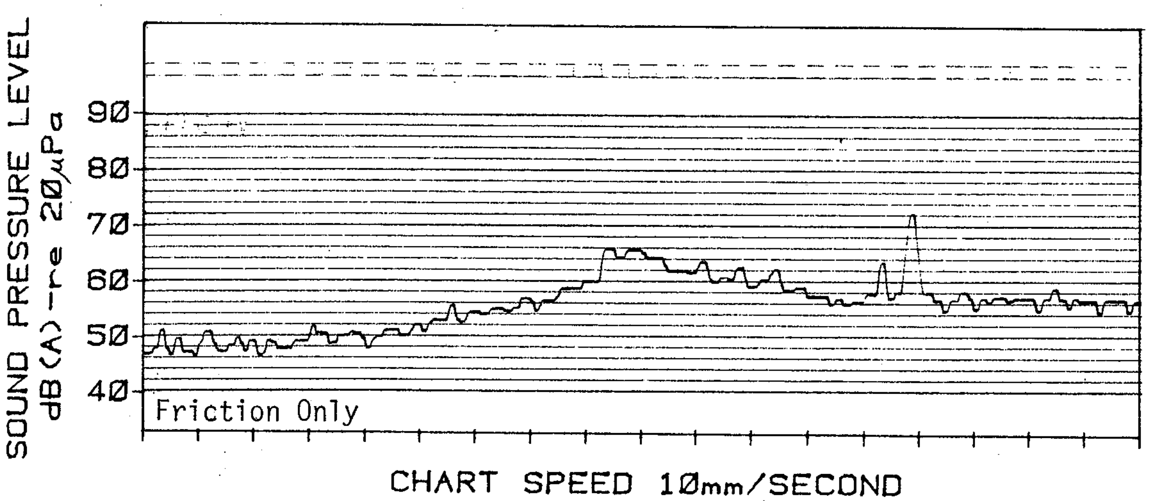


FIGURE N9. TRACK AND FRICTION ONLY BRAKE AT PASS BY FROM 15 MPH.

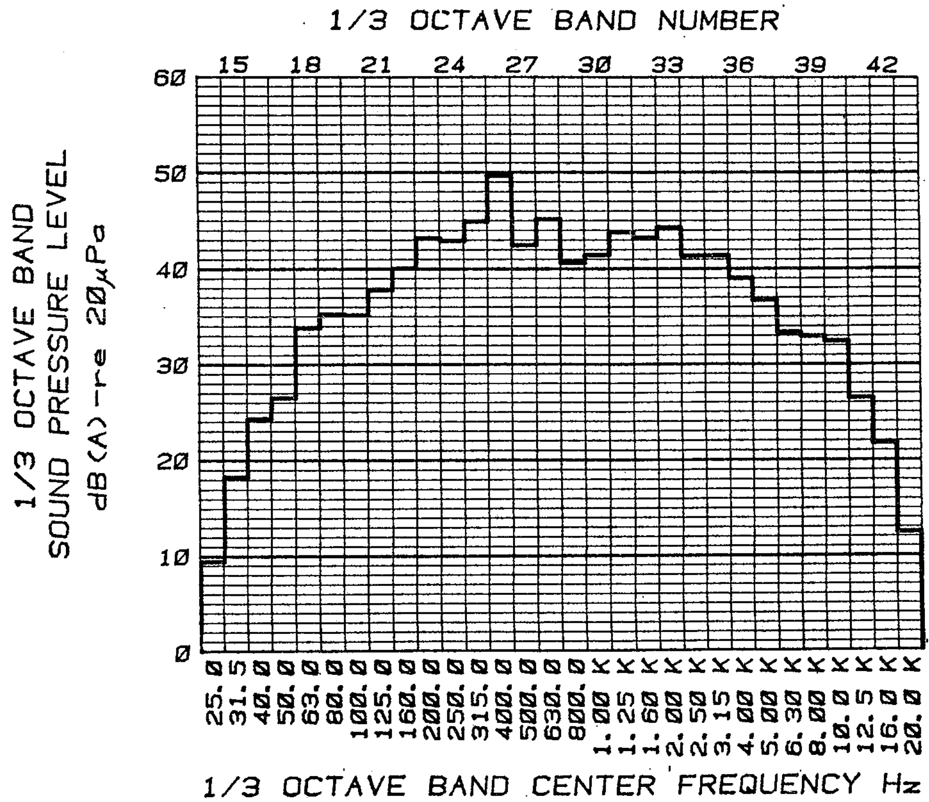


FIGURE N10. 1/3 OCTAVE BAND LEVELS 'ALL AUXILIARIES ON', MICROPHONE AT WAYSIDE.

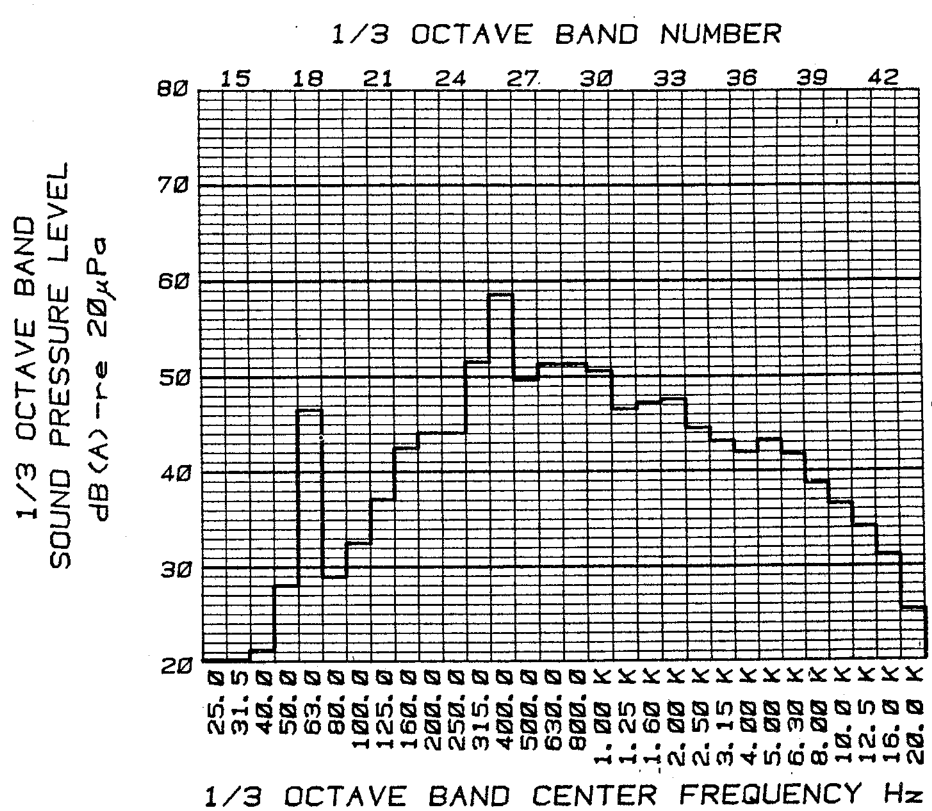


FIGURE N11. 1/3 OCTAVE BAND LEVELS - 'A' END TM BLOWERS ONLY.

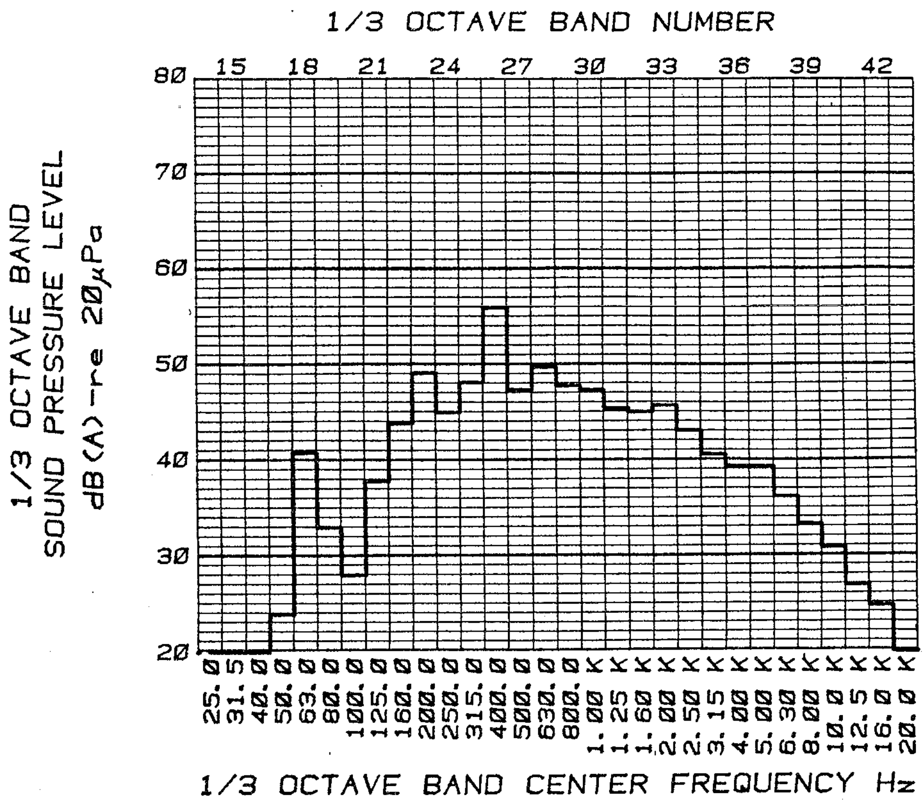


FIGURE N12. 1/3 OCTAVE BAND LEVELS - MID CAR TM BLOWERS ONLY.

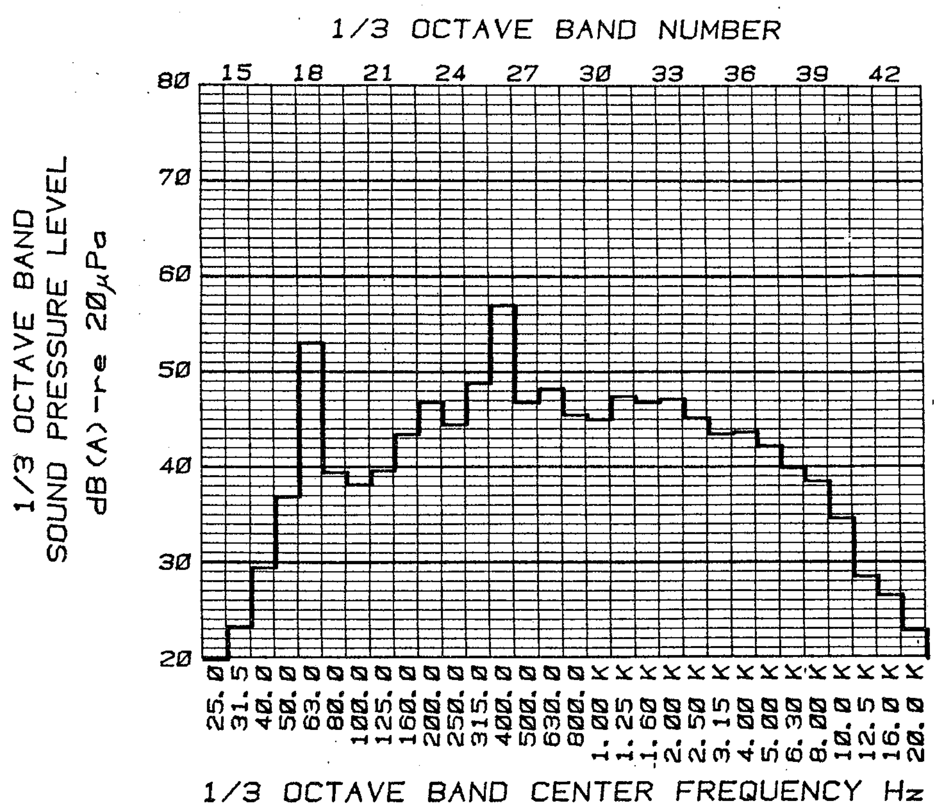


FIGURE N13. 1/3 OCTAVE BAND LEVELS - 'B' END TM BLOWERS ONLY.

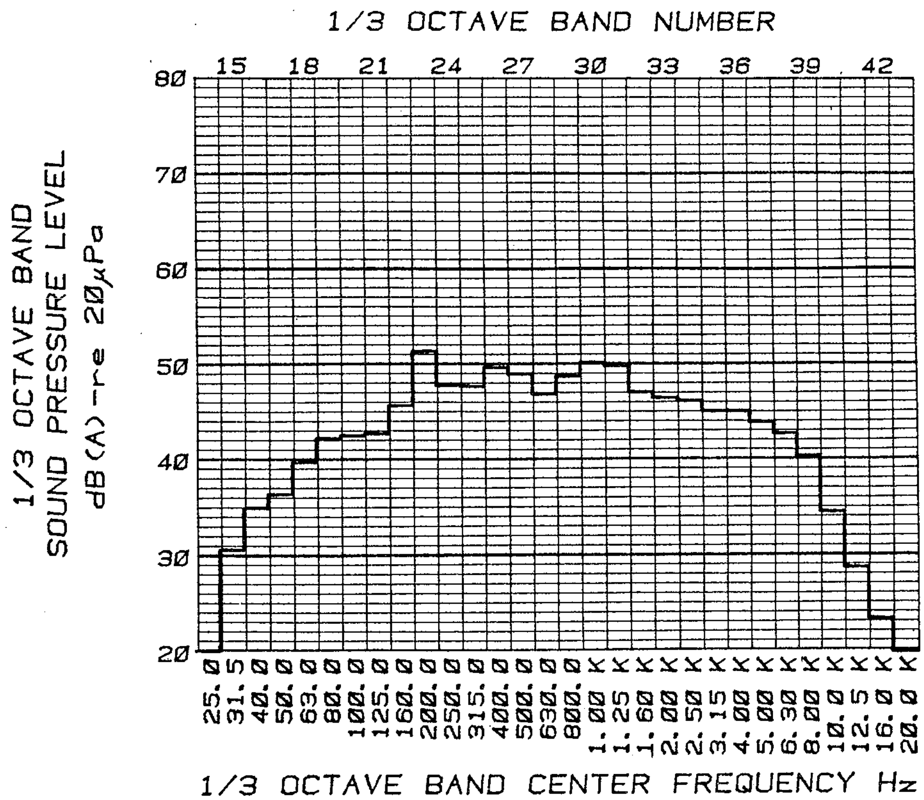


FIGURE N14. 1/3 OCTAVE BAND LEVELS - 'A' END AIR CONDITIONING ONLY.

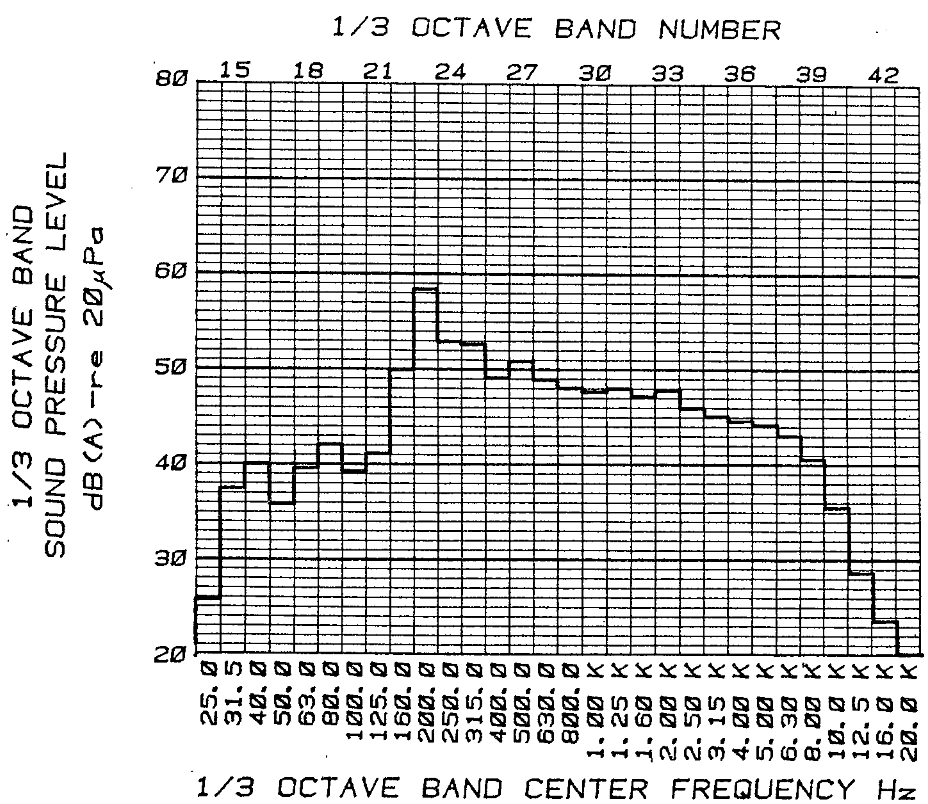


FIGURE N15. 1/3 OCTAVE BAND LEVELS - MID CAR AIR CONDITIONING ONLY.

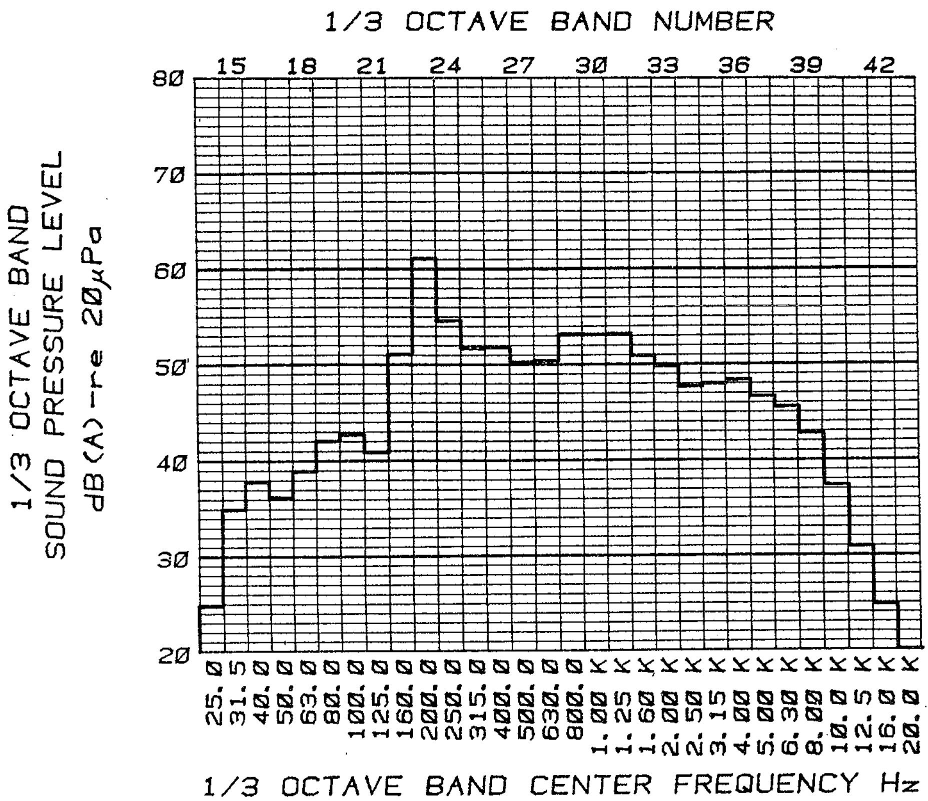


FIGURE N16. 1/3 OCTAVE BAND LEVELS - 'B' END AIR CONDITIONING ONLY.

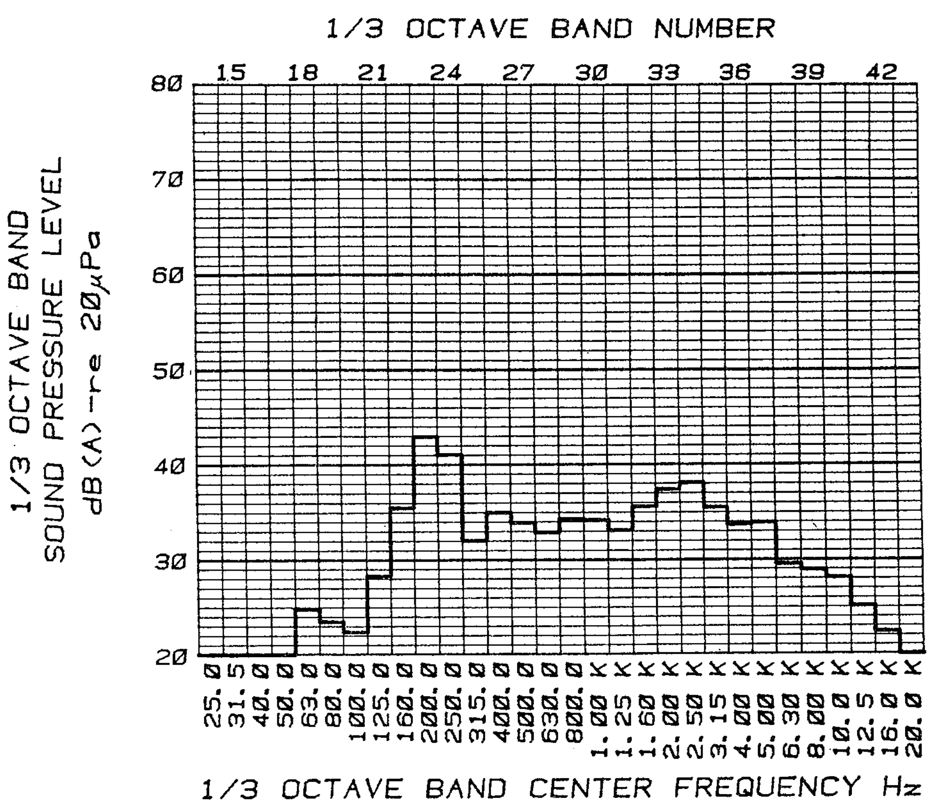


FIGURE N17. 1/3 OCTAVE BAND LEVELS - 'A' END AIR COMPRESSOR ONLY.

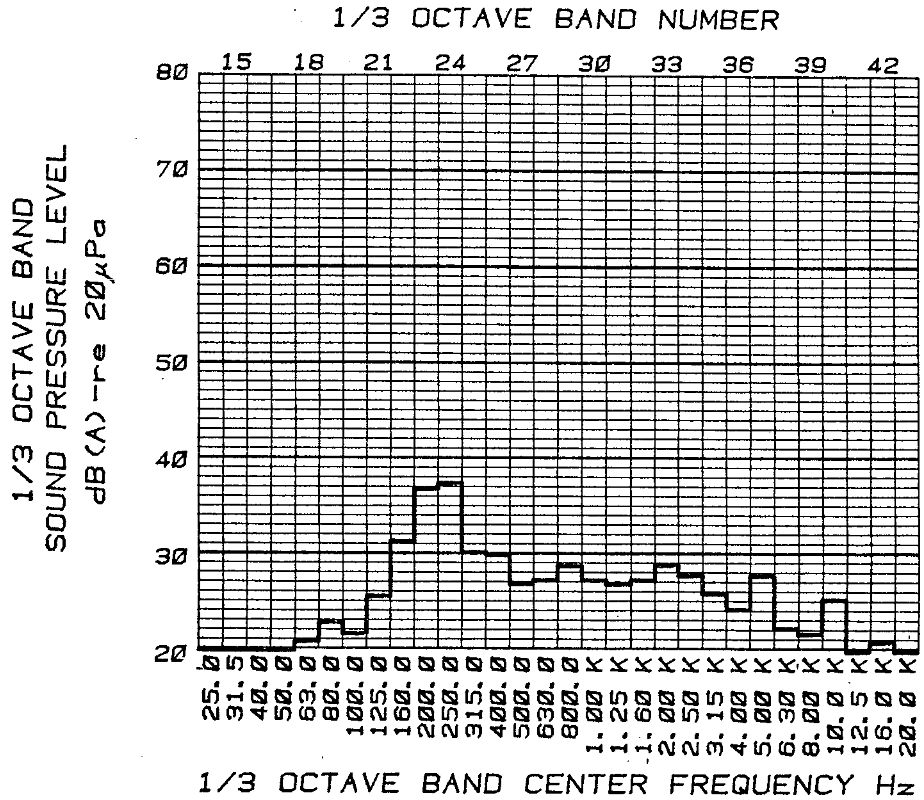


FIGURE N18. 1/3 OCTAVE BAND LEVELS - MID CAR AIR COMPRESSOR ONLY.

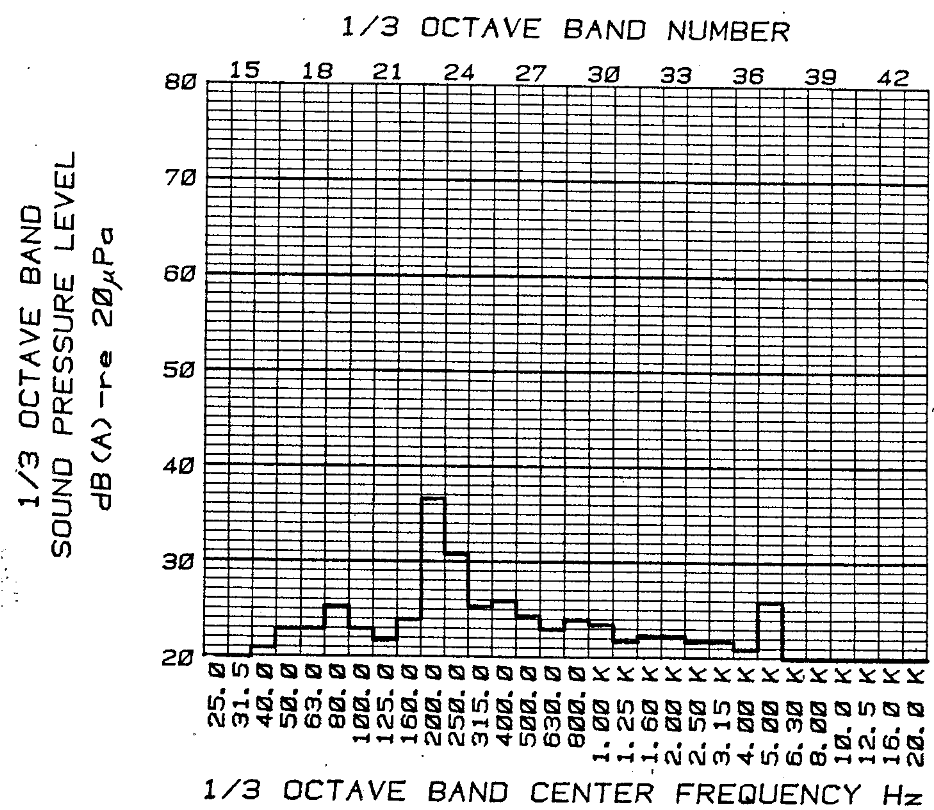


FIGURE N19. 1/3 OCTAVE BAND LEVELS - 'B' END AIR COMPRESSOR ONLY.

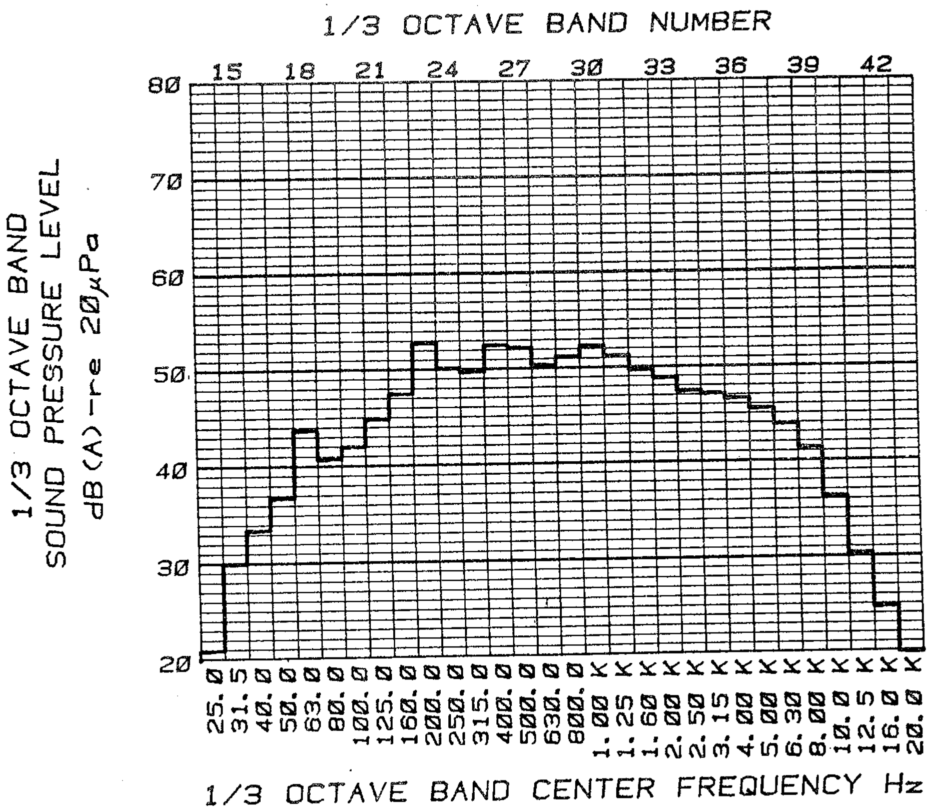


FIGURE N20. 1/3 OCTAVE BAND LEVELS - 'A' END ALL ON.

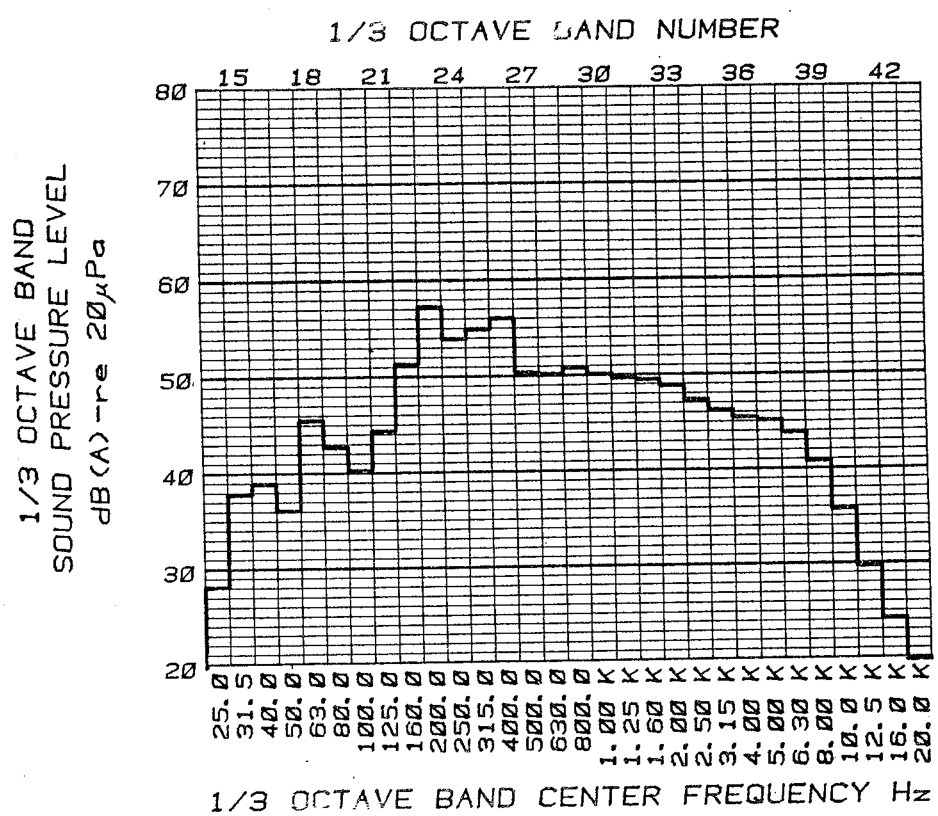


FIGURE N21. 1/3 OCTAVE BAND LEVELS - MID CAR ALL ON.

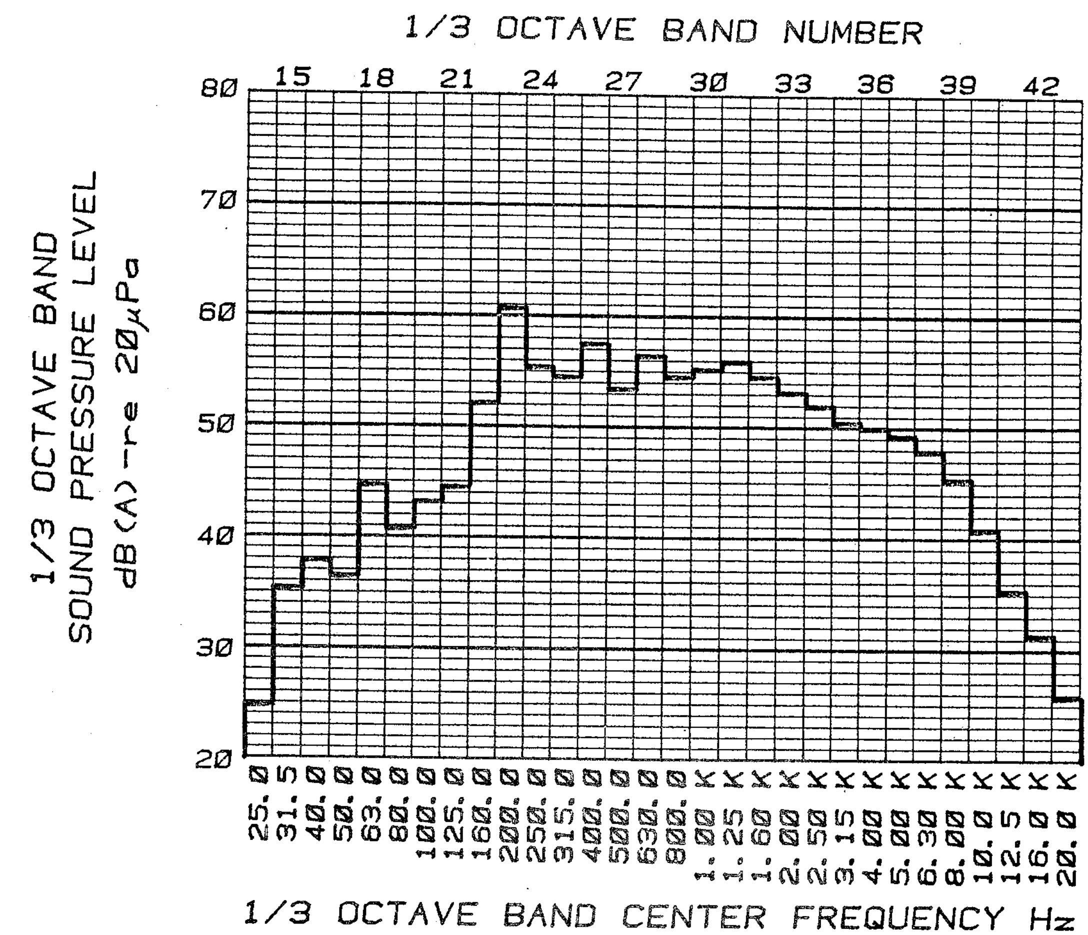


FIGURE N22. 1/3 OCTAVE BAND LEVELS - 'B' END ALL ON.

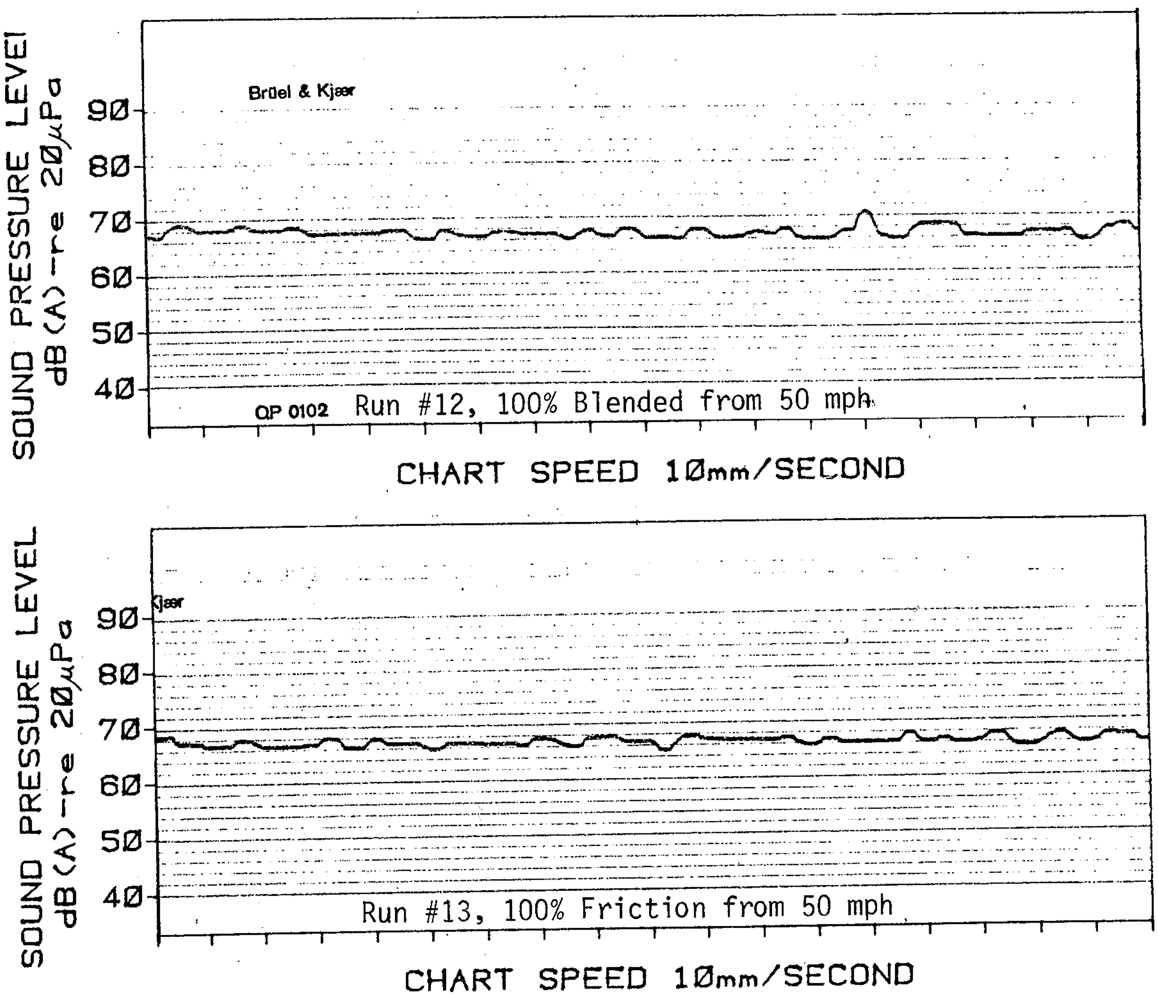
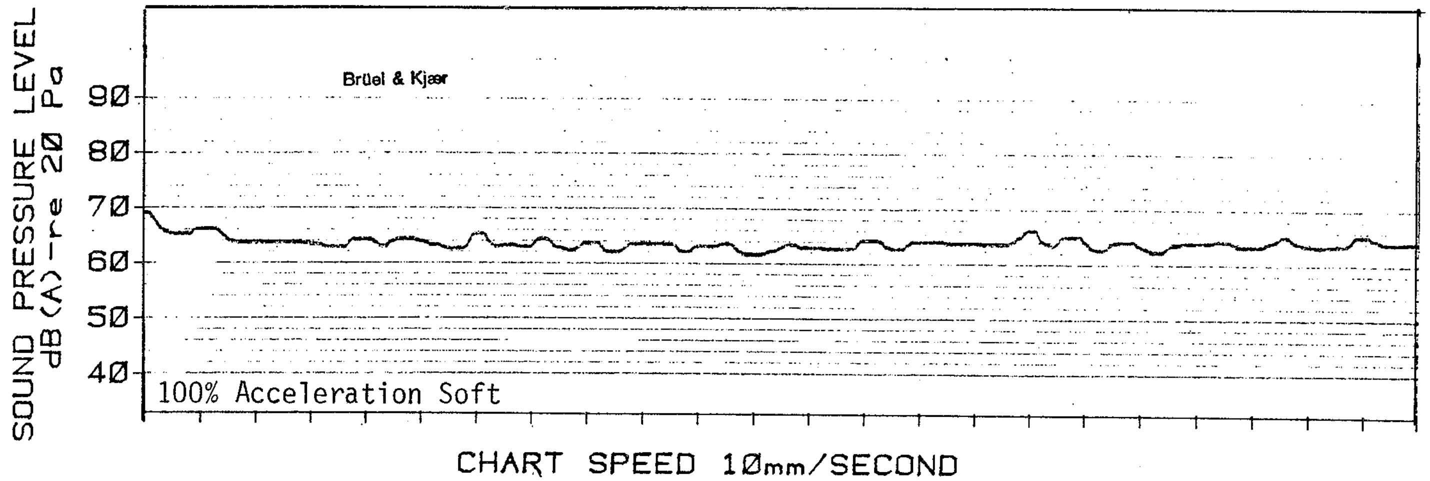


FIGURE N23. 'A' WEIGHTED SOUND PRESSURE TIME HISTORIES DURING BRAKE MODES.



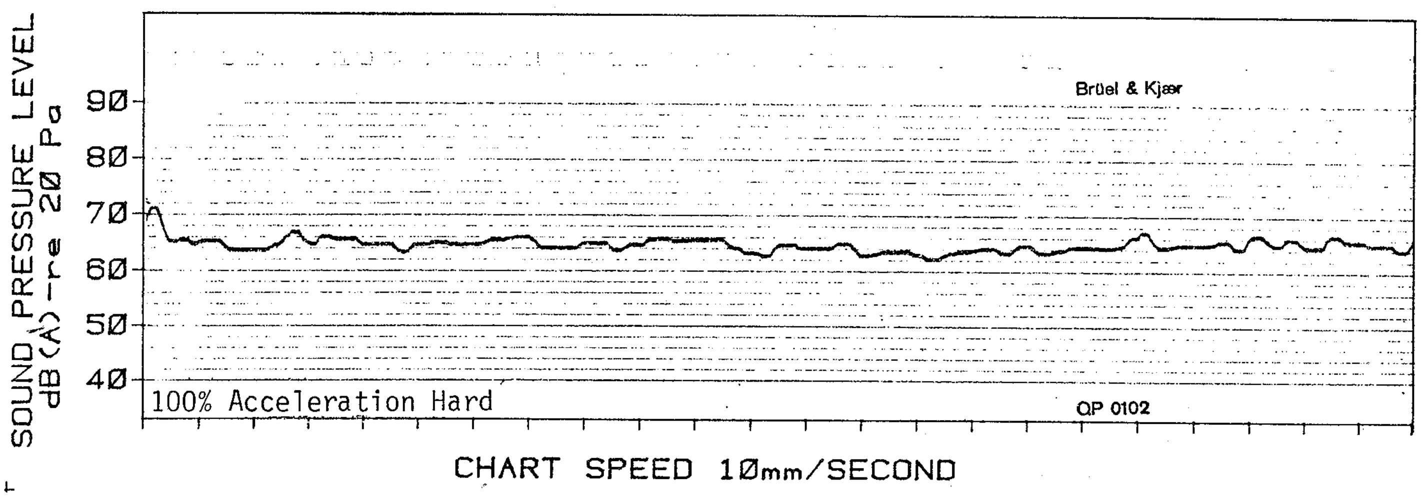


FIGURE N24. 'A' WEIGHTED SOUND PRESSURE TIME HISTORIES DURING ACCELERATION MODE.

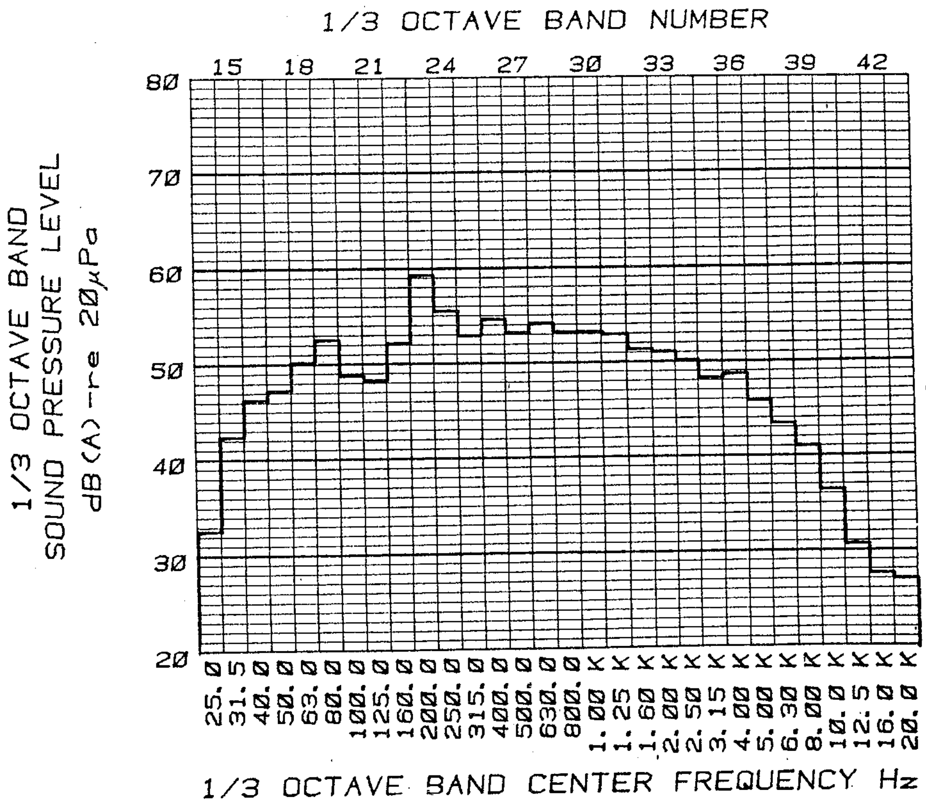


FIGURE N25. 1/3 OCTAVE BAND LEVELS, 50 MPH, MID CAR.

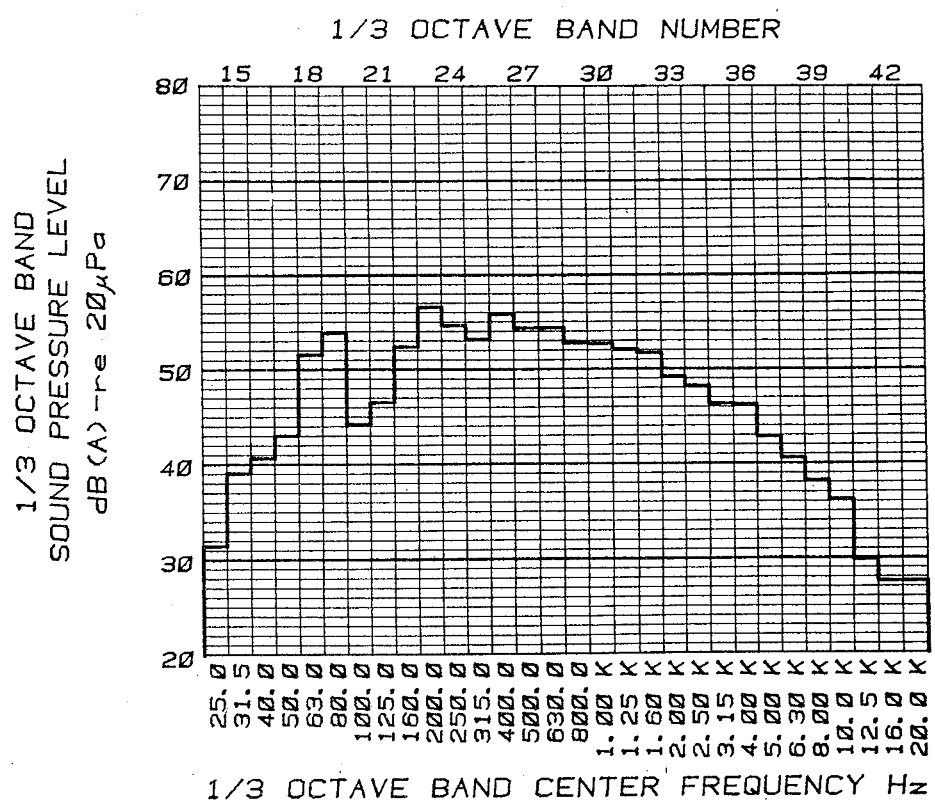


FIGURE N26. 1/3 OCTAVE BAND LEVELS - MID CAR, 50 MPH WITH AIR CONDITIONING OFF.

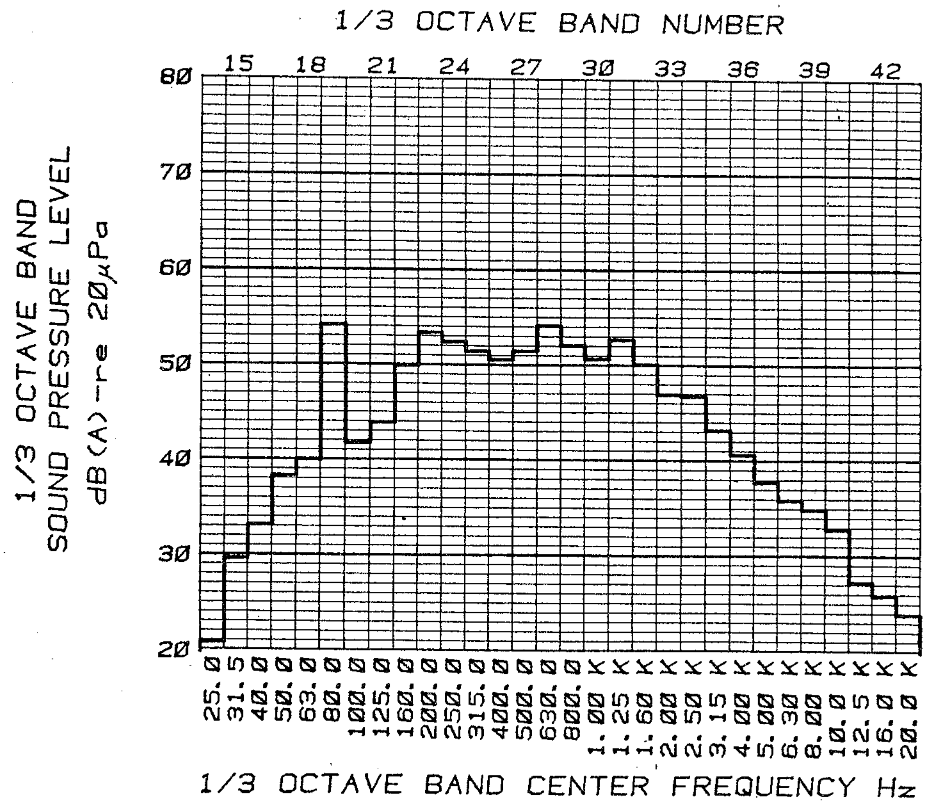


FIGURE N27. COAST MODE, PANTOGRAPH DOWN, MID CAR AT 50 MPH, 1/3 OCTAVE BAND LEVELS.

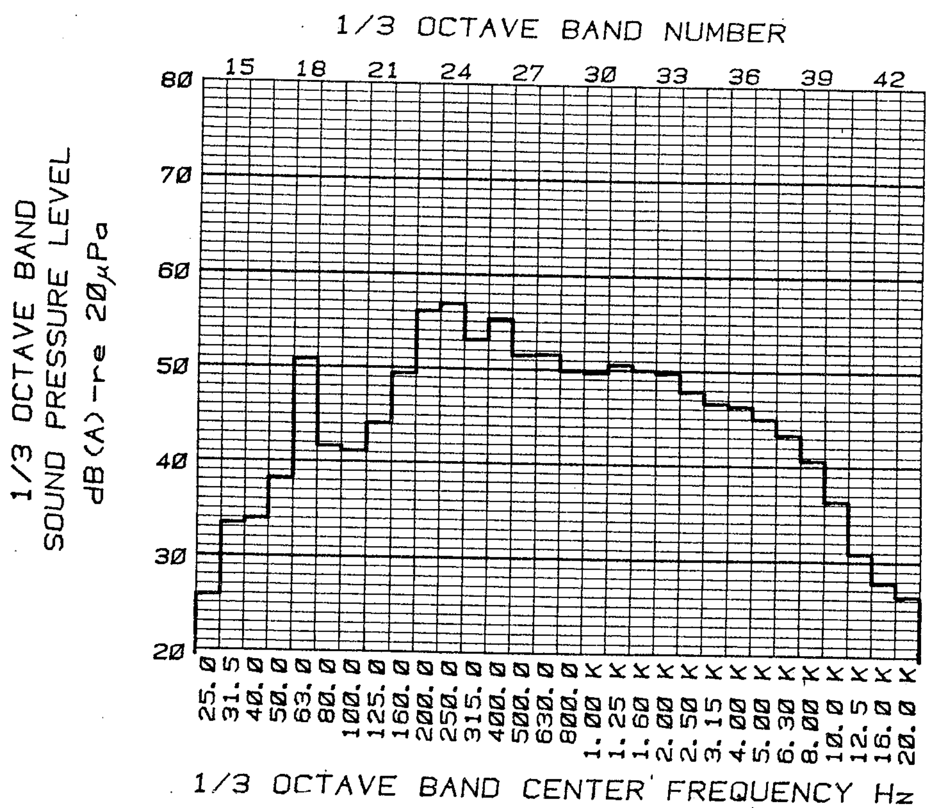


FIGURE N28. 1/3 OCTAVE BAND LEVELS AT APPROXIMATELY 15 MPH FULL POWER, MID CAR.

6.0 GROUND VIBRATION TESTS

The ground vibration field tests were performed on the Transit Test Track (TTT) using the NFTA Vehicle Proto 101 on June 23, 1983. The tests were conducted by Wilson, Ihrig and Associates, Inc. under separate contract.

The field testing was performed in three phases: (1) preparation, (2) impedance tests, and (3) groundborne vibration tests. The tests were conducted between Section 34 and 36 in the west tangent portion of the TTT. The tests were conducted by Wilson, Ihrig personnel using their special equipment. The results of the testing will be the subject of a separate report written by Wilson, Ihrig and Associates, Inc.

7.0 SPECIAL TESTS

7.1 STATIC TRUCK CHARACTERIZATION

7.1.1 Test Objective

The objective of test was to define the truck in terms of the following parameters:

- Truck Rotational Stiffness
- Primary Suspension Stiffness
- Axle Alignment

7.1.2 Test Method

7.1.2.1 Truck Rotational Stiffness

With the secondary suspension air bags inflated, both axles of a test truck were supported on a single air bearing table such that the truck was allowed to yaw freely with respect to the ground. Lateral forces of equal magnitude were applied to diagonally opposite corners of the air bearing table. The magnitudes of the applied forces were monitored with load cells placed between the actuators and the table. With the truck floating freely, the applied force was slowly increased to the point where gross truck rotation occurred. The movement was monitored with table to ground dial gage indicators. The magnitude of the break-away torque (rotational stiffness) was then determined by multiplying the levels of applied force required to obtain gross rotation by the longitudinal distance between the force locations and the rotational center of the truck.

7.1.2.2 Primary Suspension Stiffness

The stiffness characteristics of the primary suspension were investigated by applying and releasing directional loads to either a test truck or a wheelset and measuring the deflection of the truck relative to the wheels. Unfortunately, the disc brakes were not properly released during these tests; thus, true primary suspension stiffness characteristics were not determined.

7.1.2.3 Axle Alignment

The axle alignment of the NFTA test truck was measured while each test truck was free floating on individual air bearing tables. However, during these measurements the disc brakes were applied and the axles did not rotate freely. Therefore the "natural" axle alignment was not determined.

7.1.3 Test Results

The truck rotational stiffness test procedure was repeated four times for accuracy. Each time the rotation was almost continuous and break-away occurred at very low torque levels. The average of the four test results show that the break-away torque for the NFTA truck is 1,700 ft-lbs.

7.2 RIGID BODY VIBRATION MODES AND FREQUENCIES

7.2.1 Objective

The objective of the test was to obtain the rigid body frequencies of pitch, bounce, yaw, roll, and upper body sway, with the vehicle at a weight of AW0.

7.2.2 Test Method

The hydraulic shock absorbers between the trucks and the truck bolsters were removed, leaving the vehicle body free to move on the air bags with the only damping coming from the air bags themselves.

The vehicle was located over the pit in the URB. It was instrumented with equipment for the special roll angle tests and also with ride quality accelerometers. This instrumentation, in conjunction with a strip chart, provided a useful way of measuring frequency by counting cycles in a given time window.

7.2.3 Test Results

7.2.3.1 Pitch

Input was provided to the vehicle so as to set one end of the vehicle pitching and then the oscillation was increased at the other end, providing input in antiphase. While the vehicle was pitching at a significant amplitude a strip chart was made of the string pot output. Over a period of 40.9 seconds there were 50 cycles, for a frequency of 1.222 Hz.

7.2.3.2 Bounce

Input provided beneath the middle of the vehicle was found to be effective in exciting the bounce mode without pitch content. With a significant bounce induced, over a period of 32.3 seconds there were 40 cycles, for a frequency of 1.238 Hz. This frequency is very close to the pitch frequency.

7.2.3.3 Yaw

The yaw mode setup at one end of the vehicle was augumented by applying input in anti-phase at the same side of the car at the other end. A substantial oscillation was produced over a period of 28.8 seconds, i.e., 30 cycles, corresponding to a frequency of 1.042 Hz.

7.2.3.4 Roll

Input was applied to the rain gutter. A significant roll was produced, giving 20 cycles over a period of 36.5 seconds, corresponding to a frequency of 0.5479 Hz.

7.2.3.5 Upper Body Sway

Because of difficulty experienced in other transit tests in obtaining this mode in isolation of the roll mode, it was not attempted in favor of other testing. However, it is suggested that for the next test, the car could be restrained at two points in the horizontal plane with a fixture (such as two fork lift trucks), such that the roll mode is inhibited and the upper body sway can be obtained in isolation.

7.2.3.6 Summary of Results

The rigid body frequencies are:

Pitch	1.222 Hz
Bounce	1.238 Hz
Yaw	1.042 Hz
Roll	0.5479 Hz
Upper Body Sway	Not Found

The four modes attempted were easily found. It is suggested a fixture be used for upper body sway.

7.3 FLEXIBLE BODY BENDING - FIRST VERTICAL MODE

7.3.1 Objective

The objective was to find the frequency of the first body bending mode of the carbody. The first body bending mode is often significant in the ride quality performance of the vehicle in the vertical direction, particularly at the center of the vehicle. Subjectively, it was noticed when riding in the vehicle that other body modes such as lateral bending, twist, etc., were not significant in affecting ride quality and they were not evaluated, although they could have been evaluated by the same method. The test to find the first body bending frequency was performed with the vehicle at AW0 at the end of the test program.

7.3.2 Test Method

The test method was to strike the end of the vehicle on the anticlimber in the vertical direction with a force transducer instrumented hammer, and feed the signal to an HP 5420 B Digital Signal Analyzer. At the same time, a signal from a piezo-electric accelerometer located at a series of twelve locations on the floor of the vehicle was fed to the second channel of the analyzer. The analyzer computed the transfer function of the two signals which indicated resonant frequencies. From the transfer function, the analyzer computed the 'Nyquist' plot. This is a plot of the imaginary versus the real part of the transfer function. A series of Nyquist plots were made, one for each location of the accelerometer down the centerline of the vehicle. The Nyquist plots contained information which enabled identification of the first body bending mode and its frequency.

The hammer used to impact the anticlimber was a special sledge hammer fitted with a quartz load cell and a special soft tip suitable for the excitation of large structures at low frequencies. The hammer was allowed to fall with slight assistance, a distance of about 2 feet to give a relatively small impact to the anticlimber, in the vertical direction. This was found to give ample input to the structure. Care was taken that the hammer blow did not overload any of the electronics, and that a single clean blow was delivered without rebound of the structure to the hammer tip.

The hammer and accelerometer were both connected, by way of a miniature coaxial cable (10 feet long), to battery-powered charge amplifiers with adjustable gain. The two signals were then fed with normal coaxial cables to a dual filter to remove high frequency content above 100 Hz. The signals were then fed to channels A and B of the analyzer.

The quartz accelerometer was of high sensitivity, with a small magnet on the base, which was attached to a steel plate 6" x 6" x 1/2", resting on the floor of the vehicle. A series of trials was made in which it was established that the vehicle gave good results by impacting the anticlimber with the hammer, and sensing vibration with the accelerometer at a series of locations down. Here, the impact was made directly into the solid structure of the vehicle.

The transfer functions were later replayed from tape and plotted, along with the associated Nyquist plots, on an HP thermal plotter.

7.3.3 Test Results

Analysis included an investigation into the resonance which could be attributed to the the first body bending mode. The transfer function from 0 to 12 Hz in magnitude and phase form is shown in Figure M01. This plot is from nearby the midpoint of the vehicle and shows what was thought to be the first body bending frequency at 9.72 Hz. This was confirmed by the Nyquist plots shown later in the text.

The Nyquist plot for the motorman cab is shown in Figure M02 and for the mid car in Figure M03. The Nyquist plots show the characteristic circle associated with the resonance, and it can be seen that the plots for end of car and mid car are in 'anti-phase', indicating that they are from locations on either side of the mode. Figure M04 is the mode plot produced by plotting the magnitude of each Nyquist circle against the location of the accelerometer for the 12 locations, the diameter was estimated by 'eye'. The mode plot clearly shows the first mode, confirming that the 9.7 Hz frequency is associated with the first body bending mode.

The vertical first body bending of the transit vehicle was 9.72 Hz. This test showed that real time modal analysis with the simple hammer and accelerometer was possible on the vehicle structure and because the HP 5423 A Structural Dynamics Analyzer collects data in the same way as the instrument used, the results via this analyzer for more complex shapes should be successful.

The frequency of 9.72 Hz of the carbody indicates a stiff structure.

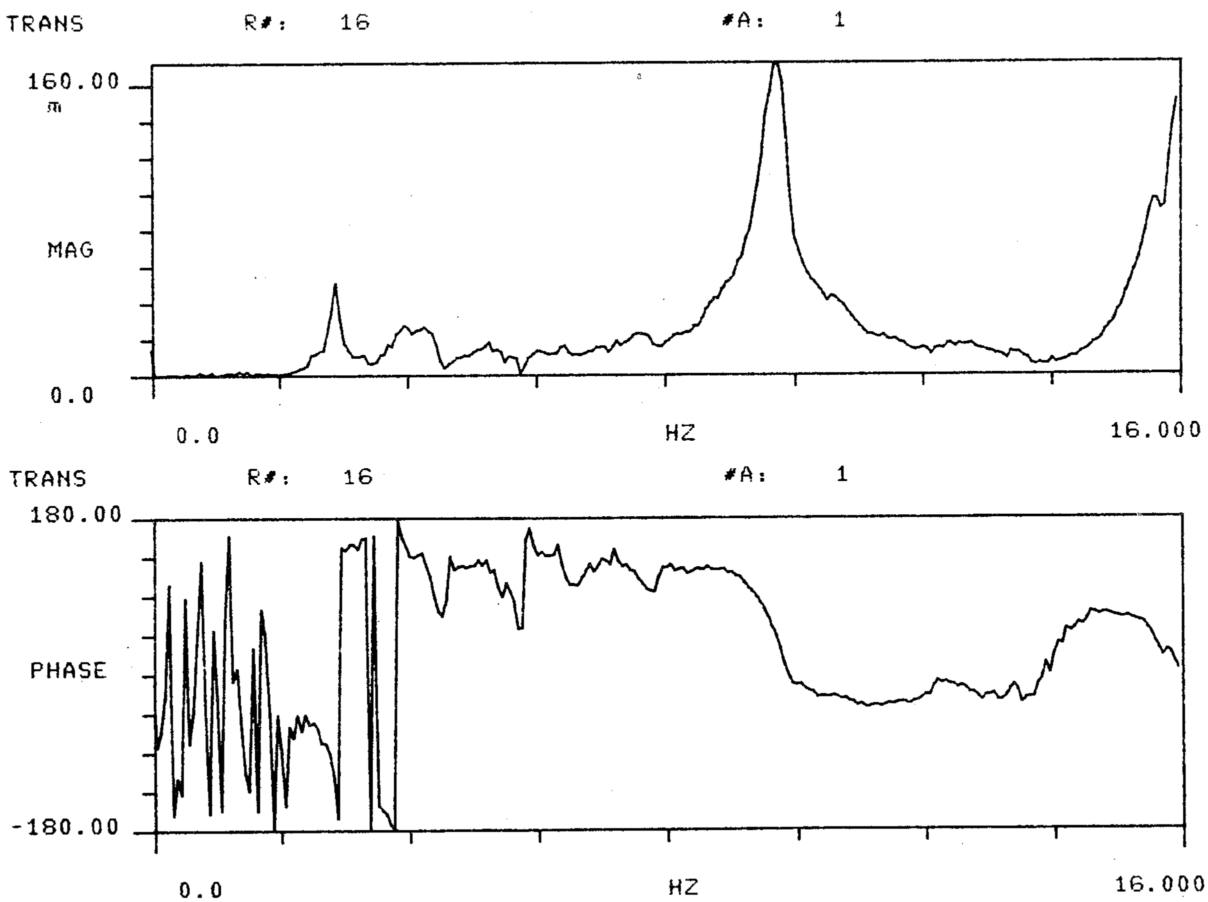


FIGURE M01. FIRST BODY BENDING MODE.

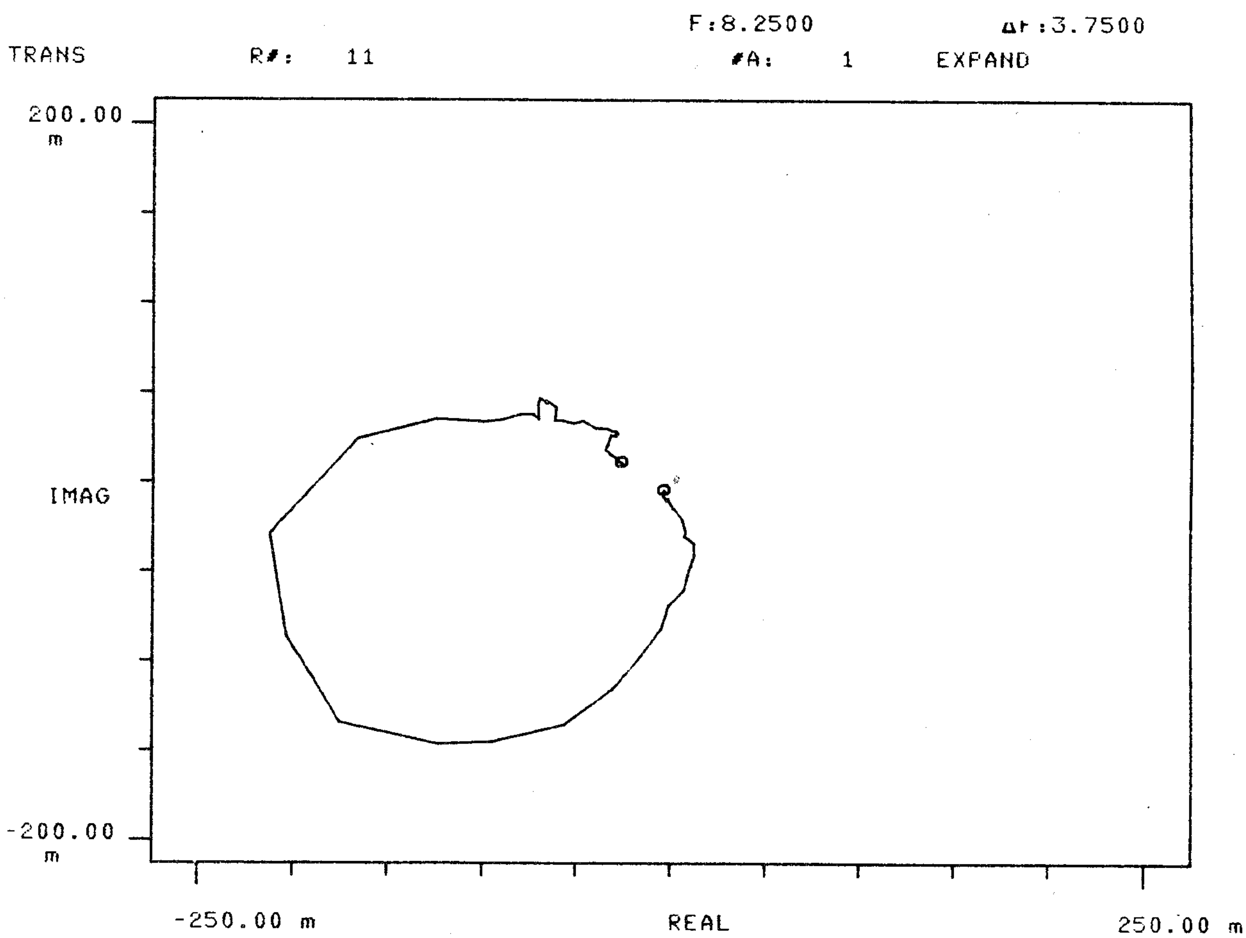


FIGURE MO2. NYQUIST PLOT FROM CAB POSITION.

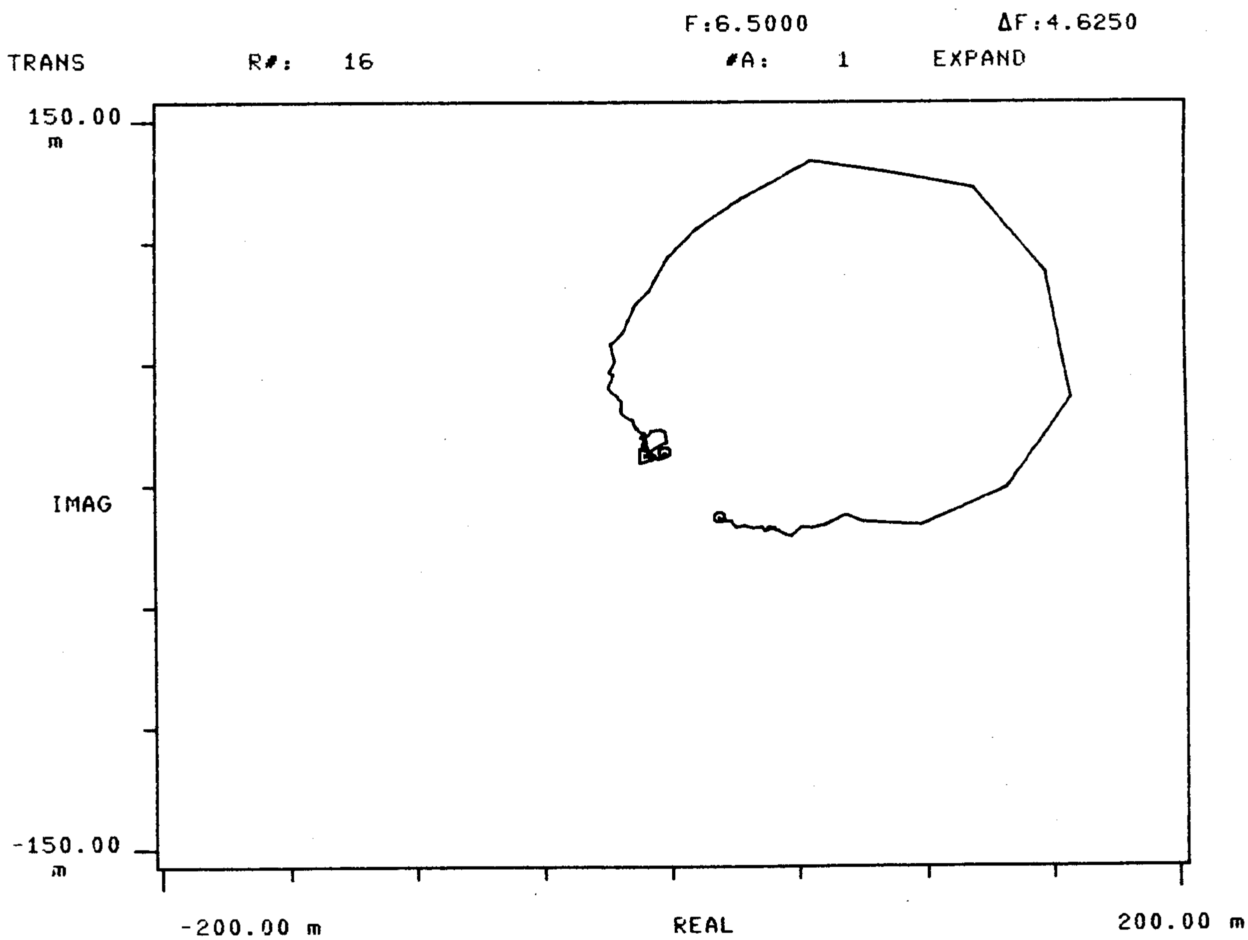


FIGURE M03. NYQUIST PLOT FROM MID-CAR POSITION.

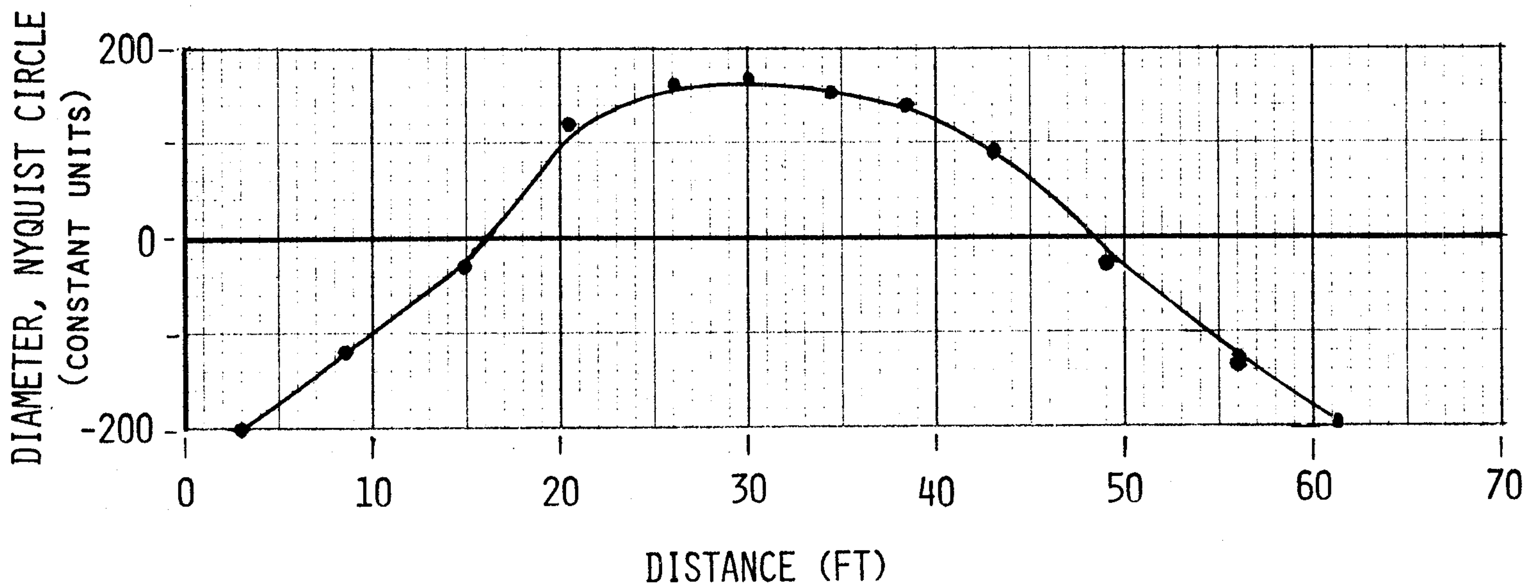


FIGURE MO4. COMBINED NYQUIST PLOT AMPLITUDES.

7.4 SPECIAL DYNAMIC YAW/ROLL TEST

7.4.1 Objective

The purpose of this test was to determine the maximum lateral displacement of the vehicle centerline (relative to the track gage) due to carbody roll or yaw motion. This value is important in determining acceptable wayside track clearances.

7.4.2 Test Method

Two string potentiometers were attached vertically between the carbody and the track-brake bracket, and one potentiometer was connected between the carbody and the truck sideframe. From the two vertical string pots, rolling motion may be observed if the movement of one side of the vehicle is out of phase when the other side is measured with laterally mounted potentiometers.

The vehicle was also instrumented with accelerometers: one on the middle of the vehicle roof centerline to measure roll, and the other mounted on the centerline of the vehicle floor (at the very end of the vehicle, in the cab area) to determine yaw.

In this test, the NFTA car began running from a standstill position and accelerated to a speed of 50 mph, taking approximately 37 seconds, while accelerations and displacements were measured and recorded. This test was conducted on tangent, welded-rail track.

7.4.3 Test Results

Figure YR1 shows a typical strip chart of the data output. Channels 1 and 3 show the vertical displacement measured by string potentiometers. It can be seen that the movement was sinusoidal and the left side was almost in phase with the right. This indicates that the "bump stops" were not being met and the movement was simple harmonic, pure rigid body bending, generally in the pitch or yaw mode. The amplitude of the vertical deflection did not appear to be influenced by the vehicle speed.

Channel 2 of Figure YR1 shows the lateral motion of the carbody relative to the truck sideframe. Again, simple harmonic, pure rigid body bending was observed, however, the lateral movement did increase as the vehicle accelerated.

Since the motion was simple harmonic in nature, the nomograph shown in Figure YR2 was used to determine the lateral vehicle movement. The accelerometer mounted in the longitudinal middle of the vehicle measured the roll motion. The data were filtered so that the remaining band width was between 0.4 and 0.7 Hz. The data from the end-mounted accelerometer measured yaw and was filtered to a band width of 0.8 to 1.2 Hz. Then, the amplitudes of accelerations were converted to inches of displacement by the following two equations.

At 0.54 Hz, 1g peak accel = 36 inches peak
At 1.025 Hz, 1g peak accel = 11 inches peak

The results are plotted in Figure YR3. From this information it was determined that the maximum lateral displacement from the mean was less than 1.0 inch; therefore, the roll motion on tangent track with good geometry and new wheels was not significant at speeds up to 50 mph, and although yaw movement was noticeable subjectively, it, too, was quite small.

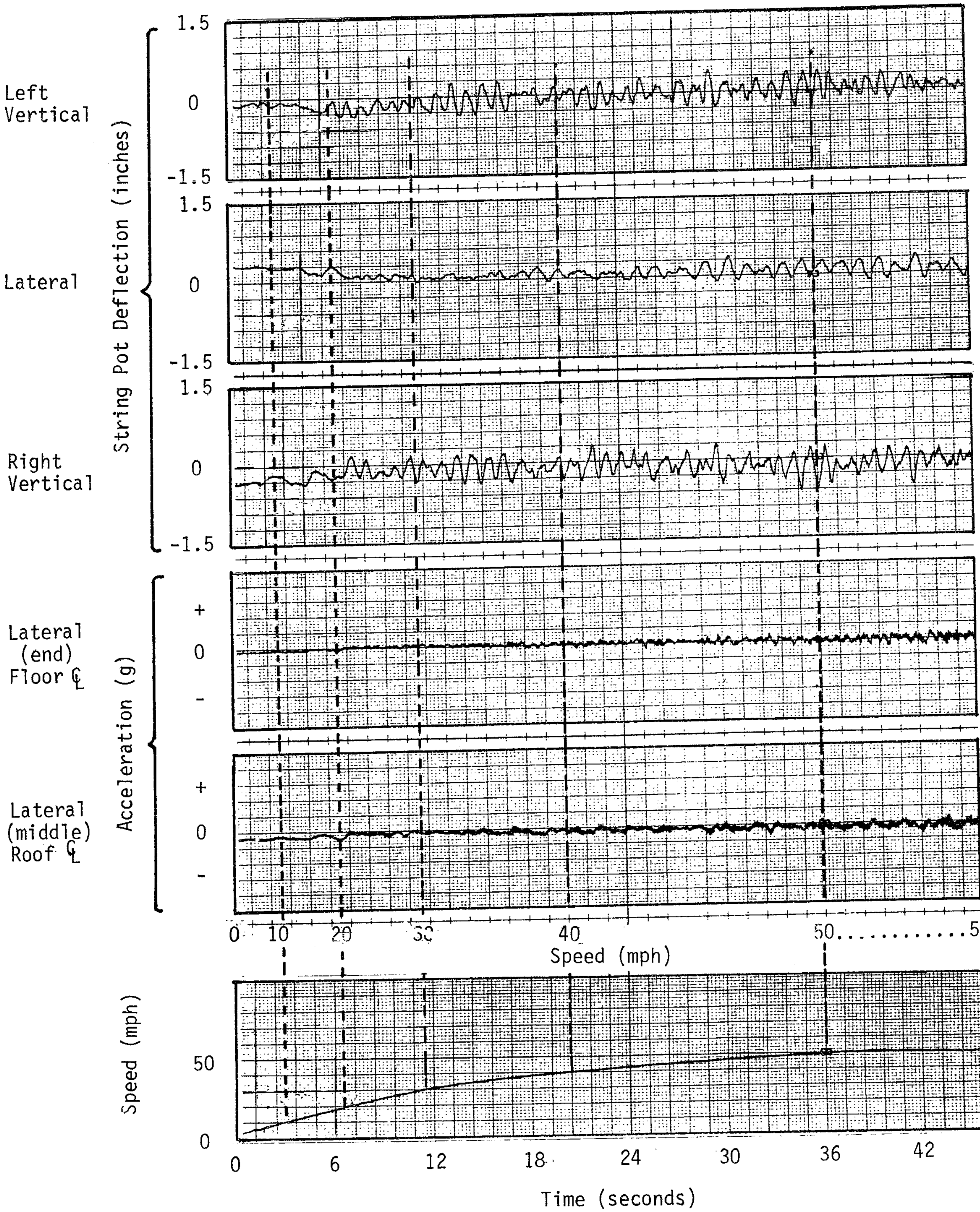


FIGURE YR1. TYPICAL YAW AND ROLL DATA.

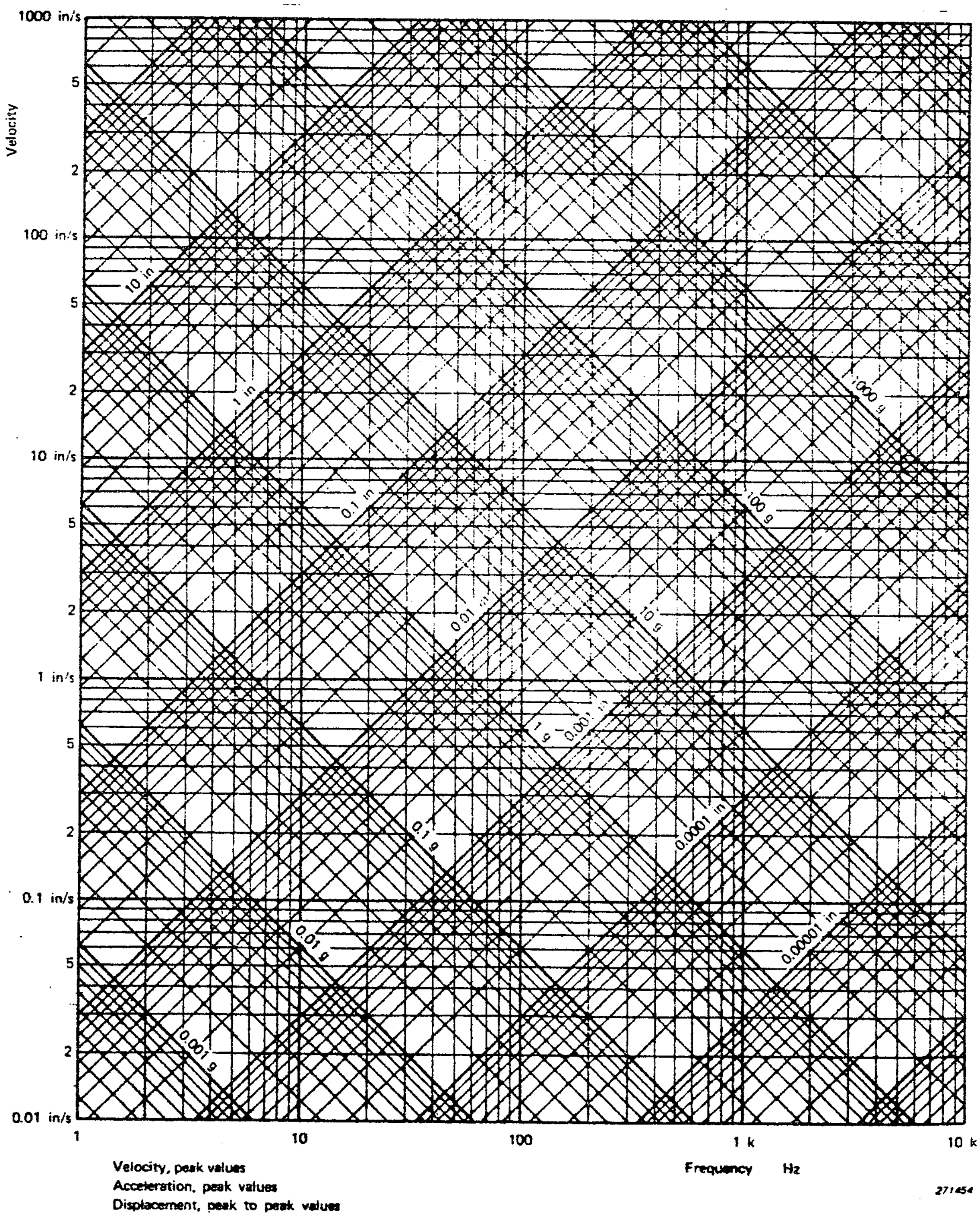


FIGURE YR2. FREQUENCY, ACCELERATION, VELOCITY, DISPLACEMENT NOMOGRAPH (BRITISH SYSTEM OF UNITS).

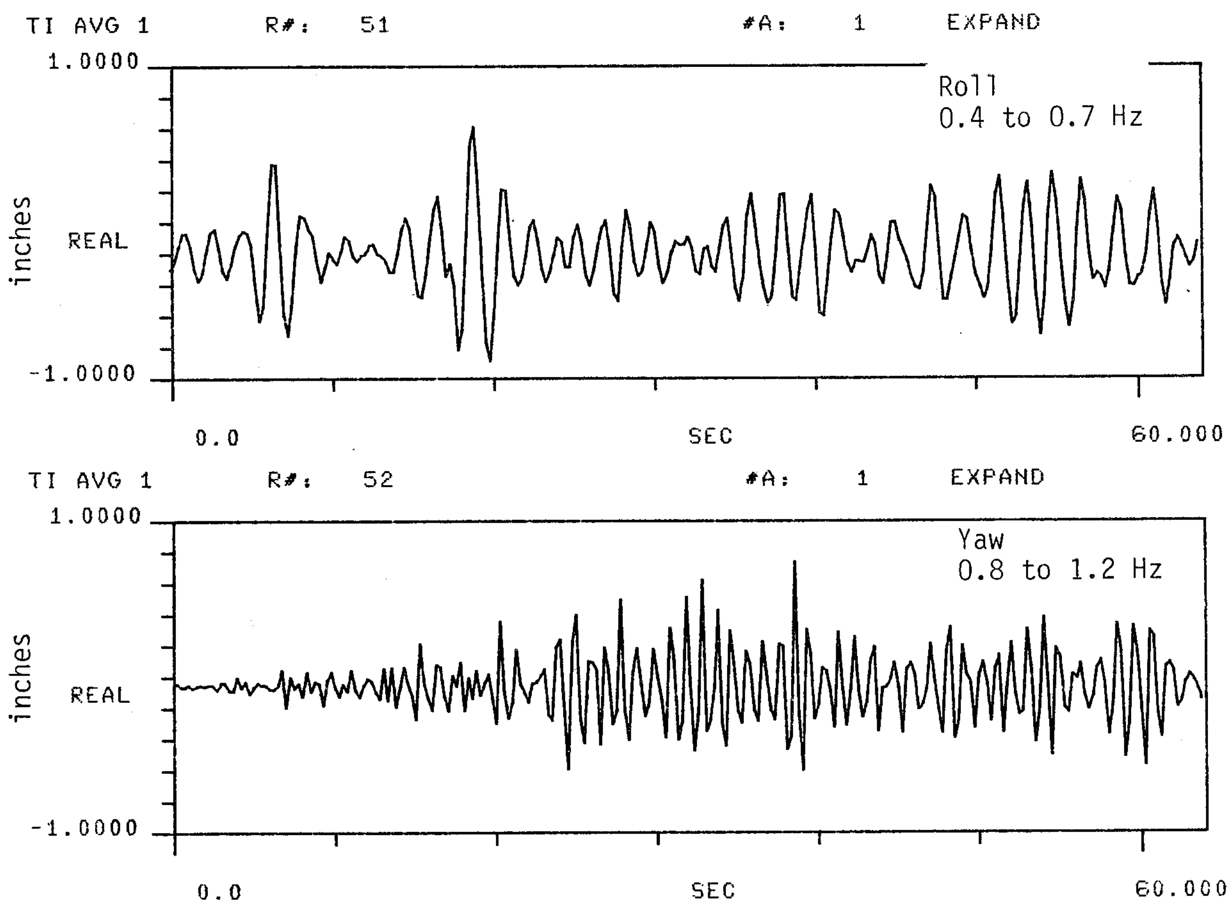


FIGURE YR3. YAW AND ROLL DISPLACEMENT.

8.0 CONCLUSIONS

8.1 ACCELERATION AND DECELERATION

- The propulsion system and dynamic brake system was fully adjustable and satisfied the specification requirements. Testing demonstrated the load weigh, default load weigh, linearity, time to speed, wheel wear, jerk rate, characteristics.

- The friction brake system satisfied the specification requirements when fitted with replacement pads, however, these affected the blending transition between dynamic and friction brakes adversely. The disc brakes were adequate to stop the vehicle the required three times in succession from 50 mph.

- The critical emergency braking rate of 4.7 mph/second, from an initial speed of 30 mph at AW3 was met with the track brakes operating and with the replacement brake pads.

8.2 SPIN/SLIDE PROTECTION SYSTEM

The wheel slip protection system adequately protected the wheels against damage throughout the speed range. The system satisfied the specification efficiency requirement.

Continuous operation in spin/slide mode where the system defaults to "friction only" could cause disc overheating.

The special spin/slide tests were not conclusive, but did indicate the need for trackside water spraying to produce steady adhesion levels.

8.3 TRAIN RESISTANCE

The test showed a smooth force characteristic, indicating no abnormal operation of equipment and good steering qualities of the truck in both directions. The characteristic obtained includes resistance caused by motor/gearbox losses.

8.4 POWER CONSUMPTION

The test showed a specific energy consumption of 7.431 kWh/mile for a vehicle at AW3, propulsion power only, and over a complete round trip profile of 12.756 miles. A series of five complete profiles gave almost exactly repeatable power consumed. The test at sea level would produce slightly higher level due to the greater aerodynamic drag at sea level. The TTC test was limited to tangent track, open air running. The power consumption test was stopped by traction motor flashover during the 6th profile.

8.5 DUTY CYCLE/ENDURANCE TESTS

1. The vehicle completed the 7 return round trip profiles without flashover or other serious problems.

2. The conditions of the test were: AW3 running, hot but very dry, with low air density caused by altitude (5,300 feet and the hot day).

3. The tests were restricted to tangent level track in the open air.

4. Traction motor exhaust temperatures were stable after the 6th return profile. Thyristor temperature was not found because of severe difficulties with the thermocouple equipment.

5. A satisfactory method needs to be found for temperature measurement of thyristors, etc.

6. Traction motor RMS current per round trip profile was approximately 300 Amps per truck.

8.6 VEHICLE VIBRATION EXCITED BY EQUIPMENT AND AUXILIARIES

The 'B' end traction motor blower produced vibration levels which were significantly above the vehicle specification and which, although not critical as far as the ISO reduced comfort criteria are concerned, were noticeable. The vibration levels appear to be a function of motor speed. Because the seats are of plastic construction, any auxiliary vibration problem is transmitted directly to a passenger without attenuation and this factor must be considered when evaluating the advantages of this type of seating. If the 'B' end traction motor vibration levels were the same as the 'A' end, the vehicle would have passed the specification.

The control electronic equipment box is located on the floor without vibration isolation. The floor vibration levels were not significant near this equipment during these tests; however, in the event of serious vibration failure of the underfloor equipment, the control equipment may be subjected to unacceptably high vibration levels.

Throughout the operation of the vehicle at the TTC no vibration of ceiling, panels, etc., was observed, although, under certain conditions, the doors rattled.

Given that the vibration of the 'B' end traction motor could be improved, the vibration environment of the vehicle was excellent. However, any deterioration of any equipment will probably be immediately felt by passengers because of the rigid nature of plastic seats.

8.7 RIDE QUALITY

The ride of the vehicle was excellent in all modes of operation. Vibration levels in the vehicle were well below the specification boundaries.

When the ride quality was compared with ISO 2631 1978, 'Guide for the Evaluation of Human Exposure to Whole-body Vibration', the ride was of excellent quality. The ISO Standard indicated that the most noticeable input of the ride to a passenger was the vehicle yaw mode, which was greatest at the ends of the vehicle, and this was confirmed subjectively.

The hard plastic seats were not significant in reducing comfort in this case because of the good quality of the ride. However, should the vehicle operate in service with deteriorated components unlike the condition of the vehicle tested, then vibrations caused by wheel flats, etc., would be transmitted directly to a seated passenger. In this case, the quality of ride could deteriorate significantly. A seated passenger may compare the ride with a soft automobile seat and this may not be favorable.

8.8 ACOUSTIC PROPERTIES

The wayside data showed that the vehicle was within the specification limit of 80 dBA at 50 mph with a level of 75 dBA.

The pass-by noise on tangent track contained no wheel squeal, indicating the trucks were running true.

With a vehicle weight of AW2, the pass by level was 80 dBA.

The vehicle produced no objectional noise in any of the power/brake modes with only a slight degree of disc squeal.

The interior noise data with the vehicle stationary showed the vehicle to be within specification of 69 dBA for any one system operating. The vehicle was also within the specification limit of 72 dBA when moving at all speeds up to 50 mph.

There were no rattles produced by any of the vehicle fixtures, except that the doors vibrated occasionally when the vehicle was operating at speed with a strong cross wind.

The interior noise was dominated by the air conditioning, which provided masking of the power system and track noise. The interior noise levels contained no objectionable squeals in any mode of operation.

8.9 SPECIAL TESTS - STATIC TRUCK CHARACTERIZATION

The truck rotational stiffness at breakaway was 1,700 ft-lbs.

8.10 SPECIAL TESTS - RIGID BODY FREQUENCIES

The rigid body frequencies were:

Pitch	1.222 Hz
Bounce	1.238 Hz
Yaw	1.042 Hz
Roll	0.5479 Hz
Upper Body Sway	Not Found

8.11 SPECIAL TESTS - FLEXIBLE BODY BENDING

The frequency of the first body bending mode vertically was 9.72 Hz.

8.12 SPECIAL TESTS - DYNAMIC ROLL

Roll motion on tangent track is not significant and is comparable in magnitude to yaw movement.

APPENDIX A

INSTRUMENTATION

INTRODUCTION

The instrumentation requirements for the NFTA Test Program were determined by the particular tests being performed. The tests performed are divided into four basic groups:

- Performance
- Vehicle Dynamics
- Noise
- Special Engineering

PERFORMANCE

The performance test objectives were met by using a combination of built-in sensors inherent to the vehicle and special purpose sensors installed on the vehicle for test purposes only.

The vehicle's inherent sensor signals were obtained from the vehicle's logic monitor board. The signal outputs were then buffered with signal conditioning to prevent loading and to allow simultaneous calibration of all channels. The monitor board had the capability of dialing numerous car signals onto the hardwired outputs.

The following sensors were installed to supplement signals obtained from vehicle's monitor board.

- Pressure Transducers - Brake cylinder pressures
  - Pressure of air-actuated relays
  - Load weigh pressures
- Servo Accelerometer - Vehicle acceleration rate
- 9th Wheel Assembly/Electronics - Speed and distance unaffected by vehicle wheel slips.
- Vehicle Wheel Tachometer - A 60 pulse per revolution tachometer, used as a cross reference speed signal.
- Voltage Divider - Input line voltage - 200: 1 divider installed across knife switch.
- Current Probes - Input line current ± 2000 amp installed on pantograph input.
- Braking Signals - Obtained from Knorr brake system or hardwired to Westinghouse logic.

- IR Source/Receiver - Used for track location information, a modulated infra-red source using reflective targets mounted on track crossties at predetermined locations.

- Thermocouples - Used in conjunction with data logger to provide temperature information. Numerous temperatures monitored: brake pad temperatures, traction motor air intake and exhaust temperatures, brake grid resistor air temperatures, etc.

The measurements, sensors, and pertinent information concerning performance tests are listed in Figures INST1 and INST2. These figures list the standard measurements and patching arrangements for the particular tests performed. Often, per special request by customer or chief test engineer, various other signals were monitored for data verification or troubleshooting of vehicle subsystems.

VEHICLE DYNAMICS - RIDE QUALITY/VIBRATION

Ride quality and vibration test objectives were met by using a combination of reference data signals (speed, time, etc.) and a series of accelerometers.

- Servo Accelerometers - Ride quality and body vibration

- Piezo-Resistive Accelerometers - Truck vibration

The measurements, sensors, and pertinent information concerning vehicle dynamics tests are listed in Figure INST3.

NOISE TESTING - ON-BOARD/WAYSIDE

The noise test objectives were achieved by use of the following equipment:

- B&K 4134 1/2" condenser microphone
- B&K 2209 sound level meter
- B&K 2306 graphic level recorder
- NAGRA SJ-IV tape recorder
- B&K 4230 sound level calibrator

Figure INST4 shows the standard equipment configuration for noise tests performed.

SPECIAL ENGINEERING TESTS

Special engineering tests performed consisted of body roll angle testing, truck characterization, and expanded deceleration/brake testing. See Measurement Listing of Figure INST5.

- Displacement Transducers
  - Roll angle testing
  - Vertical displacements from body to track brake bracket
  - Lateral displacement from carbody to sideframe

- Force Transducers - Truck Characterization - Typical instrumentation setup is shown in Figure INST6
- Dial Indicators - Suspension displacements on truck characterization
- Brake Signals - Knorr braking system

DATA ACQUISITION

The on-board data acquisition system for performance and ride quality tests consisted of signal conditioning/filtering strip chart recorders and a 28-track tape recorder. A block diagram is presented in Figure INST7. Temperature data was recorded with a 30 channel data logger. Various test equipment was used throughout the test program to monitor data.

SIGNAL CONDITIONING/FILTERING AND MONITORING ELECTRONICS

The signal conditioning/filtering system consisted of 30 channels.

Basically, the system provides six independent functions:

- Excitation - DC operating power for transducer.
- Amplification - Increasing the amplitude of the transducer signal.
- Filtering - Elimination of unwanted signals from the input signal.
- Buffering - Common-mode-rejection input-output isolation and impedence matching.
- Calibration - Means of adjusting the system gain to correspond to a specific transducer calibration.
- Balancing - Means of correcting static imbalance conditions in a bridge circuit.

The following are some of the types of static and dynamic measurement applications for which the Dynamics Signal Conditioning Systems have been used at the TTC:

- Position/Displacement (linear and angular)
- Force (weight, stress, strain, etc.)
- Pressure
- Temperature
- Acceleration
- Velocity
- Flow Rate
- Electrical (amperes, ohms, volts)

Some of the various types of transducers used with the Dynamics Signal Conditioning Systems to measure the parameters listed above include the following:

- Strain Gage Types

    Custom Strain Gage Installation (flexures, fixtures, beams, columns, etc.)

- Load Cells
- Pressure Cells
- Accelerometers (resistive type)

- Direct Current Linear Variable Differential Transformers (DC-LVDT)
- Accelerometers (piezoelectric, DC type)
- Servo Accelerometers
- Displacement Potentiometers (linear and string pots)
- Resistance Temperature Devices (thermistors, PRT's)
- Thermocouple

STRIP CHART RECORDERS

The strip chart recorders that were used to monitor test progress online consisted of three Brush model 481 8-channel recorders.

TAPE RECORDER

The analog tape recorder used was a Honeywell Model 101 portable magnetic tape recorder/reproducer with microcomputer control. The tape heads were 28 track, IRIG configuration.

The tape recorder setup for testing is listed in Table INST1.

TABLE INST1. TAPE RECORDER CONFIGURATION.

Track No.	Record/Reproduce	Data
1	Direct	IRIG-B time code
2-26	FM	Data channels
27	Direct	To servo reference the tape speed when data tape replayed back.
28	Voice	Voice

NOTE: The FM data channels had bandwidths of DC to 0.625 kHz with a center frequency of 3.375 kHz ± 40% at a tape speed of 1-7/8 in/s.

X-Y PLOTTER

A Hewlett-Packard 70048 X-Y analog plotter was onboard the cars during the performance test phase to plot acceleration/deceleration versus speed from conditioned inputs from the data acquisition system.

NINTH WHEEL SPEED AND DISTANCE PROCESSOR

The ninth wheel speed and distance processor was fabricated by Garrett-Airesearch, Inc. The unit provides excitation for an electromagnetic sensor mounted on the ninth wheel assembly under the vehicle, and in turn receives pulses from the sensor caused by a 60 tooth gear wheel (attached to the ninth wheel) rotating in its magnetic field. As the wheel rotates, the sensor produces a pulsed signal whose frequency is proportional to the rotational speed of the wheel. The processor accepts this signal and produces an analog output voltage proportional to speed, together with a staircase function distance signal. The circuitry within the processor can apply scaling factors to suit the circumference of the ninth wheel and the number of pulses per revolution from the toothed gear wheel. The staircase distance signal is comprised of a series of ten additive step functions which reset to zero output voltage after every tenth step. A scaling factor can be set in the processor to equate each step to 0.1', 1', or 10'.

ENERGY CONSUMPTION WATT-HOUR METER

Energy consumption data were acquired during the test program by means of watt-hour chassis designed and constructed at the TTC. The chassis used an analog multiplier to provide an output from scaled voltage inputs of voltage and current sensors, proportional to instantaneous power consumption. The output of the multiplier was then integrated with respect to time by an integrating voltage-frequency converter. This device produced a pulse frequency of energy, the sum of which represented total energy. Output from the frequency converter was conditioned in a divider/counter driver circuit using three scaleable counters and a monostable multivibrator. This driver circuit acted as a pulse stretcher to increase the pulse width to the 20-ms minimum required to drive a 6-digit mechanical counter, which totaled power consumption over the duration of a test run.

A functional description of the system[1] and a circuit diagram of the watt-hour meter chassis[2] are maintained by the TTC.

TEST EQUIPMENT

A Six Bucket Tektronix System was used for signal conditioning setup, signal monitoring, and signal injection to spot check calibration points. Test equipment installed on the 6 Bucket System were:

- 1 - SC502 Oscilloscope
- 2 - DM501 Digital Multimeter
- 1 - PS503 Power Supply
- 1 - FG503 Function Generator

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[1] "Functional Description of Watt-Hour Meter," Memo IE/DG/76-109, Transportation Test Center, November 23, 1976.

[2] "Drawing Number SK-RDL-4255," Transportation Test Center, January 4, 1977.

Channel Number	Parameter	Sensor Type/Source	Measurement Range
1	IRIG-B Time	Time Code Generator	
2	Vehicle Low Speed Tach Signal (ASL)	Logic Monitor Board	
3	Vehicle High Speed Tach Signal (ASH)	Logic Monitor Board	69.5 mph
4	Tractive Effort Request Weighted (TERW)	Logic Monitor Board	
5	Dynamic Brake Feedback (DBFB)	Logic Monitor Board	
6			
7			
8	Line Current (IL)	Logic Monitor Board	2,000 amps
9	FWD Truck Armature Current (I1)	Logic Monitor Board	1,000 amps
10	Rear Truck Armature Current (I2)	Logic Monitor Board	1,000 amps
11	Master Controller P-Wire Signal (AP)	Logic Monitor Board	128 ma
12	Capacitor Voltage (BLC)	Logic Monitor Board	1,000 volts
13	Power/Brake	Logic Monitor Board	1V = PWR, 2V = Brake
14	Brake Cylinder Pressure FWD Truck (BCP/F)	Pressure Transducer	100 psig
15	Brake Cylinder Pressure Rear Truck (BCP/R)	Pressure Transducer	100 psig
16	Armature Voltage (V1)*	Voltage Divider	1,000 volts
17	Armature Voltage (V2)*	Voltage Divider	1,000 volts
18	Armature Voltage (V4)*	Voltage Divider	1,000 volts
19			
20	Line Voltage	Voltage Divider	1,000 volts
21	Speed - Air Pak Tachometer	Electromagnetic	60 Pulse/Rev
22	Event	Push Button	On/Off
23	Automatic Location Detector (ALD)	IR Source	On/Off
24	Vehicle Acceleration	Servo Accelerometer	±.25g, 5.48 mphps
25	Speed - 9th Wheel Analog	Electromagnetic	100 mph
26	Distance	Divider	10 ft/step
27	Tape Speed - Servo Reference	-----	-----
28	Voice	-----	-----

*Recorded for duty cycle only.

FIGURE INST1. INSTRUMENTATION LIST FOR PERFORMANCE MEASUREMENTS.

Channel Number	Parameter	Sensor Type/Source	Measurement Range
1	IRIG-B Time	Time Code Generator	
2	Speed - Axle No. 1	Knorr Brake System	100 kph
3	Speed - Axle No. 2	Knorr Brake System	100 kph
4	Speed - Axle No. 3	Knorr Brake System	100 kph
5	Speed - Axle No. 4	Knorr Brake System	100 kph
6	Brake Signal	Logic Monitor Board	On/Off
7			
8	Line Current (IL)	Logic Monitor Board	2,000 amps
9	FWD Truck Armature Current (I1)	Logic Monitor Board	1,000 amps
10	Rear Truck Armature Current (I2)	Logic Monitor Board	1,000 amps
11	Master Controller P-Wire Signal (AP)	Logic Monitor Board	128 ma
12	Dynamic Brake Feedback (DBFB)	Logic Monitor Board	On/Off, 6,275 lbs
13	Propulsion Inhibit	Logic Monitor Board	On/Off
14	Brake Cylinder Pressure FWD Truck (BCP/F)	Pressure Transducer	100 psig
15	Brake Cylinder Pressure Rear Truck (BCP/R)	Pressure Transducer	100 psig
16	9th Wheel Pulses Divided by 3	Electomagnetic	60 Pulse/Rev
17			
18			
19			
20	Line Voltage	Divider	1,000 volts
21	Speed - Air Pak Tachometer	Electromagnetic	60 Pulse/Rev
22	Event	Push Button	On/Off
23	Automatic Location Detector	IR Source	On/Off
24	Vehicle Acceleration	Servo Accelerometer	± .25g, 5.48 mphps
25	Speed - 9th Wheel Analog	Electromagnetic	100 mph
26	Distance	Divider	10 ft/step
27	Tape Speed - Servo Reference	-----	-----
28	Voice	-----	-----

FIGURE INST2. INSTRUMENTATION LIST FOR SPIN/SLIDE MEASUREMENTS.

Channel Number	Parameter	Sensor Type/Source	Measurement Range
1	IRIG-B Time	Time Code Generator	
2	Body Vertical Acceleration B-End Centerline	Servo Accelerometer	± 1g
3	Body Lateral Acceleration B-End Centerline	Servo Accelerometer	± 1g
4	Body Vertical Acceleration Mid Car Centerline	Servo Accelerometer	± 1g
5	Body Lateral Acceleration Mid Car Centerline	Servo Accelerometer	± 1g
6	Body Vertical Acceleration Mid Car Left	Servo Accelerometer	± 1g
7	Body Vertical Acceleration A-End Centerline	Servo Accelerometer	± 1g
8	Line Current (IL)	Logic Monitor Board	2,000 amps
9	FWD Truck Armature Current (I1)	Logic Monitor Board	1,000 amps
10	Rear Truck Armature Current (I2)	Logic Monitor Board	1,000 amps
11	Master Controller P-Wire Signal (AP)	Logic Monitor Board	128 ma
12	Body Lateral Acceleration A-End Centerline	Servo Accelerometer	± 1g
13	Vehicle Low Speed Tach Signal (ASL)	Logic Monitor Board	____ mph
14	Brake Cylinder Pressure FWD Truck (BCP/F)	Pressure Transducer	100 psig
15	Brake Cylinder Pressure Rear Truck (BCP/R)	Pressure Transducer	100 psig
16			
17			
18	Truck Vertical Acceleration A-End Bolster	Piezo-Resistive Accelerometer	± 5g
19	Truck Vertical Acceleration A-End Journal	Piezo-Resistive Accelerometer	± 5g
20	Line Voltage	Voltage Divider	1,000 volts
21	Speed - Air Pak Tachometer	Electromagnetic	60 Pulse/Rev
22	Event	Push Button	On/Off
23	Automatic Location Detector	IR Source	On/Off
24	Vehicle Acceleration	Servo Accelerometer	± .25g
25	Speed - 9th Wheel Analog	Electromagnetic	100 mph
26	Distance	Divider	10 ft/step
27	Tape Speed - Servo Reference	-----	-----
28	Voice	-----	-----

FIGURE INST3. INSTRUMENTATION LIST FOR RIDE QUALITY AND VIBRATION MEASUREMENTS.

Channel Number	Parameter	Sensor Type/Source	Measurement Range
1	IRIG-B Time	Time Code Generator	
2	Body Vertical Acceleration B-End Centerline	Servo Accelerometer	± 1g
3	Body Lateral Acceleration B-End Centerline	Servo Accelerometer	± 1g
4	Body Vertical Acceleration Mid Car Centerline	Servo Accelerometer	± 1g
5	Body Lateral Acceleration Mid Car Centerline	Servo Accelerometer	± 1g
6	Body Lateral Accel. Mid Car Centerline Roof	Servo Accelerometer	± 1g
7	Body Vert. Accel. A-End Motorman Cab Centerline	Servo Accelerometer	± 1g
8	Body to Truck Displacement Vertical Left	Pontentiometer	± 1.5 inches
9	FWD Truck Armature Current (I1)	Logic Monitor Board	1,000 amps
10	Rear Truck Armature Current (I2)	Logic Monitor Board	1,000 amps
11	Master Controller P-Wire Signal (AP)	Logic Monitor Board	128 ma
12	Body Lat. Accel. A-End Motorman Cab Centerline	Servo Accelerometer	± 1g
13	Vehicle Low Speed Tach Signal	Logic Monitor Board	13.9 mph
14	Brake Cylinder Pressure FWD Truck (BCP/F)	Pressure Transducer	100 psig
15	Brake Cylinder Pressure Rear Truck (BCP/R)	Pressure Transducer	100 psig
16	Vehicle High Speed Tach Signal	Logic Monitor Board	69.5 mph
17			
18	Body to Sideframe Displacement Lateral Left	Potentiometer	± 1.5 inches
19	Body to Track Displacement Vertical Right	Potentiometer	± 1.5 inches
20	Line Voltage	Voltage Divider	1,000 volts
21	Speed - Air Pak Tachometer	Electromagnetic	60 Pulse/Rev
22	Event	Push Button	On/Off
23	Automatic Location Detector	IR Source	On/Off
24	Vehicle Acceleration	Servo Accelerometer	± .25g, 5.48 mphps
25	Speed - 9th Wheel Analog	Electromagnetic	100 mph
26	Distance	Divider	10 ft/step
27	Tape Speed - Servo Reference	-----	-----
28	Voice	-----	-----

FIGURE INST4. INSTRUMENTATION LIST FOR ROLL ANGLE MEASUREMENTS.

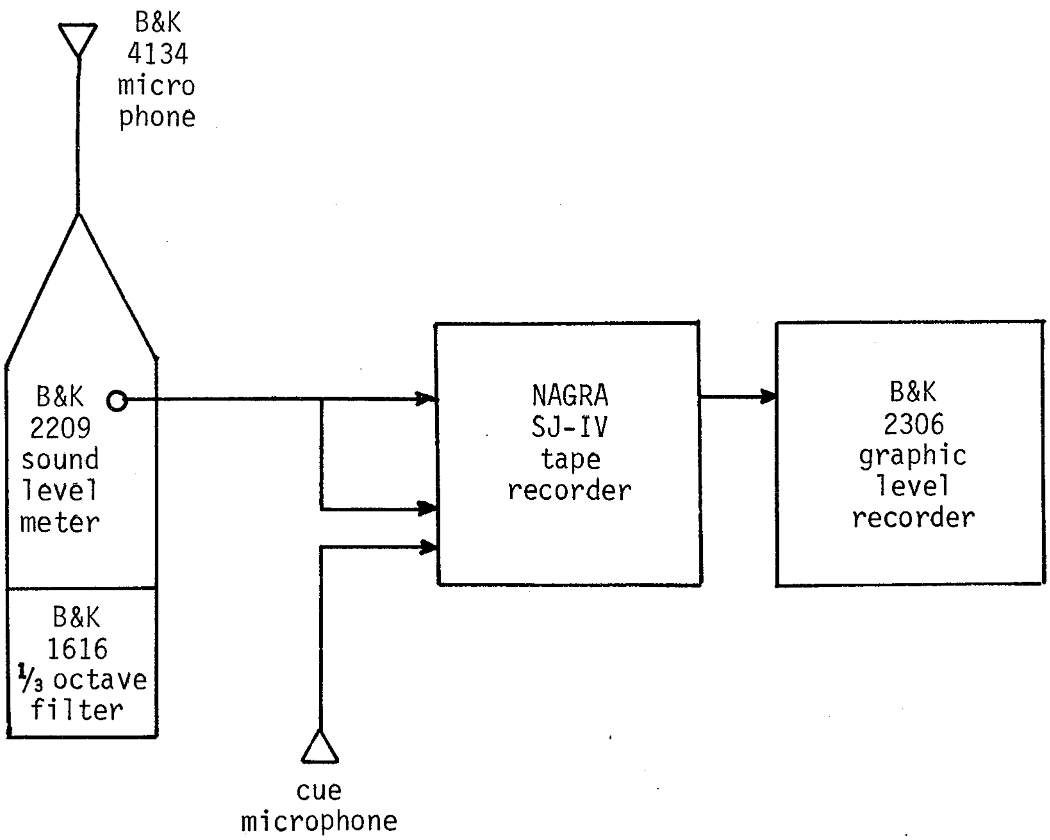

FIGURE INST5. TYPICAL NOISE MEASUREMENT SETUP.

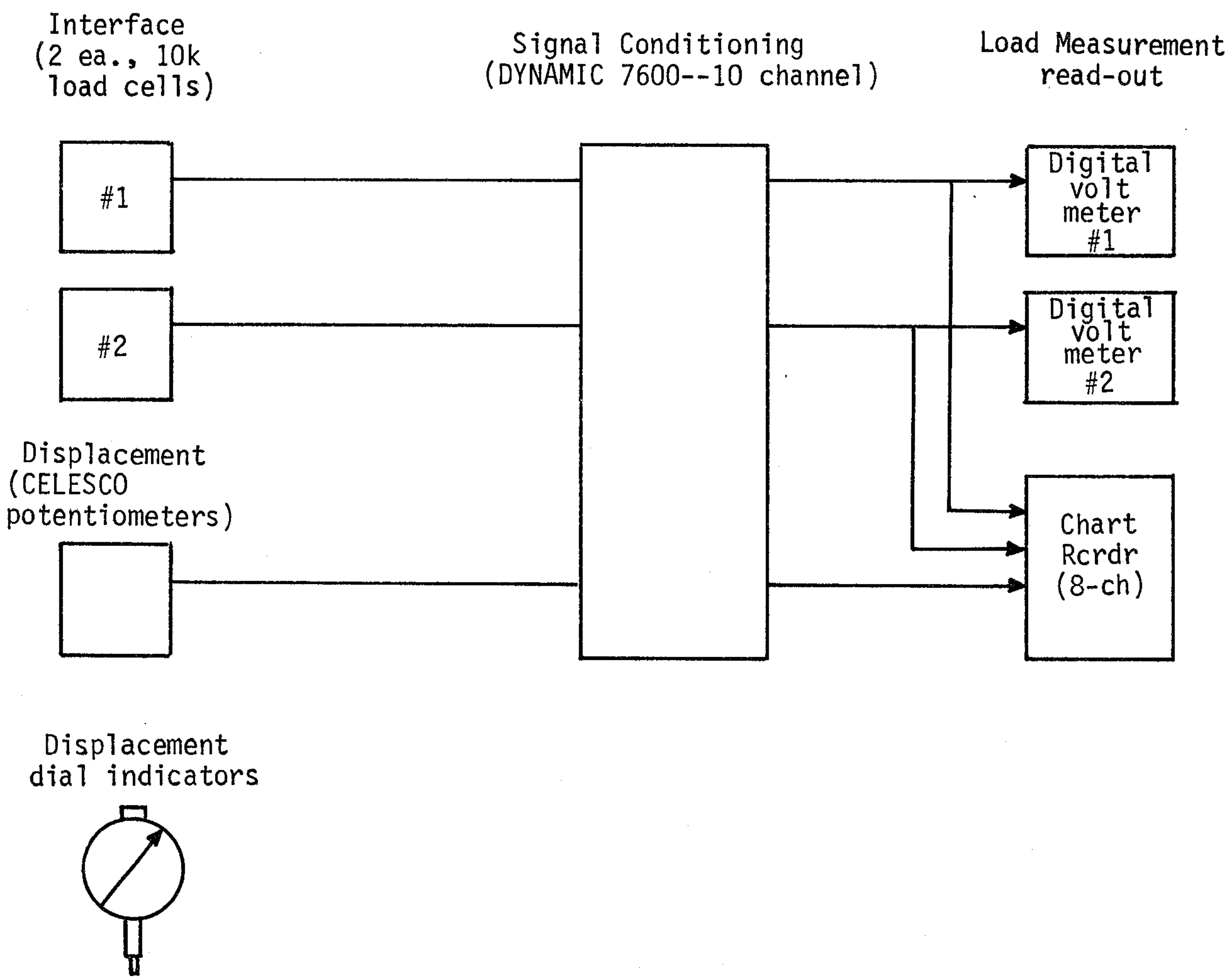

FIGURE INST6. TYPICAL TRUCK CHARACTERIZATION INSTRUMENTATION SETUP.

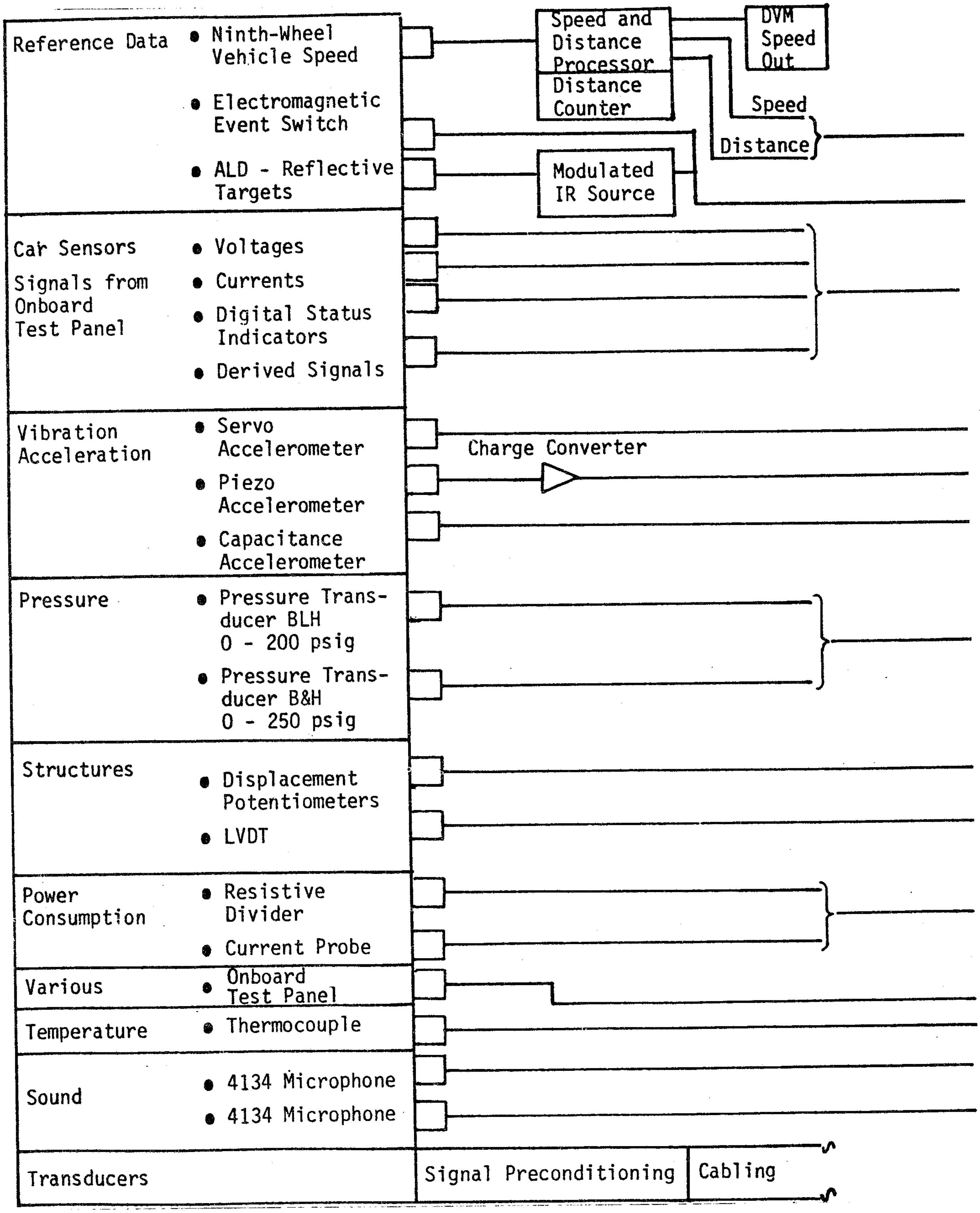

FIGURE INST7(a). BLOCK DIAGRAM, DATA ACQUISITION SYSTEM.

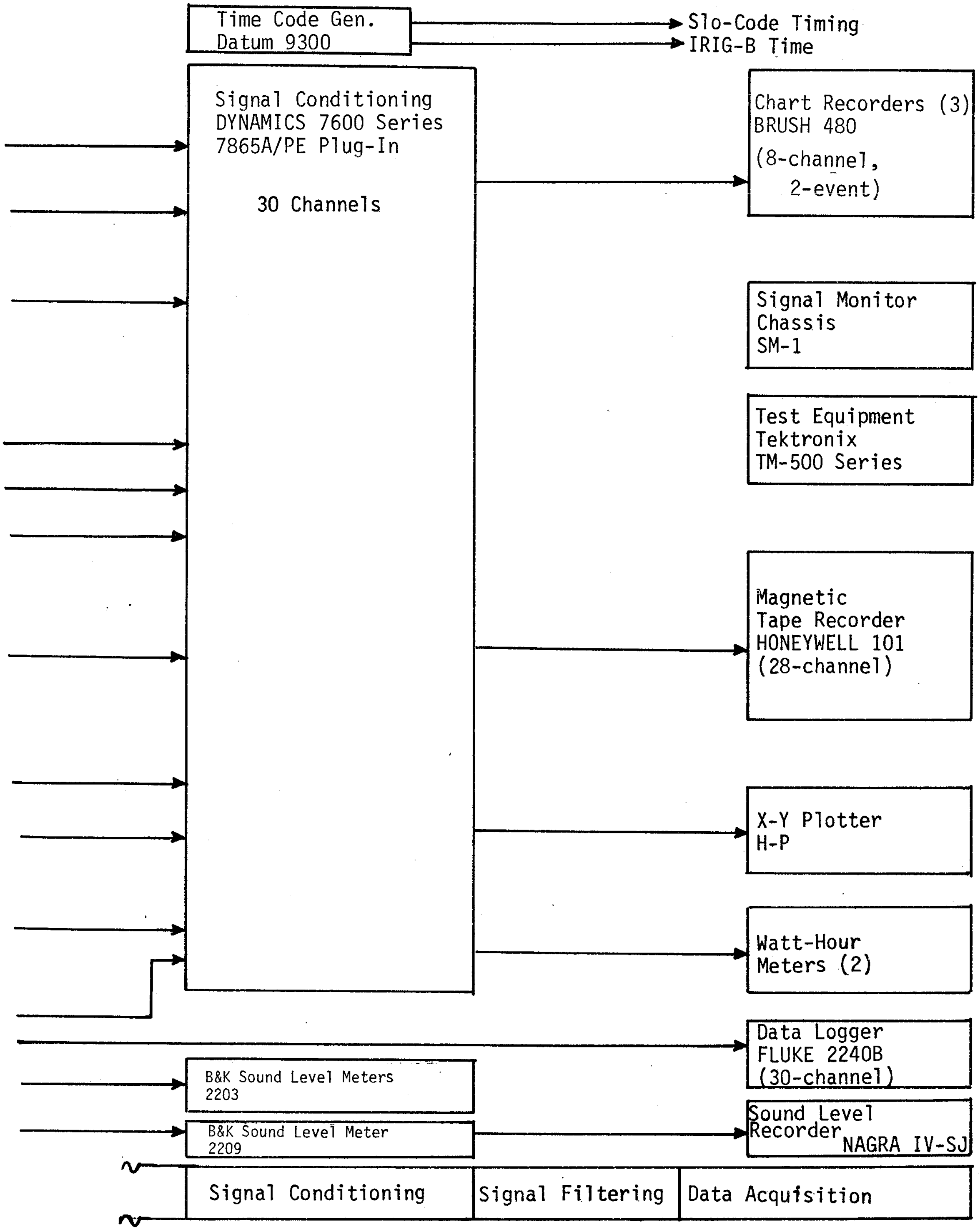

FIGURE INST7(b). BLOCK DIAGRAM, DATA ACQUISITION SYSTEM.