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AIRTRANS URBAN TECHNOLOGY PROGRAM

PHASE I

VOUGHT CORPORATION
P.O. BOX 5907
DALLAS, TEXAS 75222

JANUARY 1978

FINAL REPORT

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in cooperation with

DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSIT ADMINISTRATION
AGT APPLICATIONS
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15. Supplementary Notes Phase II, initiated early in 1978, will include the construction and demonstration of a prototype urban vehicle, and the determination of the operational capability of major subsystems under severe cold and icing conditions. The activities to be performed under Phase II of this program will be in a future report.

16. Abstract
AIRTRANS is an Automated Guideway Transit (AGT) System which provides inter-terminal transit service for passengers at the Dallas/Ft. Worth Airport. The successful deployment of this system has prompted the investigation of the extension of AGT technology into the urban environment to relieve the congestion and pollution caused by increasing auto and bus transit. Phase I of the AIRTRANS Urban Technology Program (AUTP) covers the activities of the Vought Corporation, which tested the system for operation in an urban application. Independent assessments were made to determine what changes would be required, which were: 1) higher operating speeds; 2) better passenger acceptance; 3) reduced capital and operating costs; 4) increased reliability; 5) better all-weather capability; and 6) increased energy efficiency. The AUTP was structured into a two-phase program. Phase I was completed in 1977, and includes the development and demonstration of the subsystem improvements necessary for higher speed operations, while maintaining or improving reliability, availability, cost, and performance characteristics of the overall AIRTRANS system. This consisted of baseline tests with the test vehicle at speeds of 17 and 30 mph using the existing AIRTRANS propulsion, collector, steering, and control and communications systems. After a thorough analysis of the data from these tests, design changes were incorporated and new components were acquired or fabricated. This equipment was installed on the vehicle and guideway testing was again conducted. The overall conclusion reached in Phase I is that the existing AIRTRANS AGT system can be improved to make it a viable transit system for urban deployments. The basic design, with improvements expected from AUTP Phase II will provide for the successful deployment of urban AIRTRANS systems.

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ERRATA

Cover - "URBAN MASS TRANSIT ADMINISTRATION" should be "URBAN MASS TRANSPORTATION ADMINISTRATION"

Technical Report Documentation Page, Item 9 - "Vought Corporation Systems Division" should be "Vought Corporation"

Page vii, Figure 3 - "Guide" should be "Guideway"
Figure 2-31 - "A" should be "a"

Page viii, Figure 3-7 - "Test Collector Assembly" should be "AIRTRANS Collector Assembly"

Figure 3-22 - "AUT" should be "AUTP"

Page ix, Figure 4-3 - "Auto" should be "AUTP"
Figure 4-12 - "150°" should be "150'"

Page 6, Figure 3 - "GUIDE" should be "GUIDEWAY"

Page 10, Figure 6 - Delete photo and replace with new Figure 6 (Attached) - Replacec

Page 2-3, Figure 2-1, Change table data as follows:

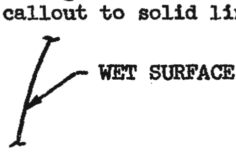
14200	15350	15850
21000	23170	24180
24400	27080	28260

Should be:

15795	16270	16770
22595	24090	25610
25995	28000	29860

Page 2-7, Paragraph 2.3.5, Second sentence after the comma should read ". . ., that is, the equipment's equivalent thermal rating."

Page 2-10 - Figure 2-5, Change abscissa headings to read "-10, -5, 0, 5, 10" and add leader and callout to solid line to right of 0 as follows:



Page 2-21, Table 2-2, Drive Train - "RAtio" should be "Ratio"
Performance Requirements: - "Duty Cycle: St. Paul DPU. . ." should be "Duty Cycle": St. Paul DPM. . ."

Page 2-34, Figure 2-20 - Delete "GRADE EQUIVALENT OF 2.63 MPH/SEC ACCEL. RATE (REF)"

Page 2-36, Paragraph 2.5.4, First line - "ramdom" should be "random"

Page 2-37, Paragraph 2.6.1, Line 18 - "interface" should be "interfaces"

Page 2-41, Figure 2-25, Label second strip "ARMATURE CURRENT (AMPS)". Delete first strip. Delete "(AMPS)" on third strip.

Page 3-2, Paragraph 3.1 - Sixth line from bottom of page - ". . . are theoretical in contact. . . " should read ". . . are in theoretical contact. . ."

Page 3-3, Figure 3-2 - Delete "CONSTRAINTS IMPOSED UPON THE COLLECTOR DESIGN BY VEHICLE SWITCHING". "CONDUCTORS SYSTEM" should be "CONDUCTOR SYSTEM".

Page 3-5, Paragraph 3.2, Fourth line - ". . . operated to 45 MPH operation in . . ." should read ". . . operated to 45 MPH in . . ."

Page 3-9, Figure 3-7 - Delete photo and replace with new Figure 3-7 (Attached) - Replaced

Figure 3-8 - Delete figure and replace with new Figure 3-8 (Attached) - Replaced

Page 3-10, Paragraph 3.3.4 - Delete last five lines starting with "The location. . .

Page 3-11, Figure 3-9 - Callout "AUTP SIGNAL COLLECTOR" should be "AUTP GROUND COLLECTOR" - Corrected

Figure 3-10, Delete and replace with new Figure 3-10 (Attached) - Replaced

Page 3-12 - Delete all but the last 3 lines, and replace with the following: "Design analysis has shown that the shoe pivot point location has a marked influence on the stable operation of the shoe. The AIRTRANS pivot point location above the contacting interface plane may allow the shoe to become unstable when the force on the trailing edge of the shoe becomes zero. This condition is expected to be amplified at the higher urban speed requirements causing shoe chattering and possible "self-destruction" of the shoe and damage to the conductor surface. The AIRTRANS shoe pivot arrangement and loading is shown in Figure 3-10(a). Theoretically, the pivot point location should be at the shoe/conductor interface to eliminate the friction induced moment tending to load the leading edge causing "toe stubbing" of the shoe. Using this concept, the location of the pivot point for AUTP collector was designed to be slightly below the conductor contact surface so that friction forces would tend to produce a moment to unload the shoe leading edge to prevent "toe-stubbing" and allow the shoe to "ski" over rough conductor surface areas. This arrangement of loading is shown in Figure 3-10(b)".

Page 3-18, Figure 3-14 - Add "μF" after capacitance value of ".1". Add "Ω" after resistance value of "300".

Page 3-22, Figure 3-18 - Add "AUTP" above "COLLECTOR" at top of data plot. Add "AIRTRANS" above "POWER/GROUND COLLECTOR" in middle of plot.

Page 3-28, Paragraph 3.4.1.6, Line 11 - "Lofting (shoe lift-off) of AUTP. . ." should read "Lofting (shoe lift-off) of the AUTP. . ."

Page 3-29, Figure 3-22 - in title - "AUT" should be "AUTP"

Page 3-34, Paragraph 3.4.2.3, Line 2 - ". . . - feet" should be ". . . - foot . ."

Page 3-44, Paragraph 3.5, Fourteen lines from bottom of page - ". . . were fabricated and installed on AIRTRANS" should read ". . . were fabricated and installed on an AIRTRANS. . ."

Page 3-45, Paragraph 3.5, First line ". . . depending on location." should read ". . . depending on collector location."

Page 4-5, Paragraph 4.3.2, Second Line - ". . . with the followup changes. . ." should be ". . . with the following changes. . . "

Page 4-7, Figure 4-3 - "RUBBER STRING. . ." should be "RUBBER SPRING". . ." in two places. In title, "AUTO" should be "AUTP"

Page 4-8, Paragraph 4.3.3 - Fourth line - ". . . commerical. . ." should be ". . . commercial. . ."
Line 15 - +0.055" should be "$\pm$0.055"

Page 4-11, Paragraph 4.3.4, 10 lines from the bottom of page: ". . . used as caging. . ." should be ". . . used as a caging. . ."

Page 4-17, Paragraph 4.4.1.2 (1) Delete last two sentences beginning with "In the first test. . ." and replace it with "In the first test, the ride was slightly better than the basic AIRTRANS in straight guideway but resulted in sharp inputs at switches. In the second test, the ride was very similar but slightly degraded in comparison with the basic AIRTRANS".

Paragraph 4.4.2.1, Line 3 - ". . . or consequence. . ." should be ". . .of consequence. . ."

Page 4-18, Paragraph 4.4.2.4, Line 4 - ". . . allows. . ." should be ". . . allowed. . ."

Page 4-20, Table 4-1, First line - "Moment[1]" should be "Moment X[1]"

Page 4-21, Figure 4.9, "GUIDEBAR (M_y, M_y, F_y)" should be "GUIDEBAR (M_x, M_z, F_y)"

Page 4-23, Paragraph 4.4.1, Line 7 - Delete "numbered"

Page 4-25, Table 4-2, Title "BASELINE RUN DEFINITION ATC - AUTOMATIC TRAIN CONTROL 17 MPH MAXIMUM SPEED" should be "BASELINE RUN DEFINITION - ATC (AUTOMATIC TRAIN CONTROL) 17 MPH MAXIMUM SPEED"

Page 4-26, Table 4-3, Replace existing Table 4-3 with Table 4-3. (Attached)-Replaced

Page 4-27, Paragraph 4.4.1.1, Line 12 - ". . . going around 150'R. . ." should be ". . . going around a 150'R. . ."
Paragraph 4.4.1.2(1), last word ". . . steps." should be ". . . stops."

Page 4-28, Figure 4-12, Top of Sketch - Delete "SIN^{-1}85, 150(12), -2.7^{o}, 150'R" and replace with "2.7^{o} for 150'R"

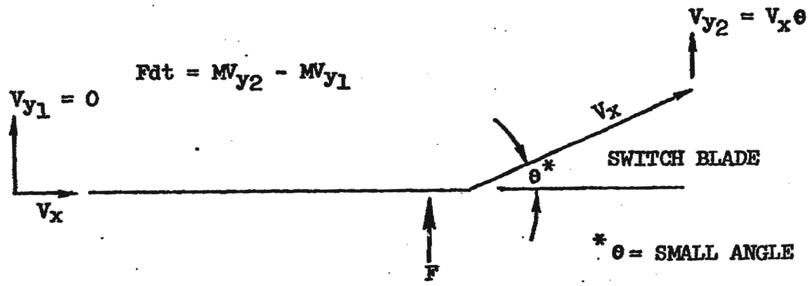
Page 4-30, Paragraph 4.4.1.2, First line - ". . .floating rear guidebar is inadequate." should be ". . . floating rear guidebar, is inadequate."

Paragraph 4.4.1.3, Line 11 ". . .relevation." should be ". . . elevation."

In Table by Run Number 102, "23" should be "19"

Page 4-32, Paragraph 4.4.1.3, Lines 1, 4, 14 and 19 - "#" should be "lbs."

Page 4-34, Revise sketch at top of page as shown:



Page 4-35, Figure 4-18 - "RIDE INDEX (GRM:" should be "RIDE INDEX (GRMS)"

Page 4-42, Paragraph 4.4.2, Line 8 ". . . microvolt relation, the . . ." should be ". . . microvolt relation. The. . ."

Page 4-43, Table 4-4, last line "(See Figure)" should be "(See Figure 4-10)"

Page 4-46, Table 4-6, Last line ".(39" should be ".0239"

Page 4-47, Table at top of page, move "MPH" under "SPEED"

Add a vertical line to divide 5SB-DIV and 4EBU-DIV and "RUN #" should be "RUN NO."

Paragraph 4.4.2.2, Line 8 - Delete ". . . as shown by examining the switch loads. . ." Add parenthesis around the last sentence "(Both . . . relation

Last line - "200 #/degree" should be "200 lb/degree"

Page 4-48, Paragraph 4.4.2.3, Line 8 ". . . the R/H" should be ". . . the R/H (outside) wall.

Lines 16 and 17 "This curve the number of times a certain load occurs in this 150' right turn. . ." should be "This curve shows the number of times a certain load occurs in this 150'R right turn. . ."

Page 4-49, Figure 4-26 - "RUN 263" should be "RUN 203"

Page 4-50, Figure 4-27, Delete "AUTP VEHICLE BASELINE TESTS" - two places.

Page 4-51, Paragraph 4.4.2.4, Line 4 - ". . . of 3076 16/in" should be "3140 lb/in."

Page 4-56, Paragraph 4.4.3.2, Line 2 ". . . based. . ." should be ". . . basis . . ."; Line 9 ". . curve. . ." should be ". . . curves. . ."; Line 11 ". . . enters. . ." should be ". . . passes through. . ."

Page 4-62, Paragraph 4.4.4, Line 17 - ". . . opeating. . ." should be ". . . operating. . ."

Paragraph 4.4.4.1, Line 13, ". . . was. . ." should be ". . . were . . ."

Page 4-66, Figure 4-39, "INPUT AMPLITUDE +.25 IN. PP" should be "INPUT AMPLITUDE +.25 IN."

Page 4-68, Figure 4-40, "MEASURES AT LVDT GAP -.75 IN." should be "MEASURED AT LVDT GAP -.75 IN."

Page 4-73, Replace Figure 4-43 with new Figure 4-43 (Attached) - Replaced

Page 4-76, Paragraph 4.4.5.3 - Delete last sentence, "The improved. . . guidelines (Reference 11)." and replace with "The improved mechanical system accelerations met the UMTA ride quality guidelines (Reference 11) for 1/3 octave band analysis but reveal some exceedances of the stringent peak acceleratior criteria when operating at normal AIRTRANS conditions."

Page 4-78, Paragraph 4.5.2 (3) ". . .3140. . ." should be ". . . .1670. . ."

Page 5-9, Paragraph 4.2 (1), Line 4 - ". . . Passenger vehicle to. . ." should be ". . .Passenger vehicle. To . . ."

Page 5-16, Table 5-2, Third line - ". . . @ 1.1284. . ." should be " . . @ 0.1284. . ."

Page 5-18, Figure 5-6, In box "SELECT LESSOR CARD" change to "SELECT LESSOR CMD" In box "INCR OR DECR CUR OR BRKS. TO DRIVE VE TOWARD $\frac{V^2}{5}$" should be "INCR OR DECR CUR OR BRKS TO DRIVE VE AND DV/DT TO ZERO PER CONTROL LAW DVSQ"

Page 5-28, Figure 5-12 - "YWC" should be "VWC"

Page 5-29, Table 5-4, In block WVC - Delete initial "Will be. ."; in fourth line, ". . . Filter Q's will be 50. . ." should be ". . . Filter Q's of 50 . . ."; In VWC block, delete initial "Will be. . .", in fifth line ". . . Filter Q's will be 50. . ." should be ". . . Filter Q's of 50. . ."

Page A-9, Line 17 - ". . . presented in Table A-1." should be ". . . presented in Table 2-1."

Page C-3, Figure C-2, Add leaders to "RELIEF VALVE (4)" and "ACTUATOR (2)" as in Figure C-1.

Page C-5, Figure C-3 - Replace with new Figure C-3. (Attached) - Replaced

Page R-1, Reference 10 - Fourth line ". . . Theses, . . ." should be ". . . Thesis. . ."

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PREFACE

This report covers the activities of the Vought Corporation, an LTV Company, during Phase I of the AIRTRANS Urban Technology Program (AUTP). AUTP was authorized by Congress in the Federal-Aid Highway Act of 1976 (P.L. 94-280) and funding for Phase I was included in the Department of Transportation Appropriations Act for 1977 (P.L. 94-387). Program funding was by an Urban Mass Transportation Administration (UMTA) grant to the Dallas/Fort Worth Airport Board and third party contract to Vought. Subsequently, funding was provided for Phase II of AUTP by the Department of Transportation and related agencies Appropriations Act (P.L. 95-85). The results of Phase II will be documented separately.

As with all programs of this magnitude, the cooperation of a large number of people contributed to its success. Among these are Dennis Elliott, Dalton Leftwich and the entire operations and maintenance staff of the Dallas/Fort Worth Airport, Steve Barsony and John Marino of UMTA, Ron Kangas, Transportation Systems Center, and Andy Wetzel of the Mitre Corporation.

In addition to the authors of this report, final review and editing was performed by Dave Benjamin, Austin Corbin, Chuck Canton, Ken Fewel, Fred Goodnight, Bill Hallmark, Dave Randolph, Roland Raven and Alex Songayllo of the Vought Corporation.

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LIST OF TABLES

LIST OF TABLES (Continued)

SUMMARY

This report covers the activities of the Vought Corporation, an LTV Company, during Phase I of the AIRTRANS Urban Technology Program (AUTP). These activities included analysis, design, manufacture and testing of improvements to the AIRTRANS Automated Guideway Transit (AGT) System to extend this technology to urban AGT applications.

PROGRAM DESCRIPTION

An automated guideway transit (AGT) system called AIRTRANS has provided interterminal transit service for passengers at the Dallas/Fort Worth Airport for the past four (4) years. This successful deployment of AGT technology prompted the United States Congress, The Department of Transportation (DOT) and the Vought Corporation to investigate the extension of this technology into the urban environment, to relieve the congestion and pollution caused by the ever-increasing auto and bus traffic. Independent assessments were made by the Transportation Systems Center of DOT, Reference (1), and by the Vought Corporation, to determine what changes or improvements would be required to operate AIRTRANS in an urban application. The recommendations were:

(1) Higher operating speeds,

(2) Better passenger acceptance,

(3) Reduced capital and operating costs,

(4) Increased reliability,

(5) Better all-weather capability, and

(6) Increased energy efficiency.

The successful achievement of these improvements would provide an urban AGT system which could intercept much of the auto and bus traffic at the outskirts of high density urban centers. This would allow a commuter to park his car (or leave his bus) and ride the AGT system to his final destination in comfort and safety. Subsequent movement within the urban center would also be possible using the AGT system; thus, the need for auto and bus traffic in the downtown area could be reduced to a minimum.

The AUTP program was structured into a two-phase program. Phase I of the AUTP program was completed in 1977. Briefly, the first phase covered the development and demonstration of the subsystem improvements necessary for higher speed operations, while maintaining or improving reliability, availability, cost and performance characteristics of the overall AIRTRANS system. A highly instrumented engineering test vehicle was used to demonstrate baseline and improved performance of the system. Phase II,

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initiated in early 1978 will include the construction and demonstration of a prototype urban vehicle, and the determination of the operational capability of major subsystems under severe cold and icing conditions.

PHASE I - OVERVIEW

The development of AIRTRANS system derivatives, for use in other AGT applications, began before the initial AIRTRANS system was put into revenue service at the Dallas/Fort Worth Airport. It was apparent at the outset that higher operating speeds would be required. The subsystems most affected by such a change were:

(1) Propulsion,

(2) Collector,

(3) Steering, and

(4) Control and Communications.

The establishment of a target for a higher operating speed was accomplished by comparing what speed could reasonably be obtained, versus what speed would be required in near-term AGT applications. This led to the selection of 45 MPH as a goal. Testing to 45 MPH of the collectors could be achieved by use of Vought's rotating drum facility; however, all other testing would be limited to 30 MPH because of the civil constraints imposed by the Dallas/Fort Worth guideway.

The Phase I AUTP Program activities involved:

(1) Testing and collection of data on the existing AIRTRANS subsystem designs,

(2) Testing and collection of data on the existing AIRTRANS,

(3) Analyses, design and development of subsystem changes and improvements,

(4) Manufacturing and installation of these changes and improvements on a test vehicle, and

(5) Demonstration of these changes and improvements through guideway testing at the Dallas/Fort Worth Airport.

The program started with the preparation of design definitions for the improvements to be incorporated and tested. Concurrently, the Dallas/Fort Worth Airport Board provided AIRTRANS Utility Vehicle U-365 for use as a general purpose test vehicle. This vehicle, shown in Figure 1, was transported to the Vought plant where it was modified for test operations. The initial modifications included removing the cargo handling equipment, and

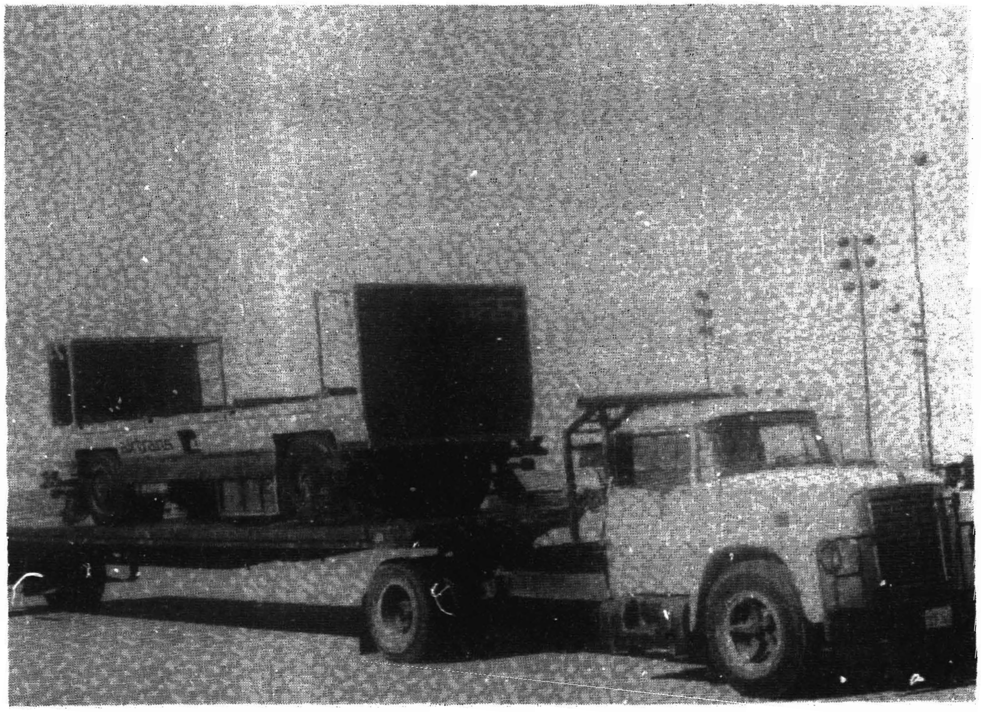

FIGURE 1 CARGO VEHICLE U-365 IN TRANSIT TO VOUGHT FOR CONVERSION

installing an aluminum body to house the test equipment and personnel. Recording equipment, sensors and instrumentation were installed in the vehicle to measure forces, accelerations, displacements, temperatures, speeds, voltages, etc. from various parts of the vehicle. These included the steering wheels, switching wheels, guidebar, brushes, steering links, chassis, motor, kingpins, etc. Some of the special equipment which was installed in the test vehicle is shown in Figure 2. This equipment recorded 51 channels of data. All subsystems on the cargo vehicle were identical to those used on the passenger vehicles and, therefore, were left unchanged.

The completed test vehicle, designated T-365 (T for Test), was returned to the guideway at the Airport, Figure 3, to take baseline data on the behavior of the standard AIRTRANS propulsion, collectors, steering and control subsystems. Testing was accomplished between the hours of midnight and 4 AM in order to prevent interference with the operating fleet. A test route, shown in Figure 4, was established on the AIRTRANS guideway, and baseline data were taken with the vehicle operating at 17 MPH. After the baseline testing was completed, propulsion gearing modifications were made to allow a 30 MPH speed capability, and high speed tests were conducted. Modifications to demonstrate the improved control and communications equipment were also incorporated and tested. The test vehicle was then returned to the Vought plant for incorporation of the improved propulsion and steering subsystems. After this work was completed, the test vehicle was returned to the Airport for demonstration of these improvements.

SUBSYSTEMS IMPROVEMENT PROGRAM

Phase I AUTP improvements included the development of a dual propulsion subsystem, an improved collector subsystem, three new steering subsystems and improved control and communications subsystem designs. These are briefly discussed in the following paragraphs.

PROPULSION SUBSYSTEM IMPROVEMENT - The AIRTRANS propulsion subsystem provides tractive effort in response to commands from the vehicle automatic control system. It has a 17 MPH maximum speed capability with an average station spacing of about 2300 feet. Urban requirements by comparison will require higher speeds and station spacings as close as 1000 feet. These requirements combine to make the AIRTRANS propulsion subsystem inadequate for most urban applications. To meet the urban requirements, a "worst case" system scenario was developed and analyzed. The improvements and changes required for the AIRTRANS propulsion subsystem to operate successfully in the urban environment were determined to be:

(1) Increased tractive effort to meet the higher vehicle speed requirements,

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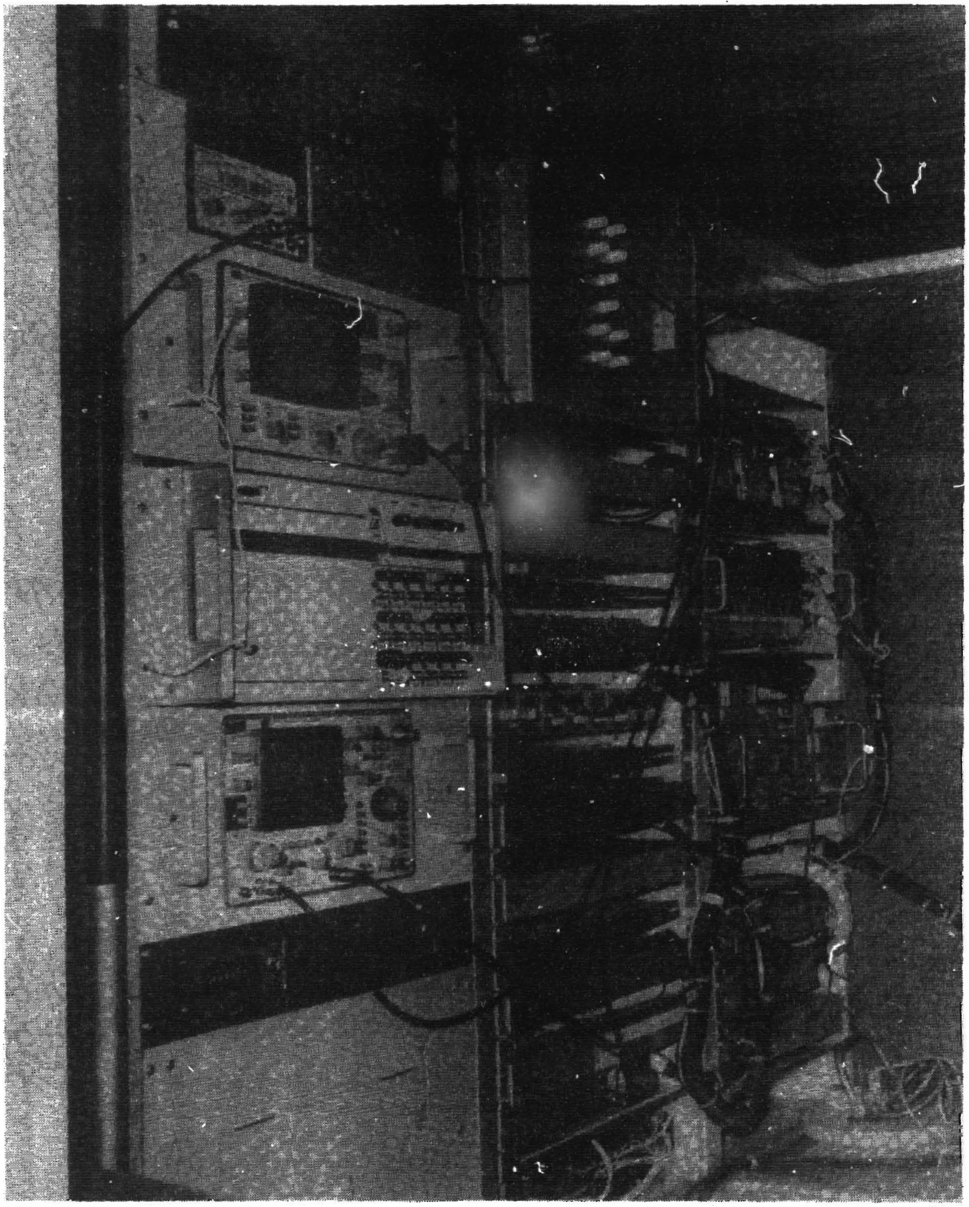

FIGURE 2   TEST EQUIPMENT INSTALLATION IN AUTP TEST VEHICLE

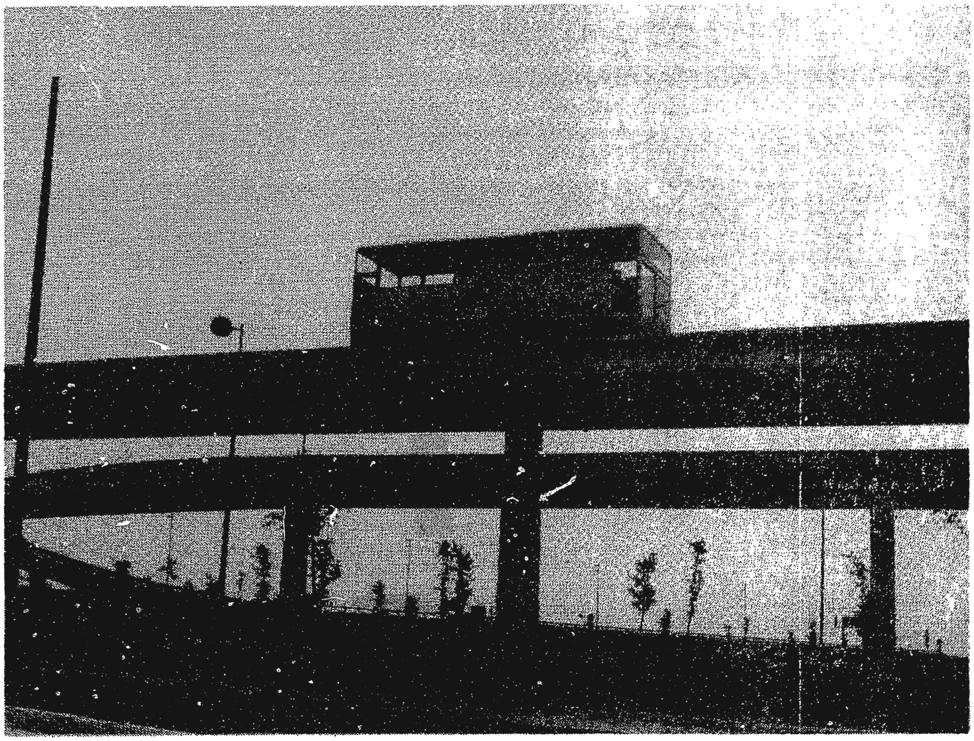

FIGURE 3 T-365 AUTP TEST VEHICLE ON DALLAS/FORT WORTH AIRPORT GUIDE

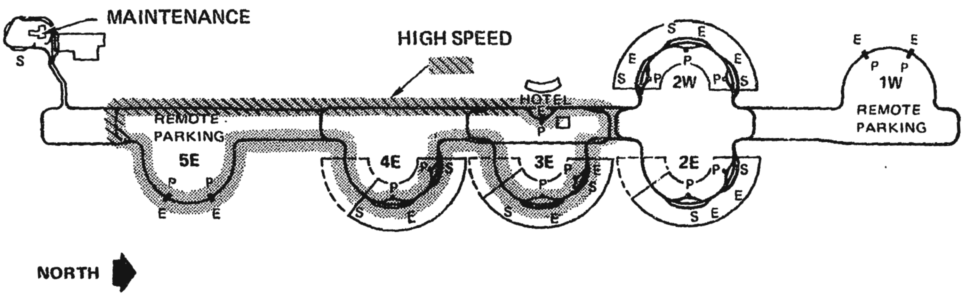

FIGURE 4 AUTP TEST ROUTE

(2) Increased traction to improve all-weather operations,

(3) Added redundancy to prevent system blockage due to a single motor/controller failure,

(4) Increased energy efficiency to reduce operating costs, and

(5) Improved motoring and braking control.

These requirements established the basic design criteria for the propulsion subsystem. They are: each vehicle axle would be driven by a separate motor/controller, and each propulsion unit would be capable of regenerative braking.

The sizing of the AUTP propulsion subsystem was accomplished by analyzing the AGT systems proposed by the finalists in the Urban Mass Transit Administration's Downtown People Mover (DPM) Program. It was determined that a maximum cruise speed of 30 MPH would satisfy all of the proposed DPM applications. A duty cycle comparison was also made which considered accelerations, grades and spacing of stations, plus the requirement for regenerative braking and a "get home" capability with a single motor. This resulted in a motor horsepower requirement of approximately 160 hp per vehicle. Sources for this type of equipment were investigated and Robicon Corporation was selected to provide the propulsion subsystem consisting of two motors and two motor controllers. (The units are similar to those provided by Robicon for the Detroit Fairlane AGT System.) Figure 5 shows a motor and motor controller prior to installation in the test vehicle. The actual motor/controller units used in the program are rated at 100 hp each due to motor availability.

This propulsion subsystem provides, in addition to the necessary 30 MPH speed capability and increased duty cycle rating, the following features:

(1) Two independent propulsion subsystems per vehicle which should increase system availability because of the single motor "get home" capability,

(2) Higher reliability objective - 70,000 miles mean distance between failure (MDBF) as compared with AIRTRANS at 22,530 miles MDBF,

(3) Regenerative braking which will conserve energy, reduce O&M costs and improve ride comfort, and

(4) All wheel traction which will improve operation in severe weather.

The dual propulsion equipment was fabricated and installed on the AUTP test vehicle to verify the design and to allow completion of Phase I tests and design evaluations. A total of 50 test

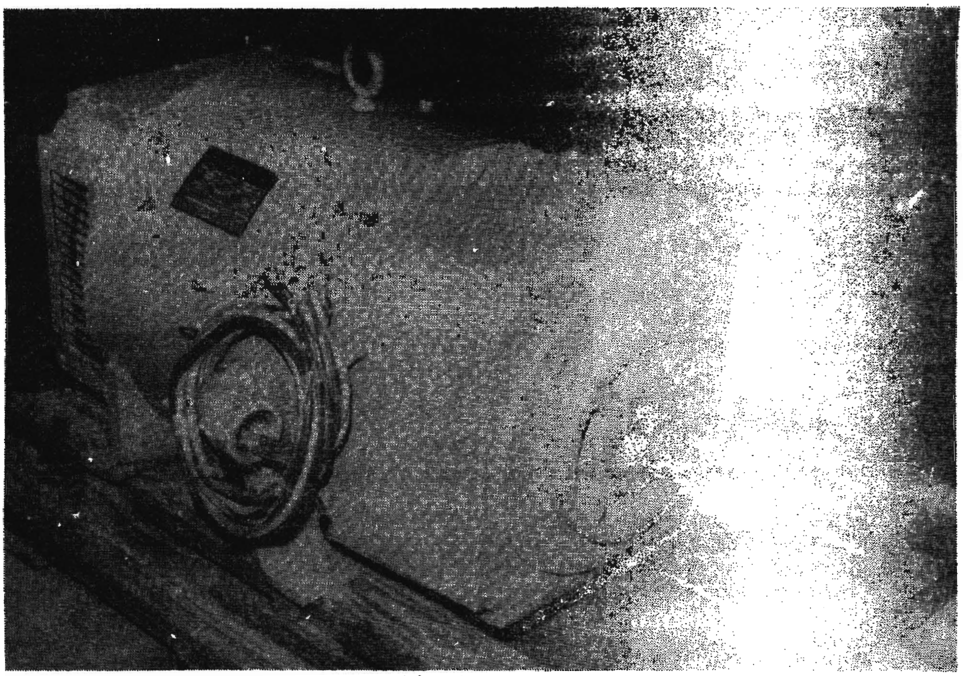

FIGURE 5(a) TRACTION MOTOR

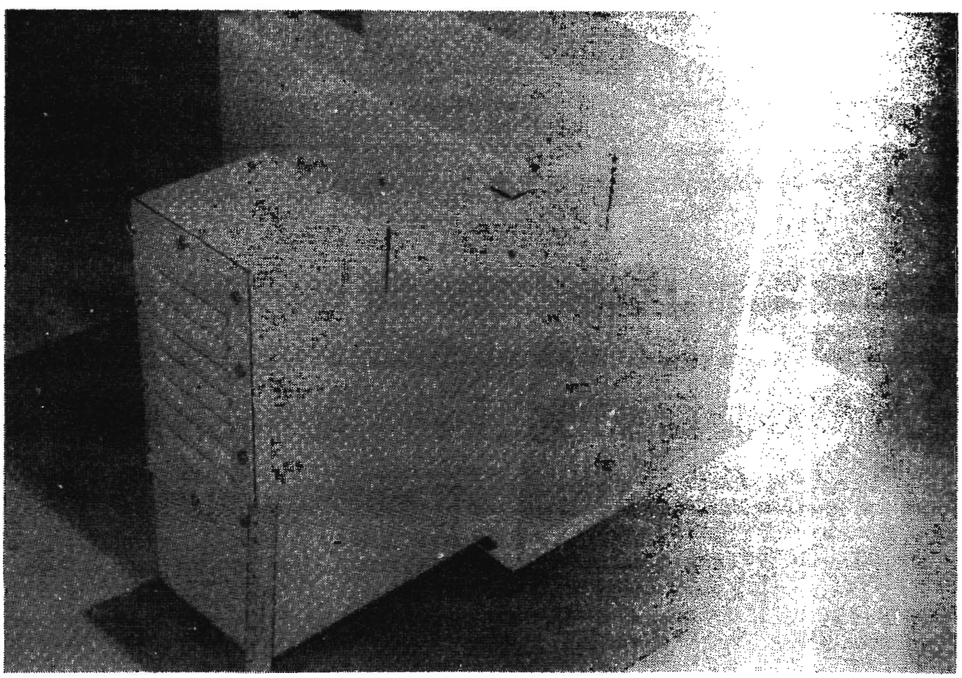

FIGURE 5(b) MOTOR CONTROLLER ENCLOSURE

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runs were made on the AIRTRANS guideway, with 17 of these operations obtaining or maintaining speeds of 30 MPH in the high-speed section. An estimated total of 280 miles were accumulated on the propulsion subsystem, small compared to a single day on an operational AIRTRANS vehicle, but adequate to determine that the propulsion improvement objectives had been achieved in terms of tractive force and the ability to sustain the desired duty cycle at 30 MPH.

COLLECTOR SUBSYSTEM IMPROVEMENT - The AIRTRANS electrical power and signal collector subsystem, shown in Figure 6, includes 5 collectors mounted on each of the four (4) corners of the vehicle. These operate in sliding contact with the guideway mounted conductor system. One collector is used for the transfer of the control and communication signals to the vehicle, one is used to provide an electrical ground, and the remaining three are used to collect three phase electrical power. The AIRTRANS collectors provide good performance at the 17 MPH AIRTRANS design speed; however, laboratory tests indicate that they may not be satisfactory at higher speeds required in urban applications. The signal collector is particularly vulnerable as it must transmit messages every 300 milliseconds with an efficiency of 70% or the vehicle will be brought to a "fail safe" stop by the automatic vehicle protection system. Thus, difficulties were anticipated at higher speeds because the missed messages caused by rail roughness, rail joints, vehicle motion, etc. will occur at a much higher rate. Therefore, the objectives of the collector improvement task were to:

(1) Evaluate the suitability of the AIRTRANS collector subsystem to operate at higher speeds,

(2) Determine possible design and material improvements for collectors and rail ramps that would assure more reliable operations, and

(3) Evaluate these improvements by both laboratory and on-guideway tests.

Prior to the AUTP, Vought had developed a new collector design to increase the collector transmission efficiencies. The new collector was designed and fabricated with the shoe mounted so that it would roll on rollers, with the point of rotation actually below the rail surface, as shown in Figure 7.

The new collector was tested on the Vought 18-foot diameter rotating drum test facility, as shown in Figure 8, at speeds up to and including 45 MPH. This facility mechanically simulates the real-world-collector/conductor interaction and allows testing under controlled conditions. Using this test facility, an existing AIRTRANS signal collector, an AIRTRANS power/ground collector and the new concept AUTP collector were evaluated as signal collectors for signal data transmission. The rotating drum tests demonstrated that acceptable signal collection/transmission was

FIGURE 6 AIRTRANS COLLECTOR INSTALLATION

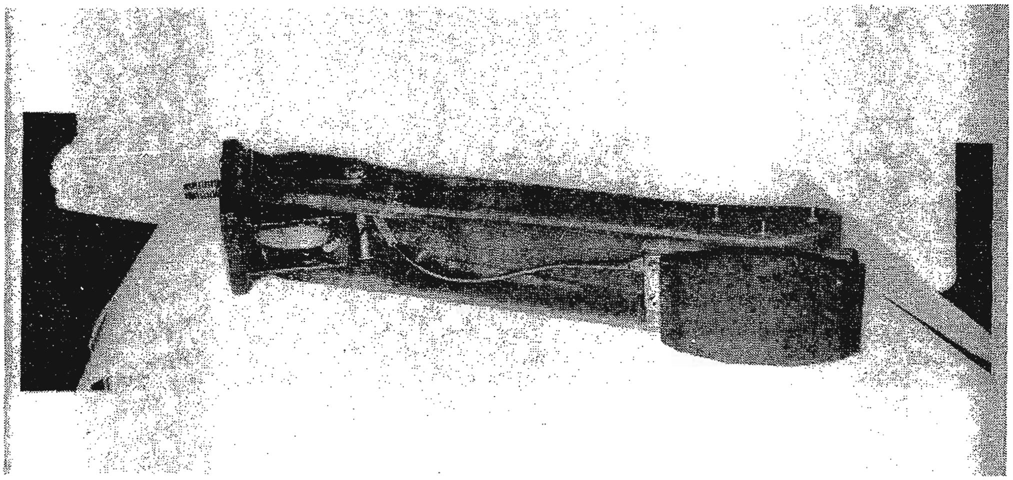

FIGURE 7 AUTP COLLECTOR

vehicle and can be used singly or entrained to form any desire-

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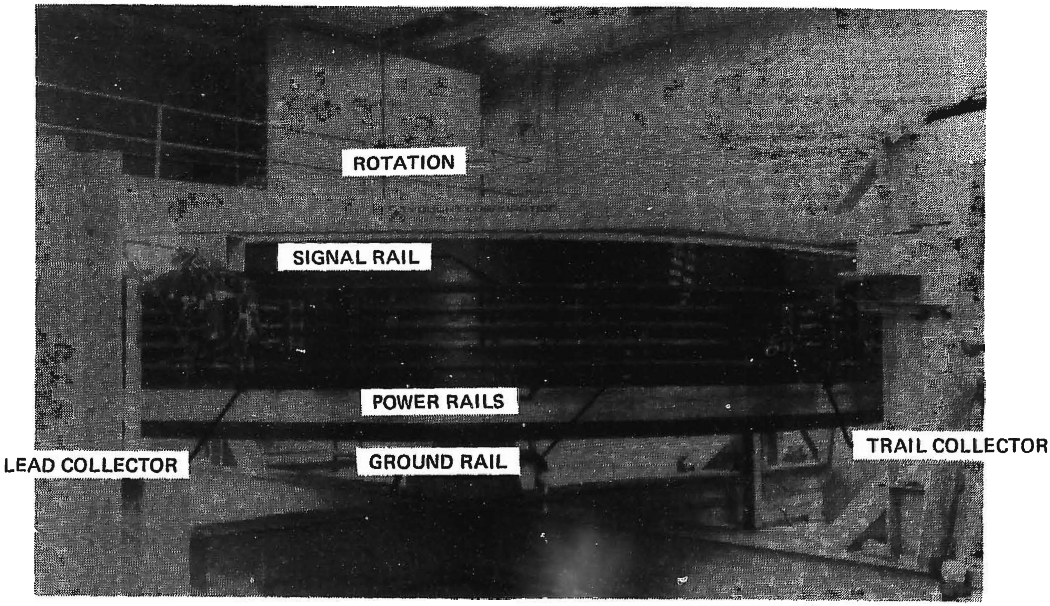

FIGURE 8 VOUGHT CORPORATION'S 18' DIAMETER ROTATING DRUM TEST FACILITY

achieved by the different collectors up to the following speeds:

(1) AIRTRANS Signal Collector - up to 20 MPH,

(2) AIRTRANS Power/Ground Collector - up to 21 MPH, and

(3) AUTP Collector - up to 45 MPH.

The existing AIRTRANS power/ground collector was tested on the rotating drum as a power collector and electrical continuity requirements were met for all speeds through 45 MPH.

In addition, the new rail ramp design with a 30 MPH profile was tested and found to provide a definite decrease in lateral impact loading and an improved wear rate at the collector intercept surfaces.

On-guideway tests of collectors consisted of the evaluation of the AUTP collector in signal and ground locations on the AUTP test vehicle, in combination with the AIRTRANS power collectors. Tests were run at speeds up to 30 MPH and both old and new ramp profiles were repeatedly and successfully negotiated. Signal and power transmissions were all within requirements. A set of the AUTP collectors was installed on an operational AIRTRANS passenger vehicle for in service wear and reliability evaluation. This installation was monitored over an operational period of 1053 hours, covering 8553 vehicle miles. Wear rate measurements indicate that the projected shoe life would be 30,000 miles.

Records indicate that the existing AIRTRANS collector shoes are replaced at 10,000 to 22,000 mile intervals, depending on location. Therefore, it is reasonable to assume a significant shoe wear rate improvement with the new collector design.

STEERING SUBSYSTEM IMPROVEMENT - Steering for AIRTRANS is accomplished by guidewheels running on the guideway parapets. Four guidewheels, two for guidance and two for switching, are mounted on each side of a traverse guidebar attached to both the front and rear axles. Guidance inputs are transferred from the guidewheels through the front guidebar to the front axle steering linkage and through an interconnect linkage to the rear axle steering components. The rear guidewheels provide steering inputs to the rear axle only when the vehicle rear end approaches the guidewall. A manual reversing mechanism is provided at each end of the vehicle to allow the directional sense of the steering input to be changed for reverse vehicle operation. In switching areas, the switch guidewheels are mechanically entrapped on one side of the guidewall or the other, depending on the route of the vehicle, to provide positive entrapment through the switch. Elements of the AIRTRANS steering subsystem are shown in Figure 9.

The steering subsystem has been the source of much maintenance expense at the Dallas/Fort Worth Airport. The problems are the high rate of guide and switchwheel replacements, and the need for maintenance of the guideway parapet surfaces. It is expected that these problems would be greatly increased at the higher speeds required in urban applications. Because of this, the primary objective of the AUTP steering subsystem improvements was to reduce both the forces on the parapets, and the forces transmitted from the parapets into the vehicle steering components.

The steering subsystem improvement task was accomplished through the following three steps:

(1) Testing of the AIRTRANS steering to establish baseline performance,

(2) Analyses and design of steering system improvements, and

(3) Operational testing of the improved steering designs.

The baseline steering tests were made on the AUTP test vehicle with AIRTRANS steering subsystem installed to determine the performance of this design. After these tests were completed, three new steering subsystems were conceived, tested and evaluated. These were:

(1) An improved mechanical steering subsystem,

(2) A hydraulic power boosted steering subsystem, and

(3) A contactless strip follower steering subsystem.

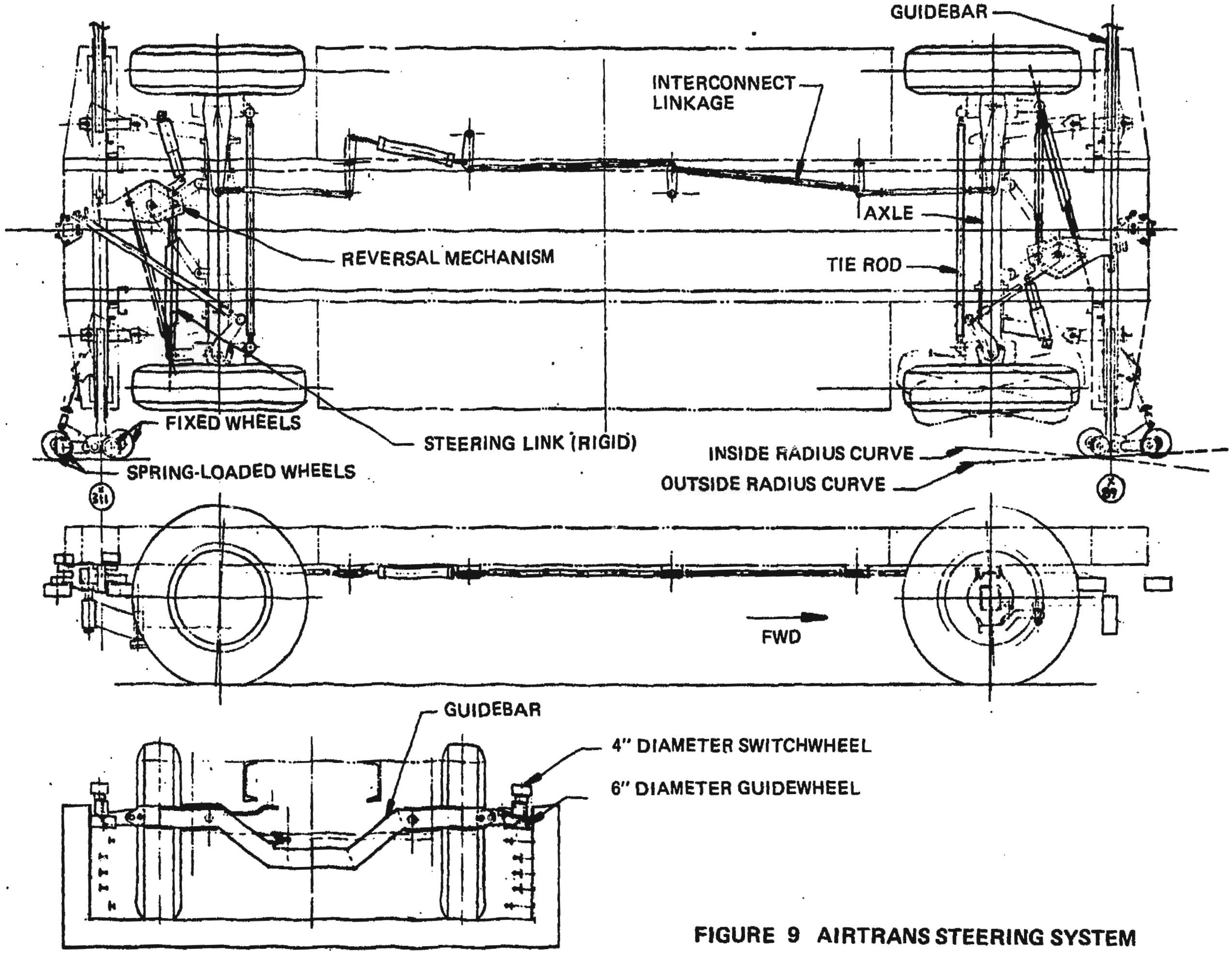

FIGURE 9 AIRTRANS STEERING SYSTEM

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The improved mechanical steering subsystem was conceived as the basic candidate for urban applications of AIRTRANS. The improvements included were:

(1) Anti-friction bearings in the kingpins,

(2) A straight guidebar of high strength structural steel to reduce guidebar mass,

(3) Eight inch diameter guidewheels with aluminum hubs,

(4) An improved collector support, to reduce weight and increase stiffness, and

(5) A low friction damper on the guidebar.

Elements of the improved mechanical steering system are shown in Figure 10.

The hydraulic power boosted subsystem was the same as the improved mechanical subsystem, with hydraulic actuators added to move the guidebar in response to signals from a power boost valve. In this subsystem, steering inputs from the guidewall cause the power boost valve to move. As the valve moves, hydraulic pressure is applied to the actuator, which aids the guidebar motion. When the proper steering angle is attained, the hydraulic subsystem is neutralized. This is the same type of equipment used in automotive power steering.

The contactless steering concept is an adaptation of a steering subsystem previously developed by Vought for use with steelwheeled transit systems. This steering subsystem used an electromagnetic sensor which tracked the steel rail and electrohydraulically positioned a steerable steel wheel to follow the rail. The purpose of the program was to develop steering and suspension equipment that would replace the standard steel wheel trucks now used on light rail vehicles. The objectives were to reduce cost and weight through the reduction of parts, and to reduce noise and wear by eliminating the wheel flange contact with the rail.

Tests of the three improved steering subsystems were conducted in the laboratory and on the guideway. Laboratory tests were performed on the 18-foot drum to evaluate the contactless breadboarded sensor's ability to track the metal strip at speed. This was completed with good results.

All three steering subsystems were then tested in the guideway at the Dallas/Fort Worth Airport, and evaluated and compared with the basic AIRTRANS steering subsystem. The improved mechanical subsystem showed a reduction in loads from the AIRTRANS baseline of 2357 pounds to 1210 pounds at 17 MPH. Further load reductions were seen in the switch encounters with the power boosted subsystem. Finally, the contactless subsystem eliminates the guidewall/guidewheel interface completely, thus eliminating any transmitted forces. Ride quality comparisons

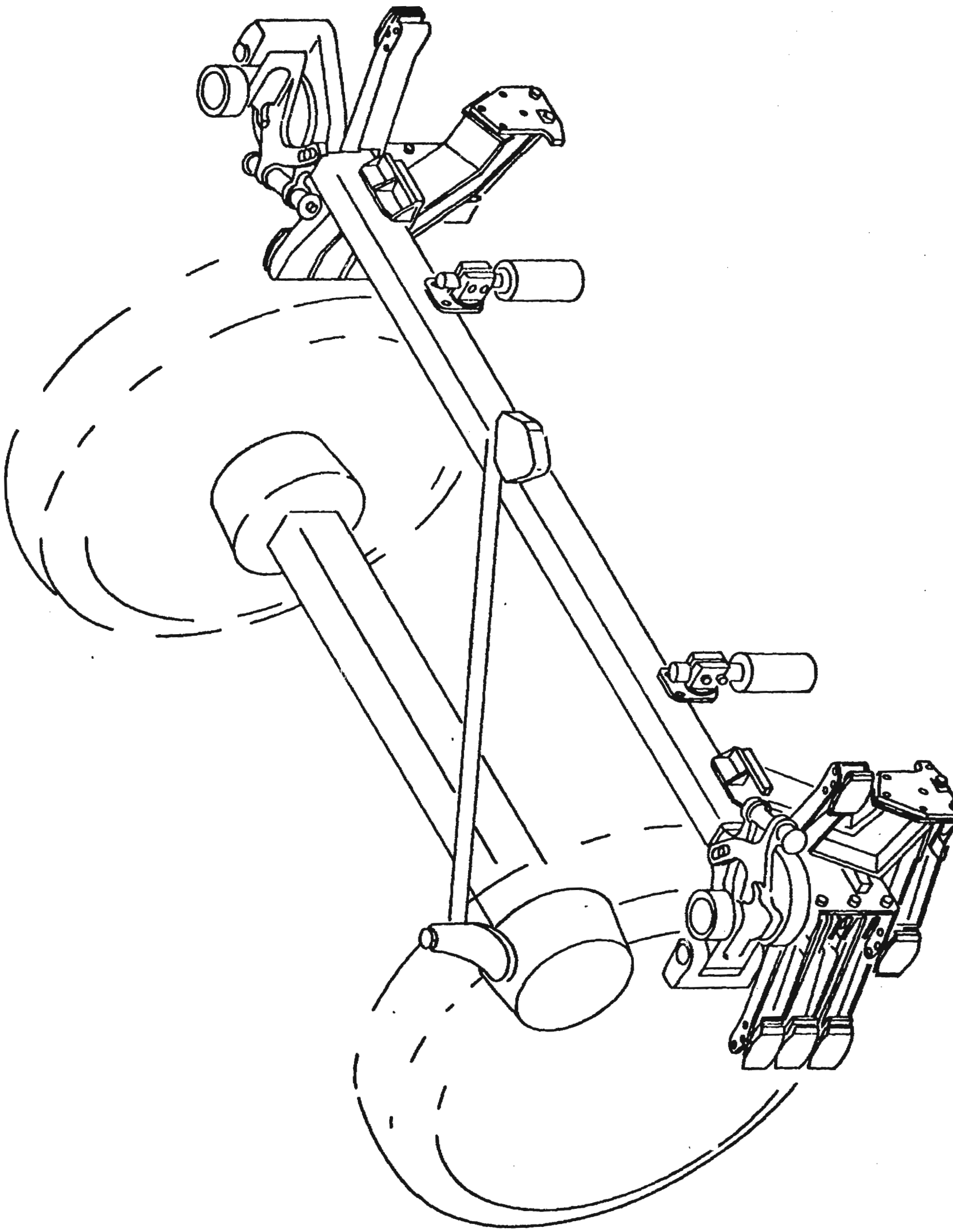


FIGURE 10 IMPROVED MECHANICAL STEERING AND COLLECTORS

showed the improved mechanical subsystem to have an improvement over the AIRTRANS subsystem at all speeds and conditions. The ride quality characteristics of the power boost and contactless subsystems were on a par with that of the improved mechanical subsystem. These tests showed that the improved mechanical subsystem is suitable for immediate deployment on AGT systems operating at speeds up to 30 MPH. The power boost and contactless subsystems are also feasible and, when fully developed, will allow AGT systems to operate to over 45 MPH.

CONTROL AND COMMUNICATION IMPROVEMENT - AIRTRANS vehicle control equitment consists of three subsystems which are used to control the movement of vehicles. They are:

(1) Automatic Vehicle Protection (AVP),

(2) Automatic Vehicle Operation (AVO), and

(3) Supervisory Data System (SDS).

The major functions of these subsystem are shown in Figure 11.

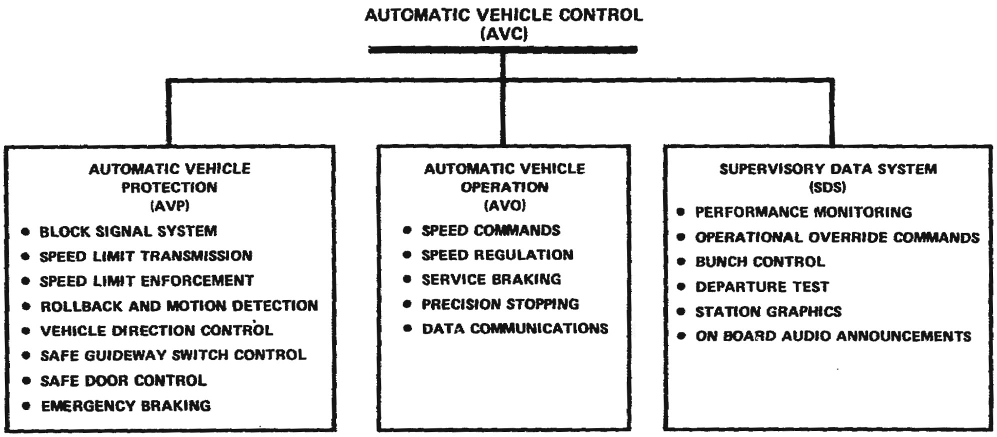


FIGURE 11 FUNCTION OF AUTOMATIC VEHICLE CONTROL SYSTEM

AIRTRANS vehicle control equipment could be used in urban applications by tailoring it to meet the route configuration and speed commands of the particular application. However, this would involve an extensive redesign and checkout effort, because of the hardware and software changes that would be required. Vought recognized this problem and initiated a program to design a control subsystem using recently developed microprocessor and solid state electronics. The reason for this endeavor was the flexibility that could be built into the subsystem through the use of easily programmable and replaceable components. This design was started prior to the AUTP and included the development of a Vehicle Safety Electronics (VSE) unit and a Vehicle Control Electronics (VCE) unit which incorporated the functions of the Automatic Vehicle Protection (AVP) and the Automatic Vehicle Operation (AVO) subsystems, respectively.

The initial design of the VSE was evaluated by Vought Safety Engineering and independently by Battelle Columbus Laboratories. These evaluations showed that the existing Airtrans Safety Subsystem was superior to the new design and that the redesign of the new VSE to meet the existing requirements would not have been cost effective.

A second generation prototype version of the VCE unit was designed, fabricated and evaluated in the AUTP test vehicle. Most functions of the VCE were successfully demonstrated, however, some software/control law improvements are required and will be implemented in Phase II. The VCE provides for increased flexibility of application and better reliability and maintainability through the incorporation of the improved electronic components. This allows easy adaptation of the VCE to new operational requirements and provides for greater reliability and maintainability through a significant parts count decrease.

The objective of improved communications was to demonstrate a radio frequency communication subsystem having the capability for greatly expanding the data and voice communication between the vehicles and central control, and for increasing the number and rate of vehicle communications within the system. This subsystem was installed and demonstrated by Motorola and shown to be technically feasible for an urban AGT system. The increased communication coverage provided by this subsystem will assure a high level of passenger safety and security in an urban application.

A Wayside Signal Analyzer (WSA) was designed, fabricated and demonstrated to add a useful means of measuring the wayside signals as received on board the vehicle. These measurements are sent to the VCE for reporting to Central Control and for on board monitoring. Analysis of these data allow isolation of trouble spots which may then be re-examined with the WSA, using visual test indicators and manual select switches, to obtain a detailed data set for a specific area of the guideway. This, in turn, allows early maintenance of the guideway signal subsystem to prevent system shutdowns. The WSA unit was tested and two valid data maps were obtained, demonstrating the feasibility and utility of the WSA.

CONCLUSIONS

Phase I of the AUTP has demonstrated that the existing AIRTRANS AGT system can be improved to make it a viable transit system for urban deployments. Major achievements of the program included:

(1) A traction subsystem with increased tractive capability, increased reliability, and regenerative braking capability;

(2) An improved collector design that provides the necessary signal and power transmission efficiencies for the speeds required in an urban environment,

(3) An improved mechanical steering subsystem that lowers component and interface steering forces, and uses low-mass alloy steel construction to provide for higher speed operation with an increase in reliability and maintainability while maintaining satisfactory ride comfort,

(4) An improved VCE unit with increased flexibility, reliability and maintainability through the use of reduced number of parts, modular fabrication and reduced size and weight,

(5) A WSA unit that allows monitoring the conditions of the control signals received by the vehicle from the wayside and provides a means to maintain the signal subsystem through the detection and correction of faults before failures occur, and

(6) A radio frequency communication subsystem with the capability for expanding the data and voice communication between the vehicle and central control.

The overall conclusion reached is that the basic AIRTRANS design, together with changes and design improvements developed in AUTP Phase I and the changes and design improvements expected from AUTP Phase II will provide the technological building blocks for the deployment of urban AIRTRANS systems.

1.0 INTRODUCTION

The Automated Guideway Transit System, AIRTRANS, has been in operation at the Dallas/Fort Worth Airport for over four years. The system has carried over 17 million riders, over 5,000 tons of cargo, and has logged over 13 million vehicle miles as of June 1978. With this extensive experience being obtained in automated guideway transit in the somewhat controlled environment of an airport, it was quite logical for the United States Congress, the Department of Transportation, and the Vought Corporation to ask the question: What changes or improvements are desirable to this system to make it deployable in an urban environment? This questioning had started even before there was a formal Downtown People Mover program within D.O.T. Similar answers to the question regarding AIRTRANS had been independently provided by the Transportation Systems Center of D.O.T. in their AIRTRANS Assessment Report, Reference (1), and by the Vought Corporation in testimony to both houses of the United States Congress. The resulting recommended changes and improvements were:

Higher Speed,

Improved passenger acceptance,

Reduction in capital and operating cost,

Improved reliability,

Improved all-weather capability, and

Energy conservation.

In 1976, Congress authorized 7 million dollars for this program and appropriated 2 million dollars to be spent in calendar year 1977. Working under a Federal Grant from the U.S. Urban Mass Transportation Administration to the Dallas/Fort Worth Regional Airport Board, the Vought Corporation, as subcontractor, has just completed work on this first phase of the program, the results of which are presented in this report.

This report contains summary which provides an overview of the accomplishments of the AUTP Phase I, and shows the relation of Phase I to the total program, outlines the approach and objectives, describes the test and demonstration program, summarizes the accomplishments made and presents the conclusions derived. The body of the report presents and discusses in detail the accomplishments made in each of the following subsystems:

(1) Propulsion,
(2) Collector,
(3) Steering, and
(4) Control and Communications.

2.0 URBAN AIRTRANS PROPULSION

2.1 OBJECTIVES

The objectives of the AIRTRANS Urban Technology Program indicate the need for AIRTRANS propulsion system changes and improvements for that type of service. The following are broad objectives and considerations which, influence the requirements for an urban AIRTRANS propulsion system.

(1) In order to achieve versatility of application and to be able to respond to identified or foreseeable performance needs for urban AGT service, a goal was adopted to make AUTP vehicle subsystems and elements basically compatible with speeds as high as 45 MPH.

(2) It is recognized that provisions for severe weather operations will be a requirement.

(3) Since the UMTA's Downtown People Mover (DPM) program schedule parallels the AUTP, the DPM cities' proposals present an excellent opportunity to utilize actual site data in the formulation of specific requirements for urban AGT systems.

(4) AGT technology developments and experiences to date point to certain features that improve the overall system availability, cost and attractiveness of AGT systems for urban service.

Analysis of operational factors in typical urban scenarios provided the design requirements for the urban propulsion system. These include:

(1) Dual propulsion systems on each vehicle to provide tolerance to failures and to improve the flexibility of systems operation,

(2) Higher vehicle operating speeds to meet the needs of urban service,

(3) Four wheel drive for improved traction, and

(4) Motor braking as an option to reduce brake maintenance and improve ride quality.

The following paragraphs of this Section discuss in detail the requirements for the propulsion system of an urban AGT system and also describe the equipment that was designed and demonstrated during Phase I of the Airtrans Urban Technology Program.

2.2 AIRTRANS PROPULSION SYSTEM

The AIRTRANS propulsion system is a single axle drive system designed specifically for the duty cycle and environment of the Dallas/Fort Worth Airport installation. It consists of a single DC motor that is supplied commercial 480 VAC 3Ø power by collectors from the wayside power system. The essential features and specifications for the system are as follows.

<u>Motor</u>

Type: Compound DC motor, self ventilated

Manufacturer: ASEA of Sweden

Rating: 60 HP, 2730 RPM base speed

Maximum Torque: 475 ft. lb.

Background: An adaptation of an ASEA industrial motor. Slight modifications have been made, including modified insulation system and motor end-turns treatment and a bearing substitution. The Morgantown AGT uses an adaptation of the same basic motor.

<u>Motor Controller</u> (Armature controller, field supply, control circuits, EMI housing and circuit protection):

Armature Controller: 3 phase full wave, phase controlled rectifier.

Field Supply: Fixed full wave (diode) bridge rectifier supplying the shunt field.

Cooling: Internal blower.

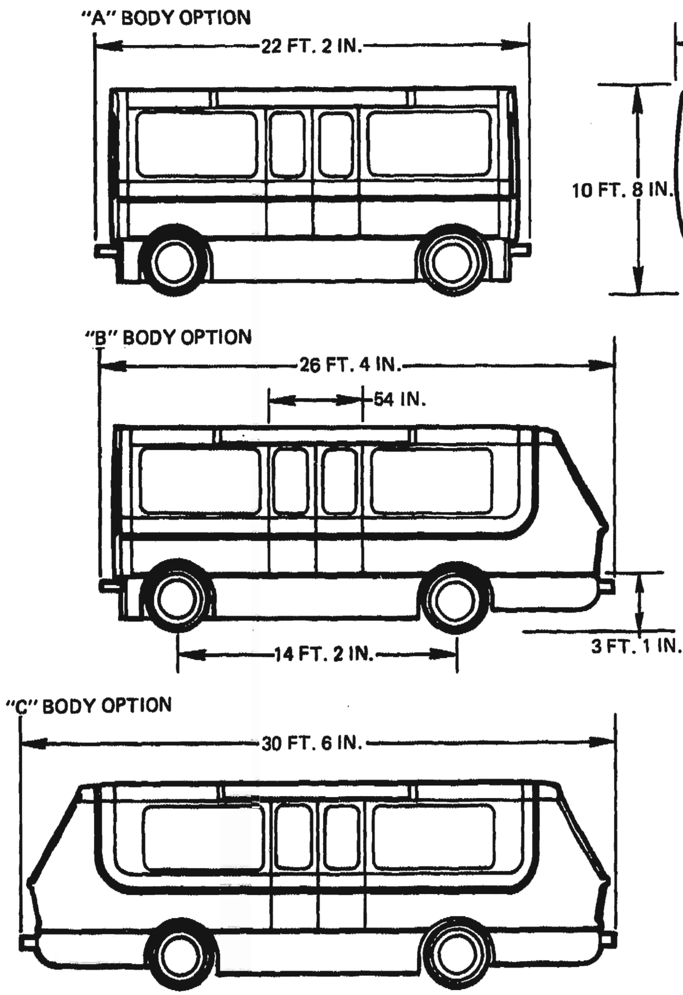
<u>Drive Train</u>

Single axle drive through a short drive shaft to the differential. Overall gear ratio is 17.44; tire size 8.25 x 20.

The motor and motor controller are supplied by Randtronics, Inc. Service requirements include operation at 17 MPH over a number of route loops characterized by frequent grades and average station spacings on the order of 1600 ft.

2.3 REQUIREMENTS FOR URBAN PROPULSION

2.3.1 AUTP VEHICLE DEFINITION - In order to quantify the propulsion requirements for an urban AGT system, a base vehicle was defined. This vehicle was selected from the family of AIRTRANS derivatives developed by Vought and shown in Figure 2-1. The "A" vehicle option is identical to the Dallas/Fort Worth Airport



		A BODY	B BODY	C BODY
WEIGHTS	EMPTY CAR, LB.	14,200	15,350	15,850
	NORMAL LOAD, LB.	21,000	23,170	24,180
	CRUSH LOAD, LB.	24,400	27,080	28,260
CAPACITY	INTERIOR FLOOR AREA, SQ.FT.	130	144	164
	SEATED PASSENGERS	16–19	16–20	16–24
	TOTAL PASSENGERS (NORMAL)	40	46	52
	TOTAL PASSENGERS (CRUSH)	60	69	77
PERFORMANCE (MAXIMUM RECOMMENDED)	SPEED, MPH		30	
	NORMAL ACCELERATION, MPHPS		2.63	
	NORMAL SERVICE BRAKING, MPHPS		2.64	
	JERK LIMIT, MPHPS PS		1.54	
	EMERGENCY BRAKING, MPHPS		4.39	
DYNAMIC ENVELOPE	HEIGHT		10'10"	
	WIDTH		9' 5"	
	LENGTH	22'2"	26' 4"	30'6"

FIGURE 2–1 URBAN AIRTRANS VEHICLE OPTIONS

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vehicle and can be used singly or entrained to form any desireable consist. It is suggested, however, that it be used as middle cars in a consist headed by single ended "B" cars. The "B" car, again, is operational as a single or in consists of two or more vehicles. The "C" body option is provided for use in applications requiring a larger capacity single vehicle.

The "C" vehicle was used as the base vehicle for design of the propulsion system because it is the heaviest and, therefore, its propulsion demands will be greatest. When applied to an "A" or "B" vehicle, the propulsion system will enjoy a performance margin capability.

2.3.2 ACCELERATION/DECELERATION RATES - A nominal acceleration/deceleration rate of 2.63 MPH/SEC (0.12 g) was selected for the propulsion system performance. This value falls within the band of values of the AIRTRANS specification. It was selected because very little improvement in trip time could be gained by increasing acceleration to 3.0 MPH/SEC which is frequently used in rail rapid transit specifications (see Figure 2-2), and because it would provide improved ride comfort especially for standees and the elderly and handicapped.

2.3.3 VEHICLE SPEED - Increasing vehicle operating speed in an urban or transit application has two primary affects:

(1) higher speed reduces trip time and thereby increases the attractiveness of public transit for the average patron, i.e. higher speed improves the level of service offered, and

(2) higher speeds for a given vehicle increases its productivity with the result that the operator is required to purchase and maintain fewer total vehicles to meet his peak service demands.

An analysis (Appendix A) of the DPM cities' proposals showed that 30 mph represents a consensus of the speed needed for DPM applications (see Figure 2-3) and also that 30 mph, for the station stop frequencies typified on these DPM routes, is a speed above which essentially no improvement in trip time can be gained. Based on these considerations and similar studies performed in the past at Vought, a basic vehicle cruise speed of 30 mph was selected for the AUTP propulsion system duty cycle studies. This selection did not alter the previously stated goal to achieve a subsystem compatibility with speeds to 45 mph within the limitations imposed by the final system's thermal rating.

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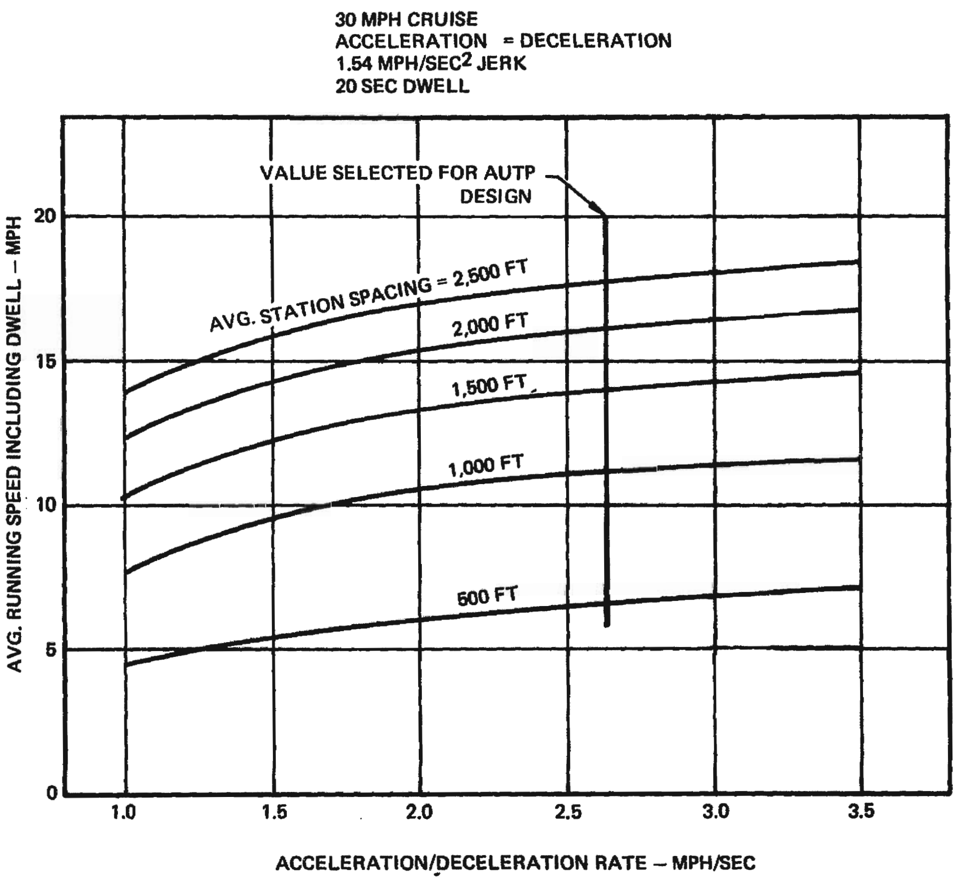

FIGURE 2–2 EFFECT OF ACCELERATION RATE ON AVERAGE SPEED

ACCEL AND DECEL = 2.63 MPH/SEC

NOTE: DATA POINTS ARE AVG STA SPACINGS AND DESIRED VEHICLE SPEEDS ARRIVED AT BY DPM CITIES' STUDIES (DATA FROM THEIR GRANT APPLICATION PROPOSALS)

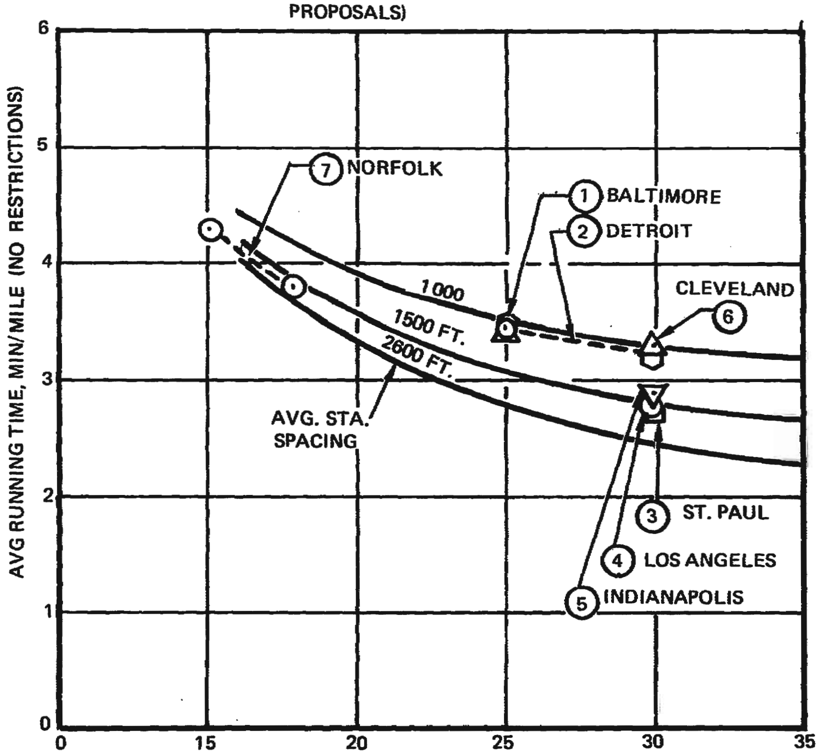

FIGURE 2–3 SPEED/TIME RELATIONSHIPS

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2.3.4 MOTOR BRAKING - The 17 MPH AIRTRANS utlizes friction brakes exclusively with a simplified control scheme. Experience has shown this system was well chosen for that application. However, certain factors indicate the desireability of motor braking for urban AGT systems. These include:

(1) Increased brake maintenance frequency. Since friction brake wear rates increase relative to the square of the vehicle speed increase.

(2) Simplification and improvement of braking controllability resulting in improved longitudinal ride quality.

The two forms of motor braking which were considered for the AUTP propulsion system were dynamic and regenerative. Regenerative motor braking was selected over dynamic motor because of the potential for improving the systems energy efficiency and the elimination of on-board braking resistors required with dynamic motor braking equipment.

2.3.5 EQUIPMENT RATING - Propulsion system duty cycle analyses were performed for a 30 mph urban Airtrans vehicle to verify the need for uprating the propulsion equipment for urban service. The propulsion system duty cycle defines the combinations of speed and tractive effort as a function of time that the system must be capable of producing, the equipment's equivalent "rating." Duty cycle determinants include:

(1) Vehicle configuration, weight and resistance to motion,

(2) Maximum speed capability,

(3) Acceleration, deceleration and jerk rates, and

(4) Velocity/grade profile (urban scenario characteristics).

Propulsion systems of the type employed on AIRTRANS consist of a DC motor controlled by a phase controlled rectifier and supplied by a wayside power system at 480 volts AC, three phase. The motor controller is sized primarily by the peak KVA that must be controlled. Peak KVA in turn is approximately proportional to the maximum motor horsepower (tractive effort - velocity product). The motor is sized by long term thermal considerations which include the integrated effects of internal thermal dissipation as a function of time.

A Vought propulsion/route simulation routine was used in the calculation of trip performance and in computing required motor thermal ratings. The routine permits one to "drive" a vehicle over a described route using a propulsion/drive system that is modeled electrically and mechanically. The routine bookkeeps distance, position, energy, etc. in addition to RMS current.

The propulsion system duty cycle analyses (see Appendix A) were performed both parametrically and with DPM cities' actual route alignment using the "C" urban Airtrans vehicle at a cruise speed of 30 mph. Table 2-1 summarizes the model physical inputs which were used prior to actual equipment selection, i.e., vehicle weights not adjusted for final equipment weights.

Figure 2-4 presents the results of the duty cycle analysis and shows that, without regenerative braking, a rating of 160 HP per vehicle will be required for St. Paul system as originally proposed. For regenerative braking, potential propulsion suppliers evaluated the additional rating increment based on the characteristics of their particular equipment and the actual St. Paul route alignment data.

2.3.6 SINGLE VS. DUAL SYSTEM - The D/FW Airtrans propulsion system is a single motor and controller driving a single axle. For urban service, however, the needs for increased power, traction improvements and a capability to tolerate at least a single propulsion failure in any consist leads to the consideration of a dual and redundant propulsion system. The following are the primary factors entering that consideration.

(1) Automatic vehicle recovery can be provided by dual propulsion systems on each vehicle and thereby eliminate passenger service interruptions resulting from a propulsion failure and improve the overall availability of the urban system.

(2) Dual propulsion systems driving both axles improve traction. With slip/slide controls (which are planned for incorporation at a later date) and four wheel drive, the vehicle can take maximum advantage of available adhesion. Traction improvements are needed for both wet and ice/snow conditions. References 1 and 2 confirm wet surface traction coefficients under certain conditions as low as 0.10 which is insufficient traction for most two wheel drive applications. Increased traction can also provide a capability for operation in most ice/snow conditions and thereby relieve the severity and frequency of ice/snow removal procedures on the part of the operator. This has been demonstrated by Ford at Fairlane. Figure 2-5 indicates the ranges of ice/snow traction coefficients that are available under such conditions.

(3) It is highly desireable for any new propulsion equipment to be an adaption of or derived from proven equipment. In the 160 HP range, availability of such equipment proved to be better as a dual system then as one large system.

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TABLE 2–1 PROPULSION ANALYSIS MODEL

VEHICLE: "C" Vehicle – normal load GVW – 25610 lb. Equivalent Rotating Mass – 1723 lb. Frontal Area – 76 ft.^{2} Tire Diameter – 39.55 in.
PROPULSION SYSTEM: 2 Compound wound DC motors – force air cooled (station dwell included in duty cycle integration) Torque Characteristics – 0–1900 RPM: 342 ft. lb. 2200–2730 RPM: 330 ft. lb. Constant Horsepower Above 2730 RPM Gear Ratio – 10.965 Base Speed – 29.3 mph (field weakening above base speed)
PERFORMANCE: Acceleration – 2.63 mph/sec Deceleration – 2.63 mph/sec Jerk – 1.54 mph/sec^2 Station Dwell – 20 sec.

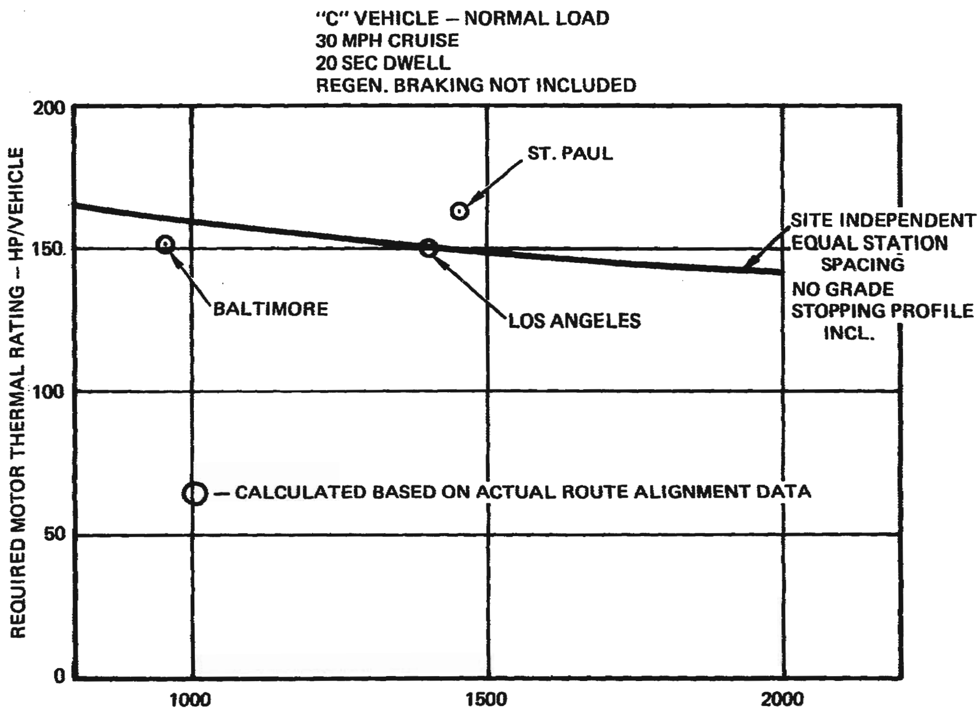

FIGURE 2–4 MOTOR THERMAL RATING REQUIREMENTS

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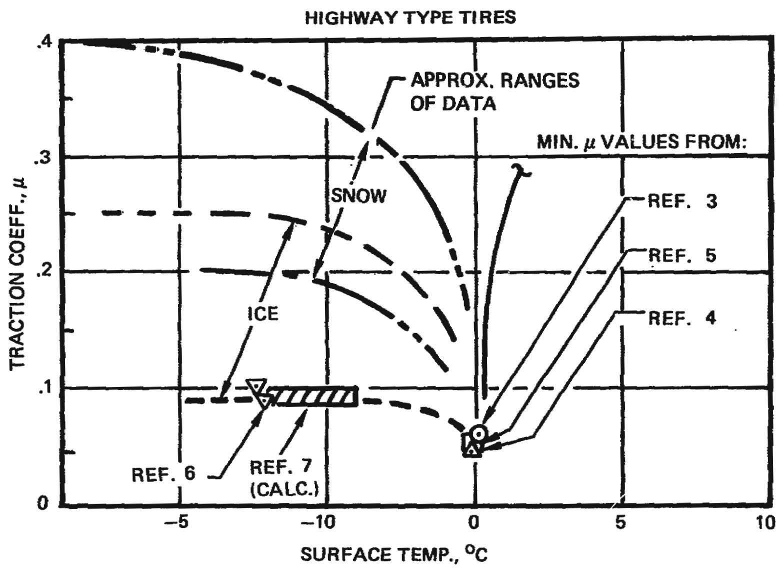

FIGURE 2-5 SNOW/ICE MINIMUM TRACTION DATA

(4) Although dual systems provide a degree of redundancy, propulsion failure rates and maintenance action frequencies per vehicle will necessarily be higher than for a single propulsion system assuming comparable individual system reliabilitis.

(5) Two systems may cost more than a larger single system of the same capability as the dual systems.

Selection of the dual propulsion system for AUTP Phase I was based on proposals from suppliers and evaluation of the preceding factors. Selection is discussed in Section 2.4.3 of this report.

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2.4 UPRATED EQUIPMENT SELECTION

2.4.1 CANDIDATES - A requirement was established for the AUTP propulsion system that it be proven equipment or be a derivative of such equipment. Based on this requirement plus the rating requirement of 160 HP without motor braking, the list of prime candidates was considered to include:

(1) Higher capacity AIRTRANS system,

(2) Dual AIRTRANS system - as supplied by Randtronics, Inc.,

(3) Dual Morgantown system - as supplied by Randtronics, Inc. for Morgantown PRT System,

(4) Ford/ACT System - originally supplied by Robicon, Inc. and in operation at Fairlane Complex, Dearborn, Michigan, and

(5) Delco ASDP Derivative - Advanced AC motor system under development by Delco Division of General Motors Corp. under the UMTA Advanced Subsystem Development Program.

2.4.1.1 Higher Capacity AIRTRANS System - The AIRTRANS system consists of a 60 hp compound wound DC motor driving a single axle (see Figure 2-6). Armature current (and torque) is controlled by a phase controlled rectifier that converts the three-phase supply power to variable voltage DC. The shunt field is fed by a separate fixed output rectifier. Reverse operation is accomplished by a reversing contactor. No motor braking capability is provided.

An uprated single motor system for the urban AIRTRANS was not pursued for several reasons.

(1) A single axle drive does not address traction improvements needed,

(2) A single motor/single controller would not provide the capability for operation after a propulsion failure,

(3) The high HP rating requirement for a single motor (160 hp) results in undercar installation problems due to motor size and weight, and

(4) Increasing restrictions on motor availability as motor rating increased.

2.4.1.2 Dual AIRTRANS System The use of two existing AIRTRANS propulsion systems would provide a total motor thermal rating of 120 hp per vehicle. This is inadequate when compared to the requirement of 160 hp. However, several modifications could be made that would allow the rating to be increased. The AIRTRANS

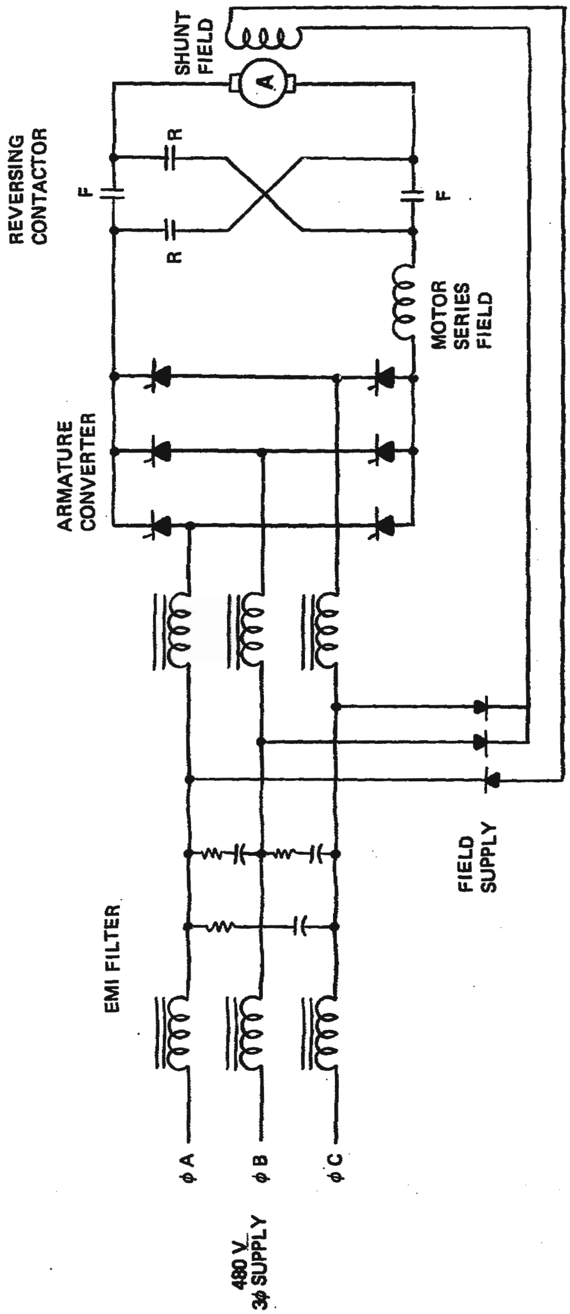

FIGURE 2–6 AIRTRANS PROPULSION SYSTEM

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motor as originally manufactured by ASEA has a 60 hp continuous rating based on:

115 ft/lb torque (99 amps with 300V field),

2736 RPM,

520V armature voltage,

105 CFM average cooling air (self-ventilated), and

Class F insulation.

Possible methods for increasing the nominal 60 hp rating include:

(1) increased base speed and rated armature voltage,

(2) increased ventilation by force air cooling, and

(3) higher operating temperature.

The nominal wayside supply is 480V 3Ø AC. The power system specification for AIRTRANS, and also adopted for the AUTP, requires that rated motor performance be available with supply voltages as low as 430V. At the 430V condition, the maximum phase controlled rectifier output is 550 VDC. An increase in maximum armature voltage from 520 to 550 volts is therefore possible and would increase the motor rating proportionally. Maximum torque would be available up to the higher base speed at the 430 V condition.

The 60 hp rating for AIRTRANS is based on self-ventilation with an average ventilation rate of 105 CFM for the Dallas/Fort Worth AIRTRANS duty cycle (station dwells excluded). The same motor frame is used on the Morgantown system with forced air cooling of 430 CFM. The continuous rating for that application is 70 hp at 2736 RPM with class F insulation and Class H materials in hotspot areas. Motor efficiency for Morgantown is virtually the same as for AIRTRANS.

As originally manufactured, the AIRTRANS motor had Class F insulation. Soon after being placed in service, all motors were upgraded with Class H or better in the armature. This improved system would also be used in any new applications of this motor. The assumption was therefore made that by increasing average ventilation from 105 CFM to 430 CFM and since armature insulation is equal to or better than that used on the Morgantown motors, the basic AIRTRANS motor continuous rating could safely be increased to 70 hp.

The combination of base speed, cooling and operating temperature changes would allow an increase in the AIRTRANS motor thermal rating to about 150 hp per vehicle. This system was considered a prime candidate although marginal in capacity since 160 hp without motor braking is needed.

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2.4.1.3 Dual Morgantown System - The Morgantown PRT propulsion system consists of a 70 hp compound wound DC motor, motor controller and a stepdown transformer (Figure 2-7). The motor controller, in addition to regulating the applied armature voltage, provides:

(1) regulated shunt field supply (field weakening) and

(2) regulated 28.5V DC supply.

The stepdown transformer supplies the motor controller and has two auxiliary windings.

The Morgantown system differs considerably from the AIRTRANS system in that the nominal wayside supply is 575V instead of 480V. The higher voltage in turn necessitates the use of the stepdown transformer. In its basic form, dual Morgantown systems would not be applicable to the AUTP vehicle and would not fit in the available space because of the transformers. With some modification, however, dual Morgantown systems could be considered for the AUTP vehicle. Modifications would include:

(1) reducing supply voltage to 480V,

(2) removing stepdown transformer,

(3) upgrading motor controller power section to accept 480V instead of 355V,

(4) deleting the DC power supply from motor controller due to inadequate capacity for the urban vehicle, and

(5) repackaging as required to fit the AUTP undercar envelope constraints.

Randtronics indicated that such modifications are feasible. The following discussions assume that the modifications would be made for application to the AUTP vehicle.

Dual Morgantown systems would likely be adequately sized in terms of motor controller capacity. Typically, the thermal time constant of an air cooled phase controlled rectifier is relatively short and the short term output generally sizes the controller. Two Morgantown controllers have a peak output greater than the AUTP vehicle requirements. The Morgantown motor rating, however, would appear initially to be inadequate, totalling 140 hp per vehicle.

The motor as manufactured by ASEA has a 70 hp continuous rating based on:

135 ft lb torque (140 amps with full field),

2730 RPM,

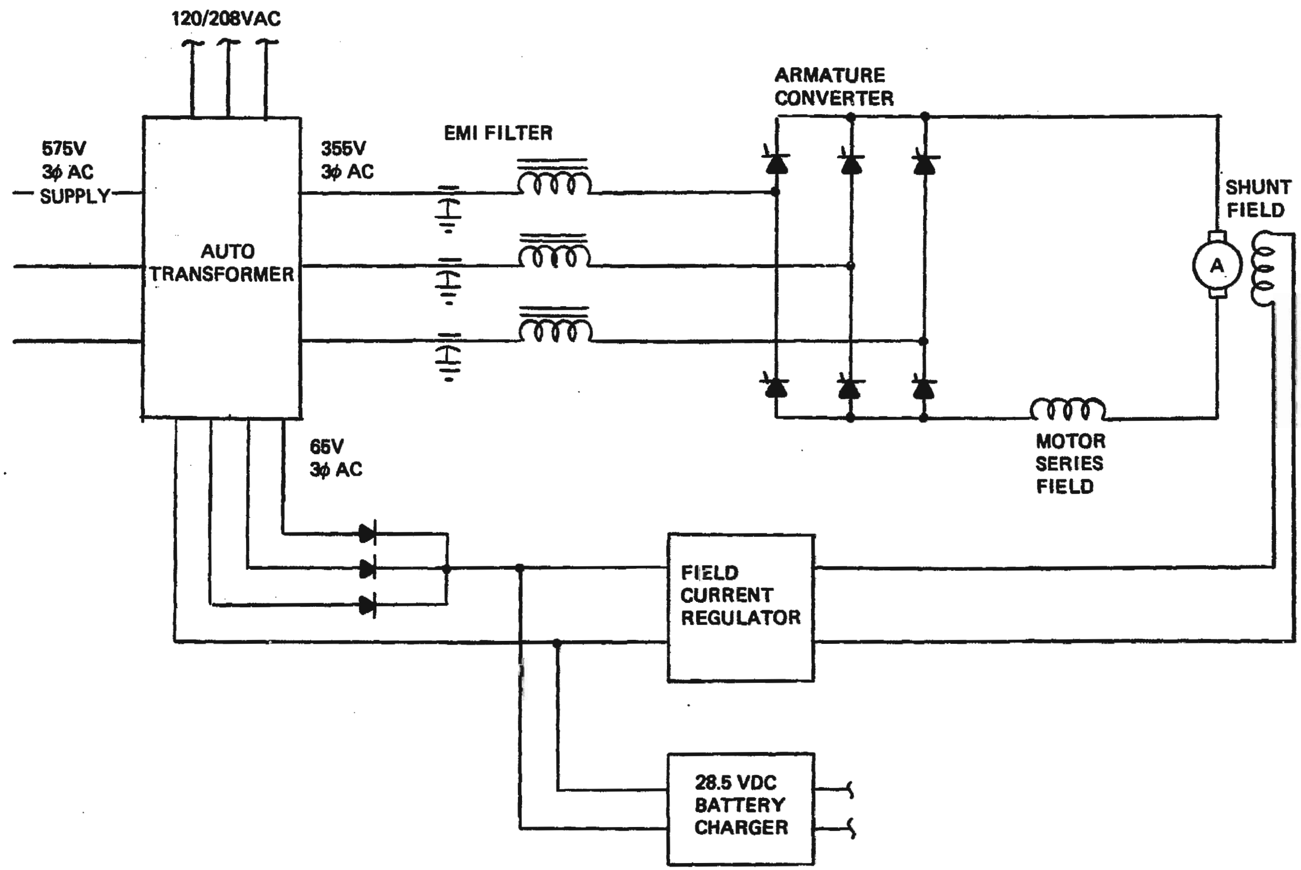

FIGURE 2–7 MORGANTOWN PROPULSION SYSTEM

420V armature voltage,

430 CFM cooling air (force ventilated), and

Class F insulation with Class H materials in hotspot areas.

With the ventilation rate and internal operating temperature already quite high, the only remaining approach for a rating increase is an increase in base speed and rated armature voltage. With a 430V minimum supply voltage, the maximum controlled rectifier output is 550VDC. Increasing the rated armature voltage from 420 to 550 would increase base speed to 3575 RPM and would result in rating of 92 hp. Discussions with ASEA later confirmed that these increases are possible. The resulting 184 hp motor thermal rating per vehicle would easily meet the required 160-170 hp non-braking requirement. Desired system configuration requirements could also be met with a dual Morgantown system making this approach suitable for the AUTP vehicle.

2.4.1.4 Robicon/Fairlane System - The Robicon system consists of two independent propulsion systems per vehicle and provides both traction and regenerative braking. Each system has a 60 hp shunt wound DC motor and a motor controller (Figure 2-8). The motor is rated at 2500 RPM with 500 VDC armature voltage and is based on a size 326 AT frame. Each motor controller consists of one phase controlled rectifier/converter for the armature circuit and two controlled rectifier field supplies for field reversing. Nominal wayside supply is 480V 3Ø AC, corner grounded delta.

The general configuration and functional capabilities of the Robicon system are well suited for the AUTP requirements. The concept of dual independent propulsion systems with the added capability of regenerative braking meets the general requirements previously outlined. The motor and controller ratings, however, are inadequate for the AUTP requirements. Modifications required for application to the AUTP vehicle would include:

(1) upgraded motor controller power stage for increased DC current output,

(2) increased motor rating by increasing frame size, and

(3) repackaging to fit the AUTP undercar constraints.

Discussions with Robicon indicated that these modifications were possible and would result in a system meeting all AUTP propulsion objectives.

2.4.1.5 Delco System - As part of the UMTA Advanced Subsystem Development Program (ASDP), Delco Electronics is developing an advanced AC propulsion concept for DC rapid rail. Features unique to the system include:

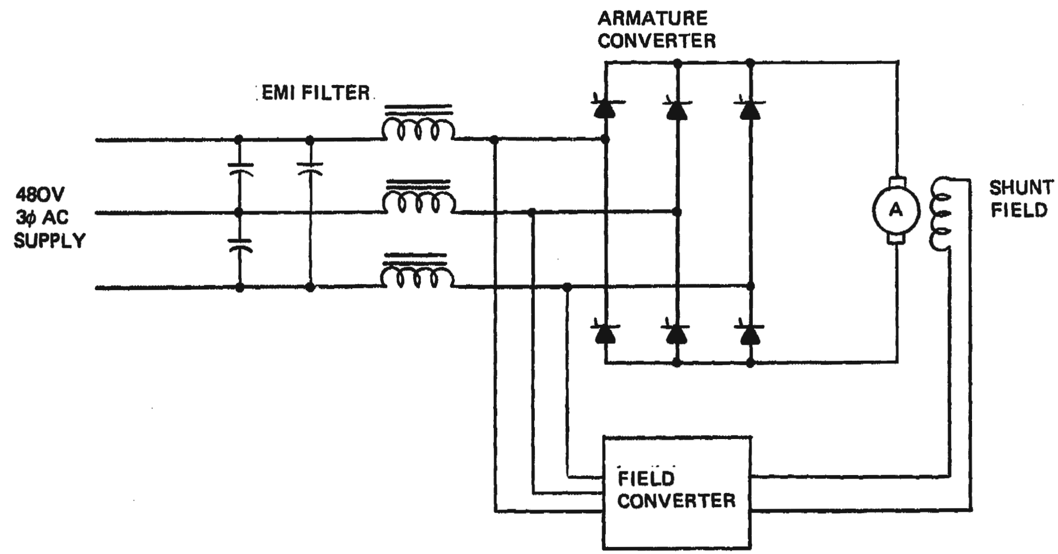

FIGURE 2–8 ROBICON/FAIRLANE PROPULSION SYSTEM

(1) brushless, salient-pole, self-synchronous motor,

(2) current transformer field excitation,

(3) capacitor coupled cycloinverter, and

(4) oil cooling of motor and motor controller.

Improvements relative to a conventional DC motor system include:

(1) lower motor and controller weight,

(2) potential for motor maintenance and reliability improvement (no brushes or commutator), and

(3) closed cooling system allowing no contaminants.

A diagram of the ASDP system is shown in Figure 2-9. Basically, the system in its DC supply form consists of a line filter, cycloinverter and an oil cooled motor that operates in the self-synchronous mode. By using a rotor position sensor combined with the cycloconverter switching system, the motor is made to perform like a brushless DC series motor when motoring. The system is also capable of producing regenerative braking. The cycloinverter consists of a frequency modulating input stage, coupling capacitors, and a cycloconverter. In motoring, the inverter generates a variable output frequency. The variable impedance offered by the coupling capacitors serves as a variable lossless impedance in series with the motor, thereby, controlling motor current. Cycloconverter conduction is controlled by the rotor position sensor so that the two serve together as an electronic commutator.

The ASDP propulsion system is not directly applicable to AIRTRANS since it is based on a 600 VDC input supply. However, an AC-to-AC derivative drive under development by Delco is applicable to an AIRTRANS type system. This concept (see Reference 8 and Figure 2-10) makes use of the motor, field excitation, cycloconverter and cooling technologies from the ASDP program. Replacing the inverter and large capacitors of the ASDP system is a switched bridge circuit which, with a large smoothing reactor, creates the square wave current input to the cycloconverter. The phase control rectifier controls the motor current. Operation of the cycloconverter, motor, and motor excitation are essentially the same as for the ASDP DC system. In terms of configuration, the Delco system could be designed to meet the requirement of two independent propulsion systems per vehicle and would also provide regenerative braking.

2.4.2 SPECIFICATION - The AUTP propulsion system was selected from suppliers proposals that were submitted in response to a procurement specification generated as a result of initial studies. The stated performance requirements were as shown on Table 2-2 and Figure 2-11. The specification required that

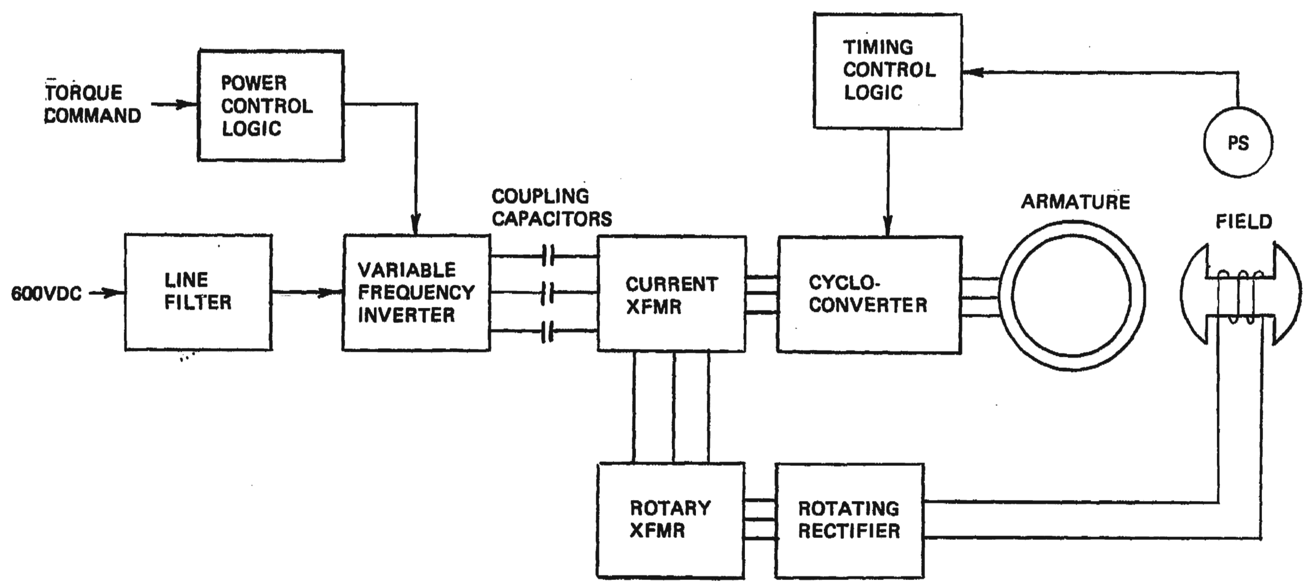

FIGURE 2–9 DELCO ASDP RAIL TRANSIT PROPULSION SYSTEM

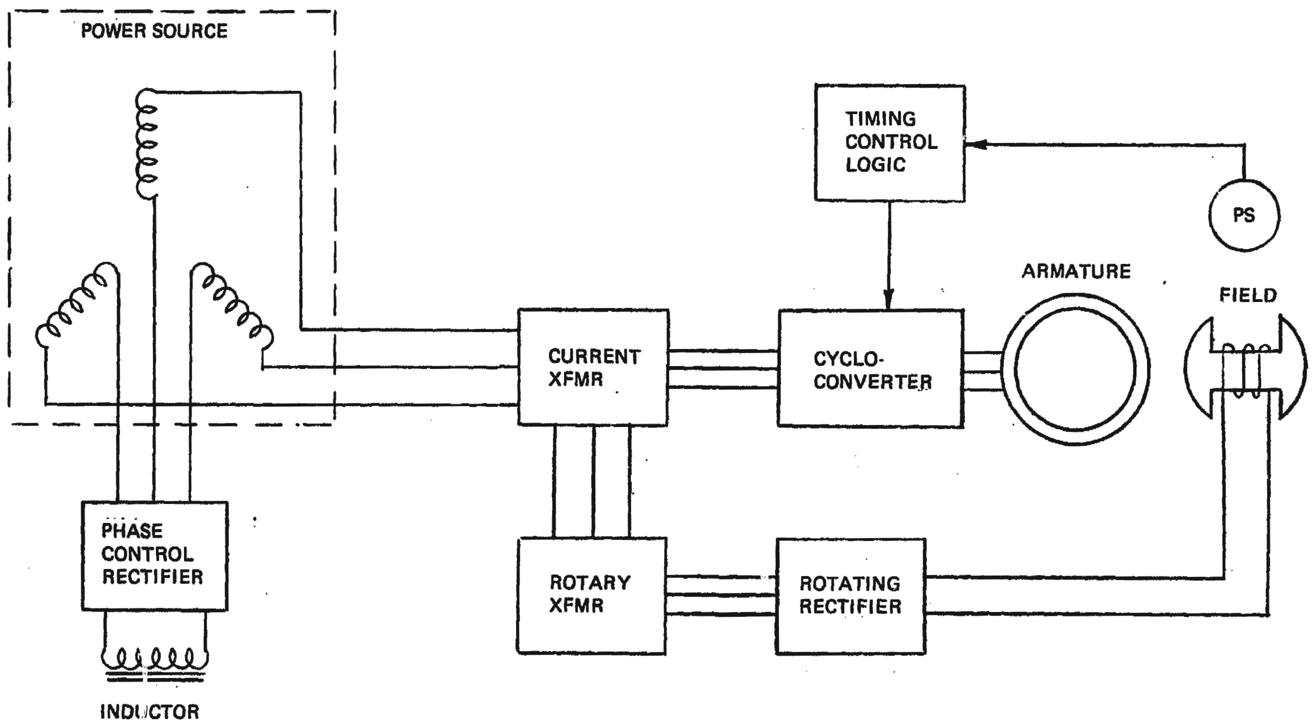

FIGURE 2–10 DELCO AC – AC SYNCHRONOUS MOTOR DRIVE

TABLE 2–2 AUTP PROPULSION PERFORMANCE SPECIFICATION

VEHICLE:

GVW: 25610 lb.
Equivalent Rotational Mass: 1015 lb.
Frontal Area: 76 $ft.^2$
Aero Drag Coefficient: 0.65
Rolling Resistance: 2.25% at V = 0
Collector Drag: 40 lb.

DRIVE TRAIN:

Overall Axle RAtio: 10.1, 11.57, 11.7, 12.72, 13.2 or 14.15
Effective Tire Radius: 1.65 ft.
Drive Train Efficiency: 0.90

PERFORMANCE REQUIREMENTS:

Cruise Speed: 30 mph
Design Accel. Rate: 2.63 mph/sec
Design Service Braking Rate: 2.63 mph/sec
Jerk Rate: 1.54 $mph/sec.^2$
Tractive Effort: Per Figure 2–11
Duty Cycle: St. Paul DPU alignment, 20 sec. station dwells

WAYSIDE POWER SUPPLY:

Nominal: 480 VAC, 3ϕ, 60 Hz.,
Normal Voltage Range: 500–430
Abnormal Range: (up to 4 min.) – 430–340

AMBIENT ENVIRONMENT:

Temperature: –30 to 120°F
Rel. Humidity: 5 to 100% with condensation
Road Splash
Other Contaminants: water, slush, snow, ice, mud, fungus, foreign objects
Altitude: sea level to 6,000 ft.

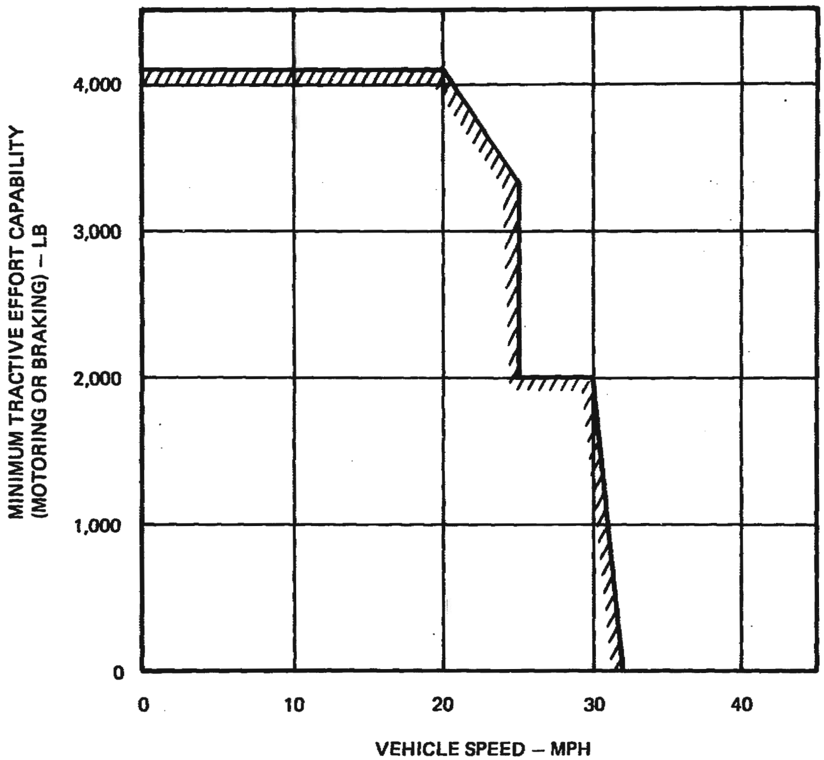

FIGURE 2–11 MINIMUM REQUIRED TRACTIVE EFFORT SPECIFICATION

proposed equipment have a documented record of satisfactory operation in a traction application or be derived from such equipment. The system was specified to consist of two motors and controllers. This requirement was based upon heavily weighing the features of duality to improve overall system availability and the need for improved traction. Regenerative braking was left to the option of the proposing supplier with the desire and intent of procuring the Phase I test unit with regeneration for evaluation purposes in the event a satisfactory proposal at an acceptable price was received.

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2.4.3 AUTP EQUIPMENT SELECTION _ The dual Robicon propulsion system was selected for purchase and evaluation as an available AUTP vehicle propulsion system on the basis of the following.

(1) The equipment proposal by Robicon satisfied all the requirements of the procurement specification at a competitive price.

(2) The system is similar to the system which powers the Ford Fairlane vehicle and enjoys the benefits of that background. Also, the system is very similar to the Airtrans in concept (Compound DC motor with phase controlled rectifier armature controlled/separate field rectifier).

(3) Regenerative braking, while not a hard requirement, was offered and Robicon has had experience with regenerative systems.

(4) The motors proposed by Robicon are expected to provide long life in service. They feature in their basic design the modifications that would be required for uprating the AIRTRANS or Morgantown motors, are conservatively rated, generally rugged and enjoy a good reputation in a related design.

Another factor that weighed as heavily as the foregoing was the fact that this equipment, together with the present AIRTRANS equipment (dual or single), offers a choice of demonstrated equipment that will be well suited for any future urban service application requirement. This is demonstrated by the possible choices for systems as shown in Table 2-3.

The Delco system is judged to possess potential for high reliability and meet all requirements, except that its state of development does not fully satisfy the prior history requirement set down for the AUTP system. It is based on a new unproven technology.

A dual Morgantown system offer no real advantage over a dual AIRTRANS system and could be used where it fits the application's requirements.

TABLE 2–3 URBAN AIRTRANS PROPULSION EQUIPMENT

POWER RATING	60 HP	100 HP	120 HP	200 HP
DRIVEN AXLES	1	1	2	2
SERVICE BRAKE TYPE	Friction	Friction and Regenerative Option	Friction	Friction and Regenerative Option
SYSTEM EQUIPMENT (MANUFACTURER)	1 Motor/ Controller (Randtronics)	1 Motor/ Controller (Robicon)	2 Motor/ Controller (Randtronics)	2 Motor/ Controller (Robicon)
HISTORY	Used on Dallas/ Fort Worth Airtrans	Single Version of 200 HP System	Dual Version of 60 HP System	• Demonstrated in AUTP • Has Ford Fairlane Heritage

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2.5 DUAL AUTP PROPULSION DESCRIPTION

2.5.1 FUNCTIONS - The AUTP vehicle propulsion system consists of two independent propulsion systems, each driving an axle and each system consisting of a shunt wound DC motor and a motor controller. The propulsion system functions essentially as a closed loop torque servo and provides torque in the direction specified in response to commands from the vehicle control system. Control of jerk, acceleration, speed, load weighing and brake selection are accomplished within the vehicle control electronics. A block diagram of the propulsion system showing the various interfaces is shown in Figure 2-12.

Control of the motor is performed by an AC-DC phase controlled rectifier. In motoring, the controller provides a variable, positive DC voltage to the armature (0 to 500 VDC). The applied voltage is equal to the motor back emf plus the armature IR drop and thus varies approximately as the motor's speed. Control of the applied voltage is accomplished by delaying the point of conduction of the controller's SCRs beyond the time at which they become forward biased (details of converter operation are available in Reference 9). For regenerative braking, the direction of field current is reversed while maintaining the same amature current direction. In the braking mode, the rectifier circuit functions as a line commutated inverter. Reverse operation is identical to forward operation except that the field current direction is reversed for both motoring and braking operation.

2.5.2 PHYSICAL DESCRIPTION

2.5.2.1 <u>Traction Motor</u> - The traction motor (Figure 2-13) is a four pole fully compensated design based on a 366AT industrial motor frame. The continuous rating is 100 hp at 2500 RPM with separate forced ventilation. Maximum torque capability is 420 ft-lb at speeds up to 2576 RPM. The motor is specifically designed to be compatible with control by a six pulse thryristor converter operating from a 480 volts, AC, three phase power supply. The nominal armature voltage rating is 500V.

The fields are straight shunt wound and are driven by a current regulated single phase dual converter. Reversal of torque direction is by field current reversal.

The insulation system is Class H or better throughout and is vacuum impregnated. Dual overtemperature sensing provisions are used. A Klixon type overtemperature switch is imbedded in the interpole winding and is set to open at the maximum permissible operating temperature. A platinum resistance analog temperature sensor is also placed at the same location. The temperature indication from the sensor is used by the vehicle electronics to limit commanded tractive effort when an impending overtemperature condition exists.

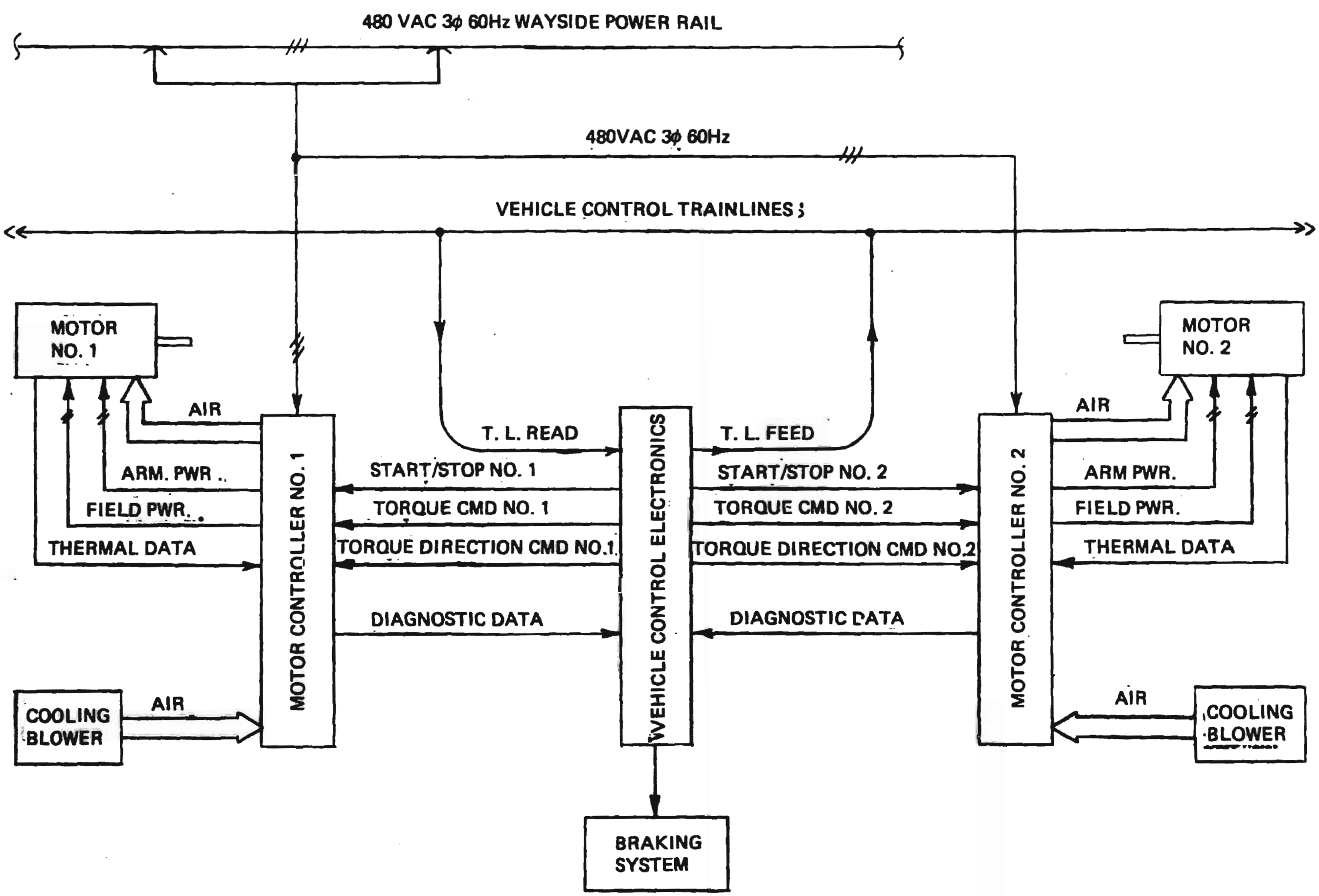


FIGURE 2–12 PROPULSION SYSTEM BLOCK DIAGRAM

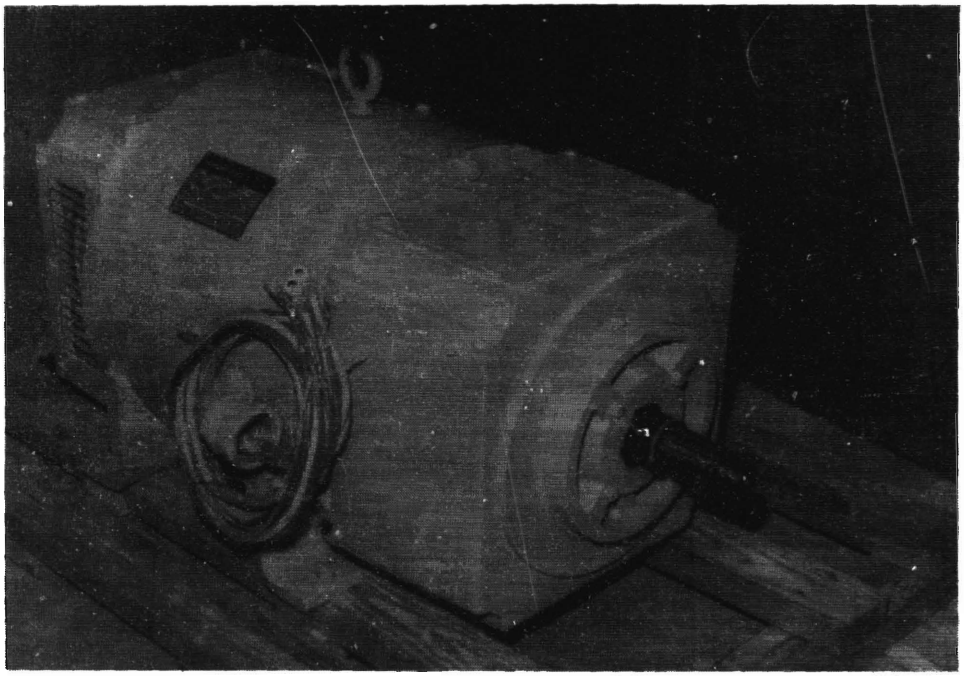


FIGURE 2–13 TRACTION MOTOR

Modifications to the motor for the AUTP traction application are as follows:

(1) The commutator end is the drive end,

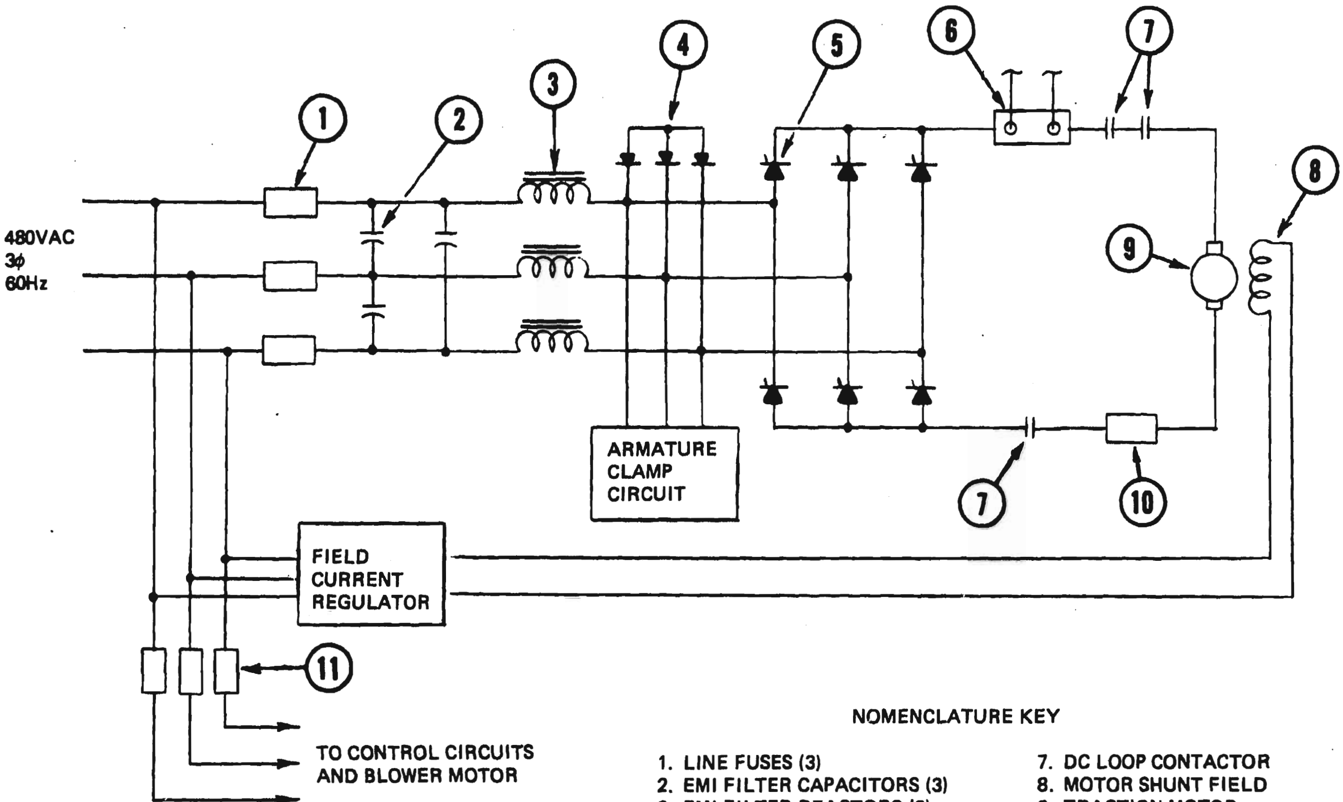
(2) The motor shaft is grounded via a carbon brush for EMI purposes,

(3) The end opposite the drive end features a special removable stub shaft, and

(4) The addition of temperature sensors.

A possible additional modification involves the end bells. Replacement of the standard ends with aluminum can reduce motor weight by 220 lb each.

2.5.2.2 Motor Controller - The motor controller contains the armature converter, field converter, line filter, DC loop contactor, fusing, phase loss protective circuitry, and necessary logic to interface with the AUTP vehicle control electronics. Figure 2-14 shows the basic circuit. A picture of the motor controller is shown in Figure 2-15, and the major subassemblies are shown in Figure 2-16.



NOMENCLATURE KEY

1. LINE FUSES (3)
2. EMI FILTER CAPACITORS (3)
3. EMI FILTER REACTORS (3)
4. TRANSIENT SUPPRESSOR NETWORK
5. MAIN THYRISTORS (6)
6. DC CURRENT SHUNT
7. DC LOOP CONTACTOR
8. MOTOR SHUNT FIELD
9. TRACTION MOTOR
10. ARMATURE CIRCUIT FUSE
11. CONTROL CIRCUIT FUSES (3)

FIGURE 2–14. SELECTED PROPULSION SYSTEM FUNCTIONAL SCHEMATIC

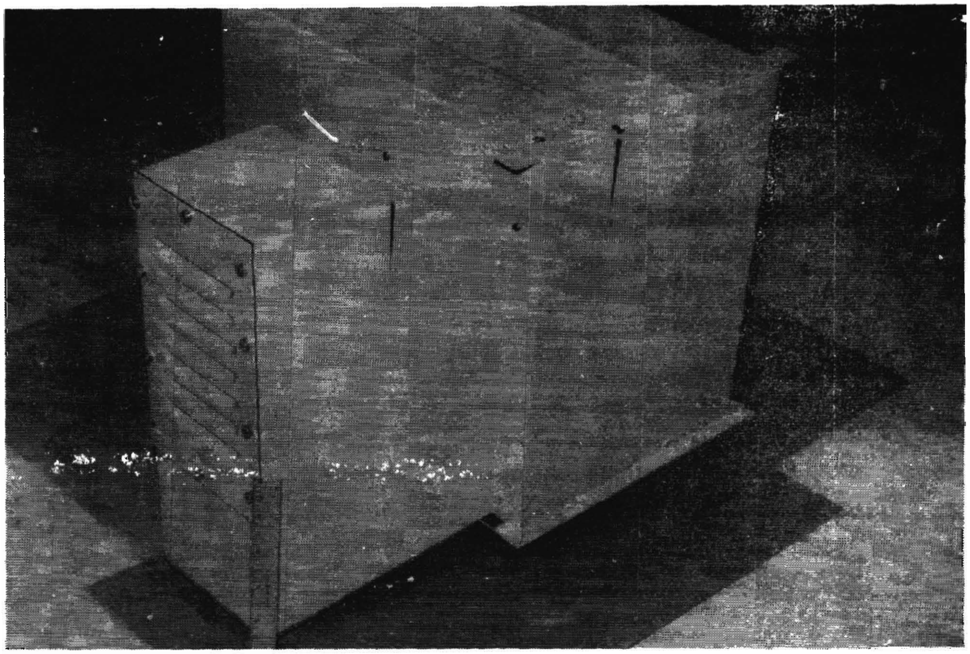


FIGURE 2–15 MOTOR CONTROLLER ENCLOSURE

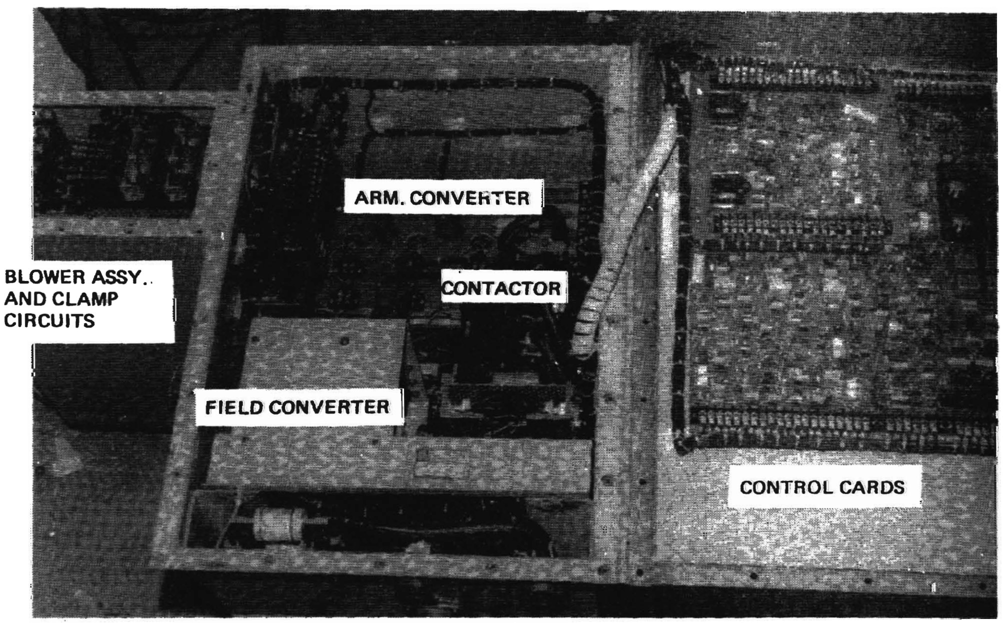


FIGURE 2–16 CONTROLLER MAJOR SUBASSEMBLIES

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The controller is designed to accept a nominal 480 volts, three phase, 60 Hz input which is brought into the enclosure through an environmental type, heavy duty connector. The input power then feeds through three semiconductor type power fuses and line filter. After the line filter network, the 480 volt power is applied to the armature converter SCR's. Also connected to the circuit at this point is the armature clamp circuit. This circuit absorbs longer term line transients as well as the energy in the armature inductance should power suddenly be interrupted while a large armature current is flowing. This circuit along with rapid system shutdown and loss of phase detection capabilities eliminate the possibility of armature converter faults, should a phase interruption occur during regenerative braking.

The motor field is supplied by a switching converter. The converter operates directly from the 480 volt line and has the capability of providing field current in either direction. Field converter control permits both regeneration and contactorless reversing. The field current is regulated such that motor torque is directly proportional to armature current.

The SCR heat sinks in the armature converter are equipped with temperature switches. When an overtemperature condition occurs, the switch opens and the controller shuts down. Overtemperature feedback is also provided to the vehicle control electronics.

Other conditions that are monitored include:

(1) low line voltage,

(2) incorrect phase,

(3) blown power fuse,

(4) controller power supplies out of tolerance,

(5) motor overtemperature,

(6) persistent field error, and

(7) illegal direction command.

2.5.2.3 Cooling System - The motor and controller are both force air ventilated by a single motor and centrifugal blower located on the side of each motor controller. Ambient air is introduced through louvers on the side of the blower housing and then through a filter before entering the blower. From the blower, air blows across the SCR heatsinks as it enters the motor controller. The air then circulates through the enclosure and exits through a flexible duct to the commutator/drive end of the motor. The blower motor operates from 230 volts, single phase AC supplied by a transformer located in the motor controller. Blower output is approximately 450 CFM.

2.5.2.4 Installation - The AUTP propulsion equipment is mounted entirely underneath the floor of the AUTP vehicle with each motor driving an axle. Figure 2-17 illustrates the location of the equipment on the underside of the vehicle.

2.5.2.5 System Weight - The total weight of the AUTP propulsion system is estimated to be 2658 lb per vehicle. The weight breakdown is as follows.

TABLE 2-4. PROPULSION SYSTEM WEIGHT

Motors (measured): 866 X 2	=	1732
Controllers (measured): 385 X 2	=	770
Power & Control Wiring (Est.)	=	60
Cooling Duct (Est.)	=	6
Drive Shafts & Yokes (Est.) 2 X 25.4	=	50.8
Mounting Bracketry & Hardware	=	39.9
Total System Weight		2658.7 lbs.

This value contrasts with 920 lbs for the 60 HP single drive AIRTRANS system. The above weight may be reduced by approximately 440 lbs per vehicle by substituting aluminum in the end bells on the motors.

2.5.3 PERFORMANCE CAPABILITIES - The following paragraphs summarize the performance capabilities of an AUTP vehicle with the dual Robicon propulsion system based on measured motor data.

2.5.3.1 Duty Cycle - Calculated root-mean-square (RMS) armature current for the AUTP propulsion system is shown in Figure 2-18 for several duty cycles. Calculations are based on a "C" vehicle operating at crush load, 30 mph cruise speed and 20 second station dwells. Figure 2-18 shows that the selected equipment meets the duty cycle requirements of the St. Paul route while using regenerative braking. Estimated duty cycle data for the Baltimore and Los Angeles DPM routes and an ideal site independent route having equal station spacing are also shown.

Figure 2-19 shows the propulsion system capabilities relative to the vehicle demands at other vehicle cruise speeds up to 45 mph.

2.5.3.2 Motor-Out Vehicle Performance - Since a capability to operate after sustaining a propulsion failure was a major consideration in selection of a dual system, motor-out performance is of interest. Figure 2-20, presents maximum speed/grade capabilities of both a single and two car consist after a propulsion failure. The grade capabilities shown on Figure 2-19 would meet the tractive effort requirements of all the DPM cities' alignments except for the case of crush loaded single car start on grades exceeding four percent.

2.5.3.3 Energy Utilization - Estimated vehicle energy consumption is shown in Figure 2-21 for the routes of Baltimore, Los Angeles and St. Paul, plus an ideal site independent route. The

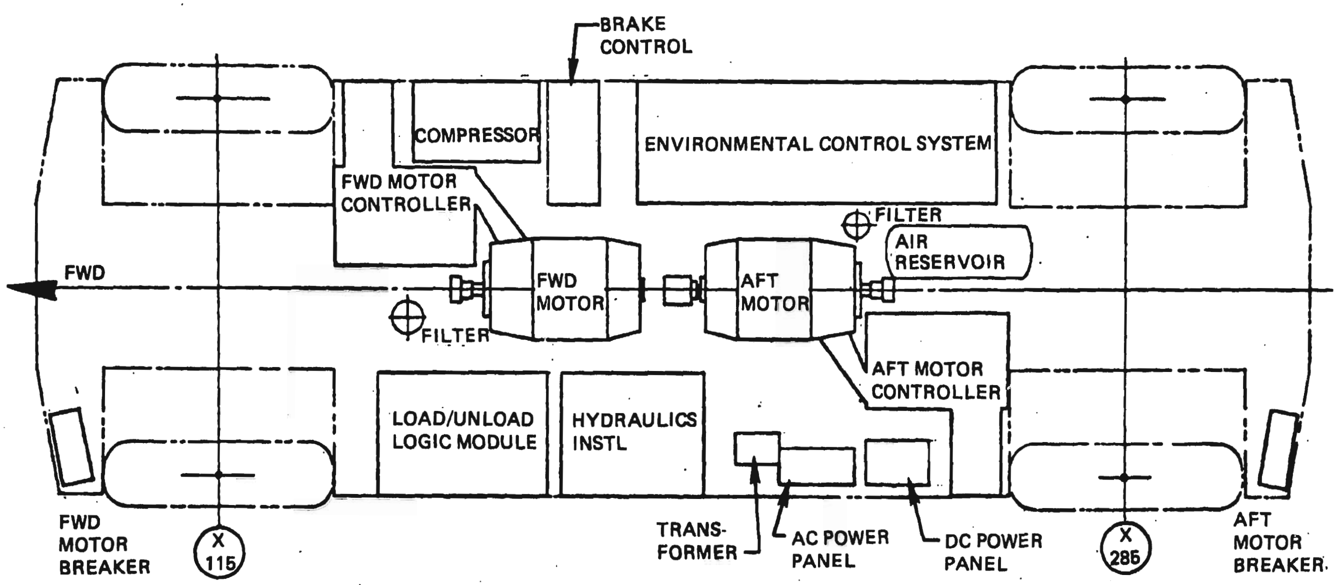

FIGURE 2–17 UNDERCAR INSTALLATION OF EQUIPMENT

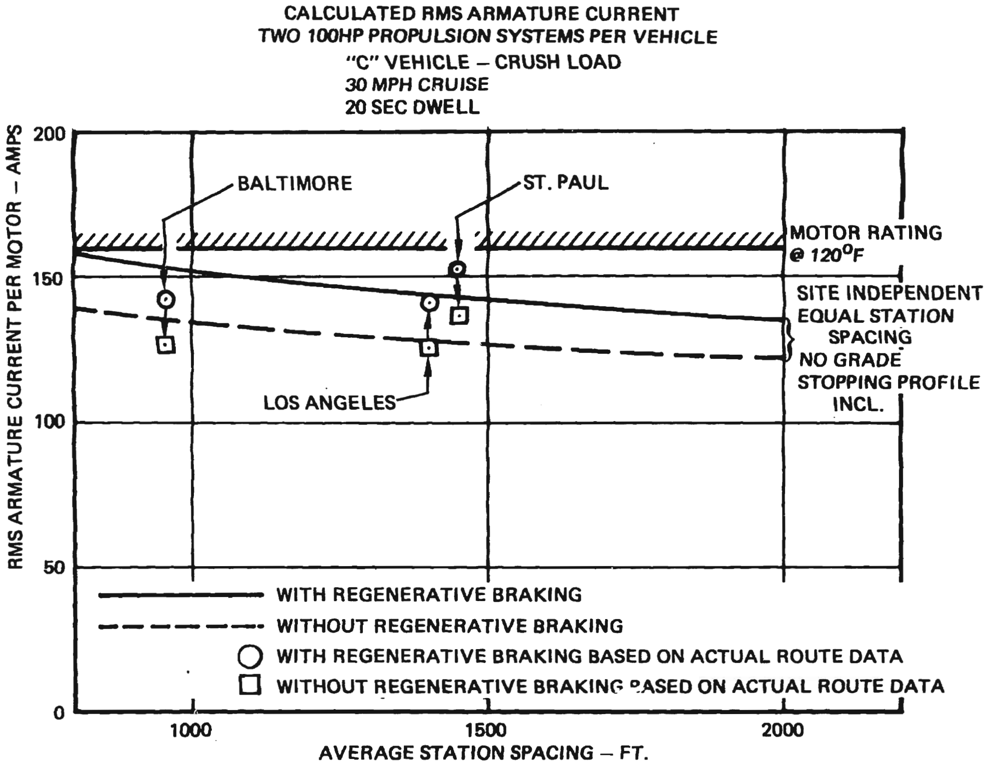

FIGURE 2–18 AUTP PERFORMANCE – DUTY CYCLE

energy values are what would be measured at the vehicle power collector and include estimated vehicle auxiliary loads. The distribution system was assumed to be completely receptive to regenerated energy. Energy consumption was calculated using the propulsion system performance program described in Appendix A. For the three routes shown, estimated energy (KW HR) savings by using regenerative braking are as follows:

Baltimore	22%
Los Angeles	20%
St. Paul	24%

Effects of regeneration on reactive power demands are discussed in Paragraph 2.6.

2.5.4 RELIABILITY - The mean distance between failures (MDBF) requirement for the production system was selected to be not less than 70,000 miles with a design goal of 140,000 miles. This requirement represents an improvement of 200% over the AIRTRANS requirement of 22,500 miles MDBF. The propulsion supplier was not required to demonstrate this criteria since demonstration

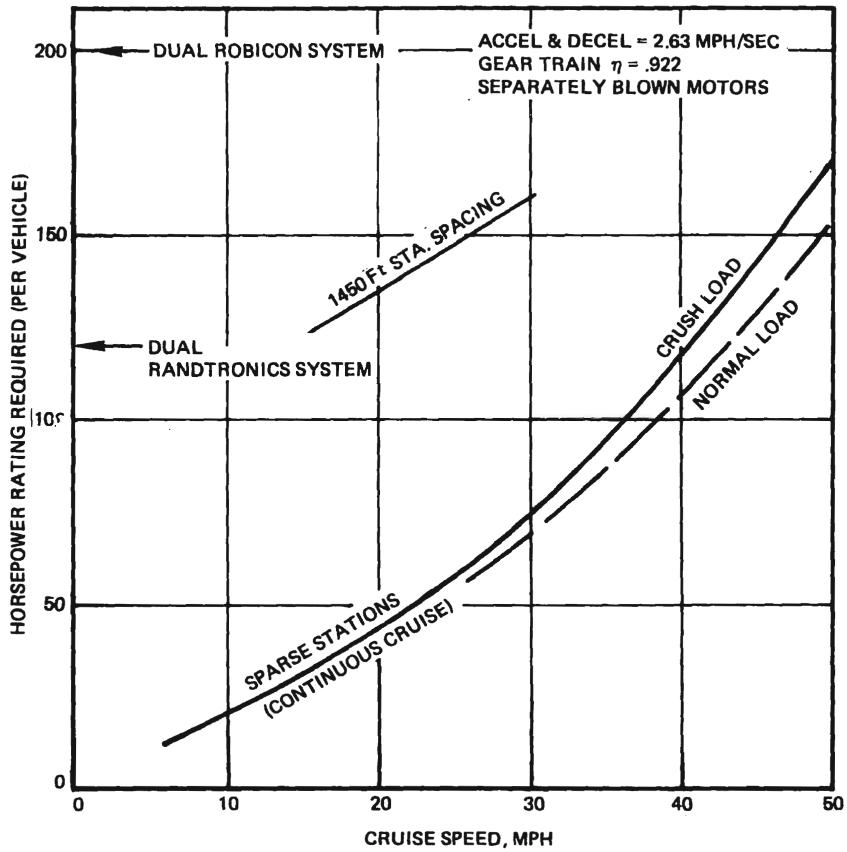

FIGURE 2–19 RATING REQUIREMENT VERSUS CRUISE SPEED

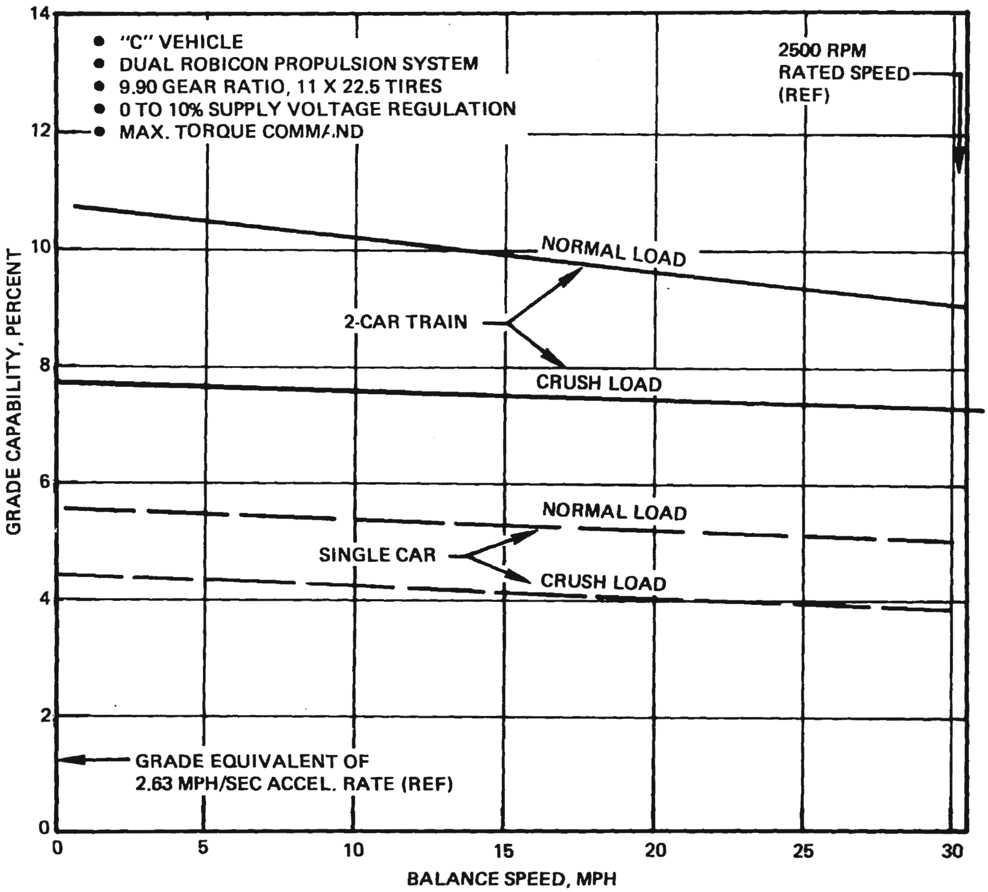

FIGURE 2–20 ESTIMATED MOTOR-OUT PERFORMANCE

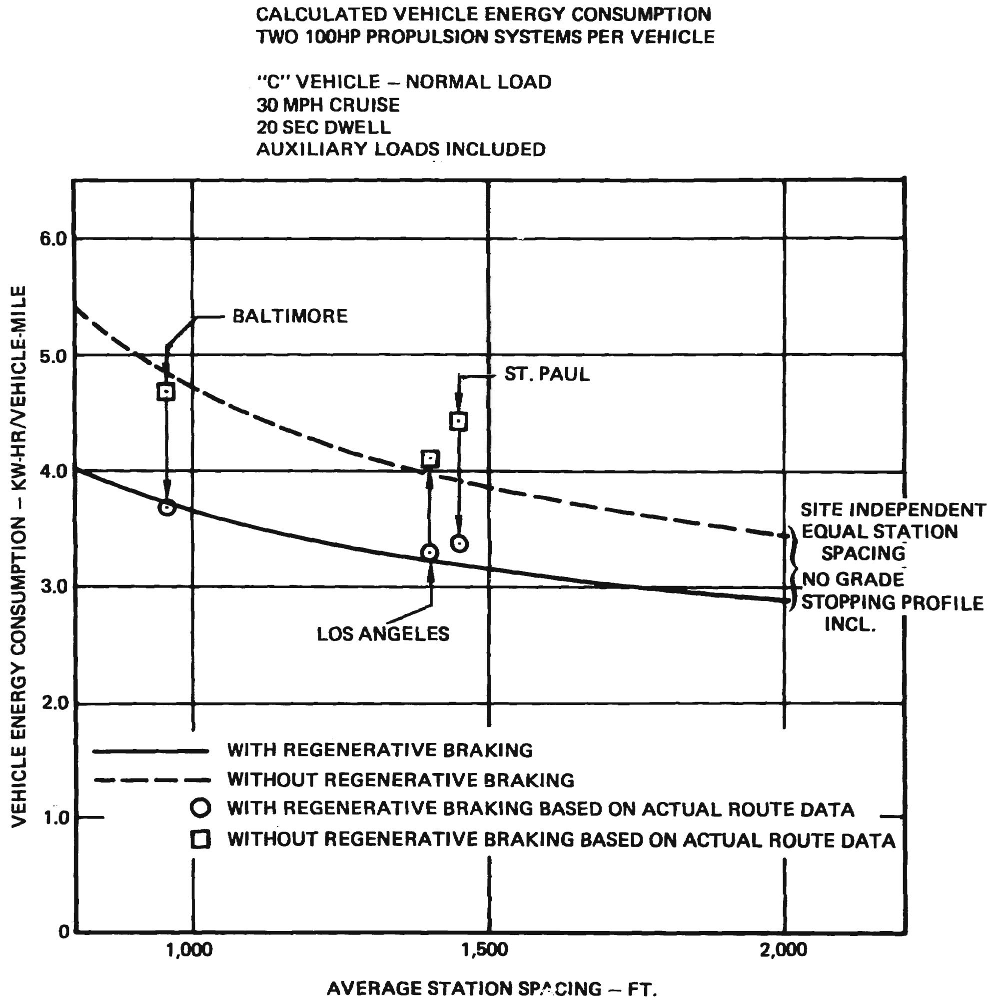

FIGURE 2–21 CALCULATED VEHICLE ENERGY CONSUMPTION

would require monitoring five ramdom vehicles for 154,000 to 721,000 miles. The MDBF requirement is considered to be realistic because of the following:

(1) An improvement in MDBF will accrue from the increased vehicle speed,

(2) The state-of-the-art in solid state motor drives is considerably advanced over that which existed at the time AIRTRANS was designed, and

(3) Both Vought and the supplier now have the benefit of prior experience with very similar equipment which is reflected in the design of the new system.

2.6 DESIGN VERIFICATION TESTS

The AUTP propulsion system was evaluated by both off-guideway and on-guideway tests. The off-guideway tests were performed at the supplier's laboratory facilites and in Vought's manufacturing/assembly facilities. On-guideway (running) tests were performed with the equipment installed in a test vehicle and run over the Dallas/Fort Worth AIRTRANS guideways.

2.6.1 OFF-GUIDEWAY TESTS - Off-guideway testing was performed at Robicon Corporation's test facilities in Monroeville, Pennsylvania. These tests included:

(1) Inspection for materials, quality, form, fit, maintainability and mechanical interface,

(2) Verification of electrical and controls interface,

(3) Verification of duty cycle capabilities, and

(4) Verification of efficiency and torque.

Due to schedule and budget limitations, laboratory environmental tests (vibration, shock, EMI, low temperature, etc.) were postponed to future developmental programs. Operating experience and design similarity substantially reduced the risk of running test problems in these areas.

Checkout and operational tests such as continuity checks were performed at the Vought manufacturing and assembly facilities during and after the system's installation on the test vehicle in preparation for the "running" tests. Electrical and controls interface were checked by operating the system with the vehicle on jacks. Techniques were developed "loading" the system with the vehicle's friction brakes to permit static vehicle operation of the system.

2.6.1.1 Laboratory Tests - Figures 2-22 and 2-23 show two views of the basic laboratory test setup. The two motors and controllers were installed (inverted) on a portable test frame. The output shafts of the two motors were connected together for the tests when high power was run and for performance measurements, i.e., the second system served as a "dynamometer" for the first. All electrical and controls interfaces were simulated as closely as possible to that specified. The electrical and controls setup for the tests are shown in the block diagram of Figure 2-24. Kw and KVAR metering equipment was designed and fabricated for these tests, delivered with the system and installed on the test vehicle. The PROGRAMMER provided the capability for automatic running of the specified duty cycle tests in both regenerative and non-regenerative modes of operation. With the motor shaft disconnected, the EXERCISER provided the capability of accelerating one motor to full speed and then automatically applying regenerative braking against the inertia of the motor until the

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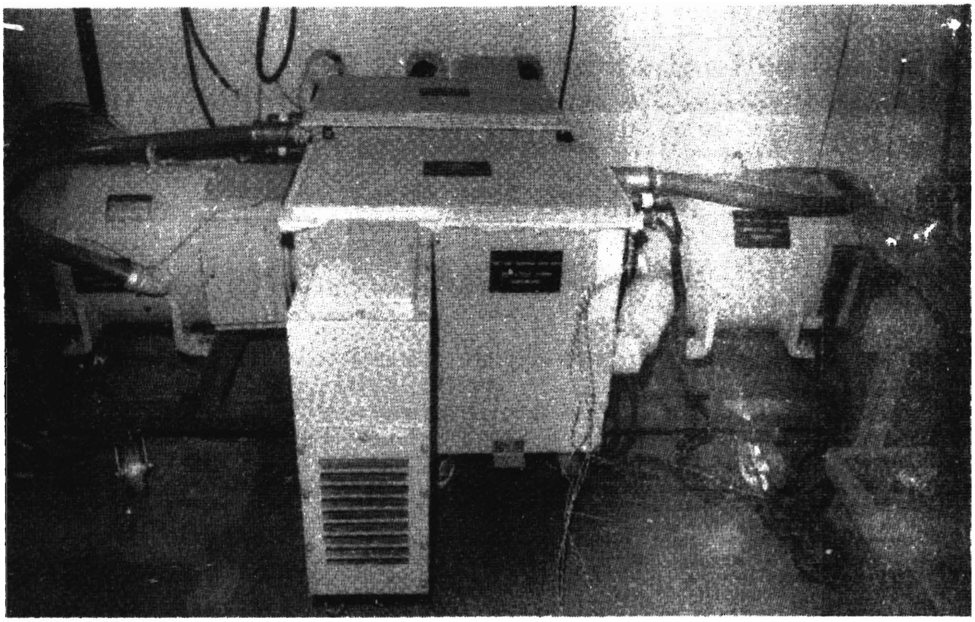


FIGURE 2–22 LABORATORY TEST SETUP – SIDE VIEW

FIGURE 2–23 LABORATORY TEST SETUP – END VIEW

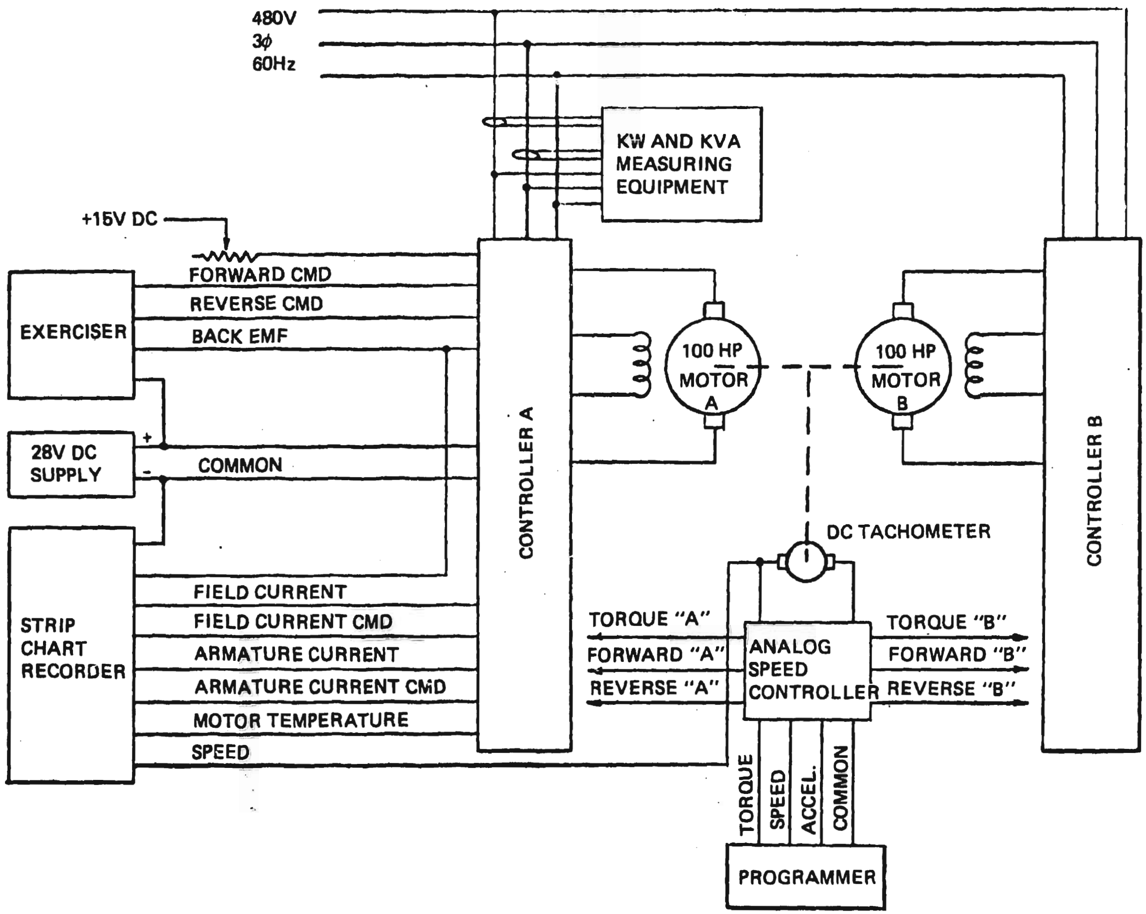


FIGURE 2–24 BLOCK DIAGRAM – LABORATORY TEST SETUP

motor stopped. The cycle was then repeated.

The AUTP propulsion equipment passed test requirements with specification waivers given to propulsion controls operations under low voltage conditions (380 volts instead of the specified 340 volts). Low voltage control operation was waived due to projected delivery delay of 8 weeks on a redesigned control transformer. Testing under low voltage power operation was also waived due to extensive modifications required to the laboratory power substation. The substation modifications would have resulted in several weeks of delivery delay.

Being a prototype unit, other minor waivers were given in regard to quality, workmanship, materials, design details and space envelope. These minor discrepancies will be corrected on any further propulsion system procurements.

Four laboratory duty cycle tests were performed. Both regenerative and non-regenerative braking modes were run at room temperature and then repeated in the hot room facility at 50°C. Figure 2-25 presents a sample record of the duty cycle tests. Approximately ten 15 minute round trip duty cycles were required to reach temperature equilibrium in all major system subassemblies. Figure 2-26 shows the worst case (regenerative, 50°C ambient) temperature levels of major system elements after 10 cycles through the design (St. Paul) duty cycle. The motor interpole temperature stabilized at approximately 97°C. According to the motor supplier, this represents a motor armature hot spot temperature of approximately 145°C, well within motor design limits of 200°C. The conclusions are that the dual motor AUTP propulsion system meets the St. Paul duty cycle.

Power measurements during the cycle tests provided data for a comparison of power demands and energy consumption over the design duty cycle. These data are summarized in table 2-5, comparing AUTP propulsion power demand and energy consumption during regenerative and non-regenerative braking modes. Receptivity of the lab test facility to regenerative power was 100%. Reference to Table 2-5 shows for the regenerative braking mode a decrease of 26% in real power with a corresponding increase of 50.9% in reactive power (reactive power is required from the source in both motoring and regenerative braking). This compares with initial estimates of real power savings of 23.9%. The greater increase in reactive power demand more than offsets the decrease in real power demand, giving an overall increase of 31.5% in Kilovolt-ampere (KVA) demand.

The net increase in KVA due to regenerative braking results in requirements for increased ratings in power substations and power conductor rails while presenting a reduced and less desirable power factor to the supplying utility. The impacts from more complex vehicle systems, increased wayside power equipment ratings, power billings, and power utility interface must be traded against real power savings, reduction in friction brake

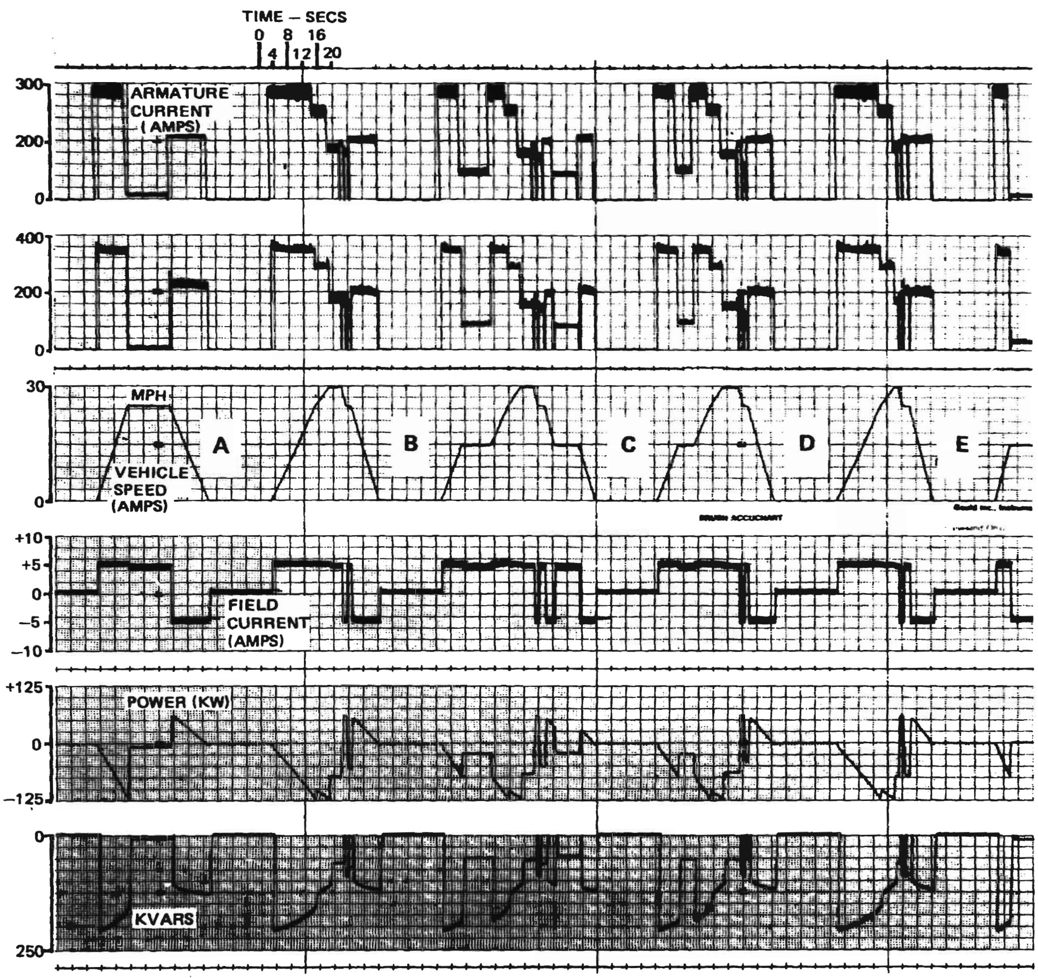


FIGURE 2–25 DUTY CYCLE TEST

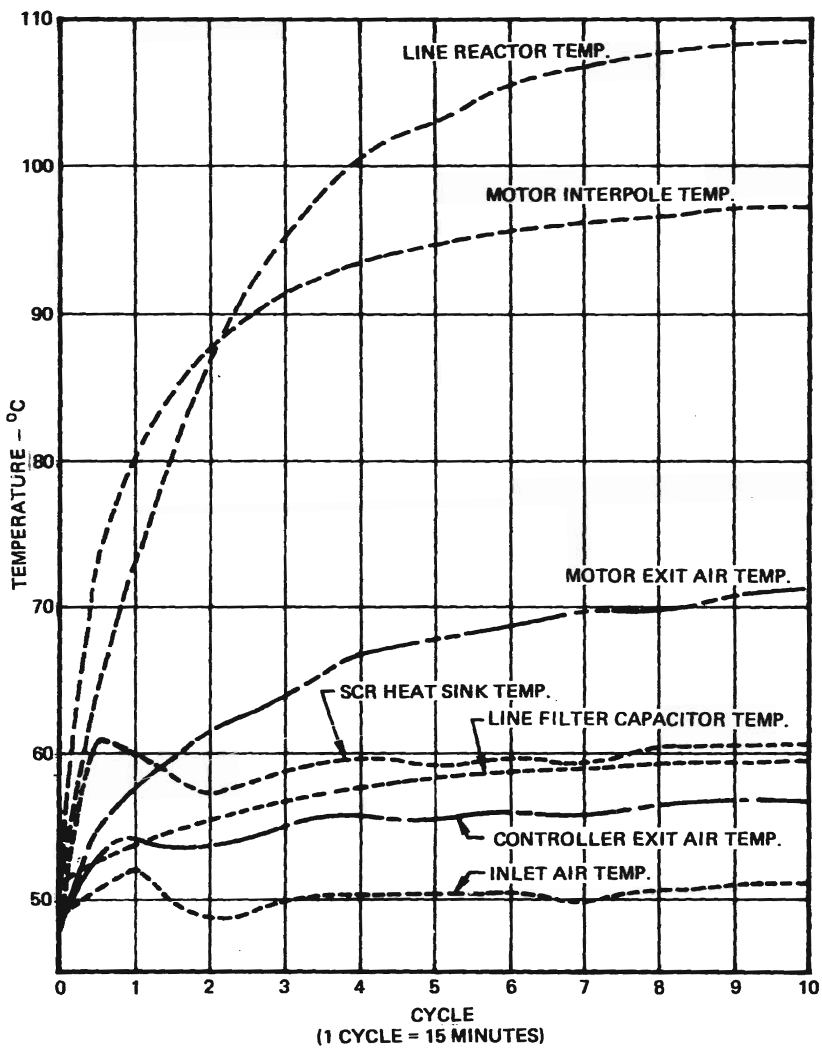


FIGURE 2–26 DUTY CYCLE TESTS – TEMPERATURE

TABLE 2–5 SUMMARY OF ENERGY AND DEMAND ANALYSIS FOR DESIGN DUTY CYCLE

	BRAKING MODE	
ITEM	REGENERATIVE	NONREGENERATIVE
1. Average KW Demand (P)	37.7	51.2
2. Average KVAR Demand (Q)	113.6	75.3
3. Average KVA Demand (S)	119.7	91.0
4. Average Power Factor (P.F.)	0.315	0.562
5. KWHR Energy Consumption	9.425	12.80

NOTE: (1) Consumption and average demands are for a nominal 15 minute design duty cycle on the propulsion system only.

(2) KW = Kilowatts
KVAR = Kilovolt-amperes reactive
KVA = Kilovolt-amperes

(3) $P + jQ = S$; $P.F. = P/S$

wear and improved ride quality obtained with the regenerative braking system. Decisions to use regenerative braking remains a site dependent function.

Figure 2-27 summarizes the results of the output torque verification tests, showing the relationship between armature current, output torque and motor speed. Measured values of torque are slightly less than projected values. Output torque can be increased 5 to 10% by field level and field augmentation adjustments within the controllers.

Figures 2-28 and 2-29 are curves of motor and controller efficiencies respectively for various motor armature currents and speeds. Significant inaccuracies in measuring input three phase power resulted in unacceptable data above 1 per unit armature current for the controller measurements. The dashed lines above 1 per unit represents projected efficiency. The controller efficiency is lower than normally expected because the cooling blower's consumption (410 watts) is charged as a controller loss.

2.6.2 GUIDEWAY RUNNING TESTS - On-guideway testing of the AUTP propulsion system was accomplished in two stages: diagnostic runs and test runs. The diagnostic and checkout runs were accomplished simultaneously while performing vehicle steering tests. Additional runs were devoted to testing of the propulsion system. The paragraphs below briefly describe the vehicle changes to accommodate the AUTP propulsion system, propulsion test equipment, instrumentation, test plans/procedures and data gathering. The running tests were completed without major problems.

2.6.2.1 <u>System Installation</u> - Test vehicle T-365 required a number of changes in order to accommodate the AUTP propulsion system. These changes included.

(1) Removing the AIRTRANS motor, controller, drive shaft, mounting bracketry and power/control wiring harnesses.

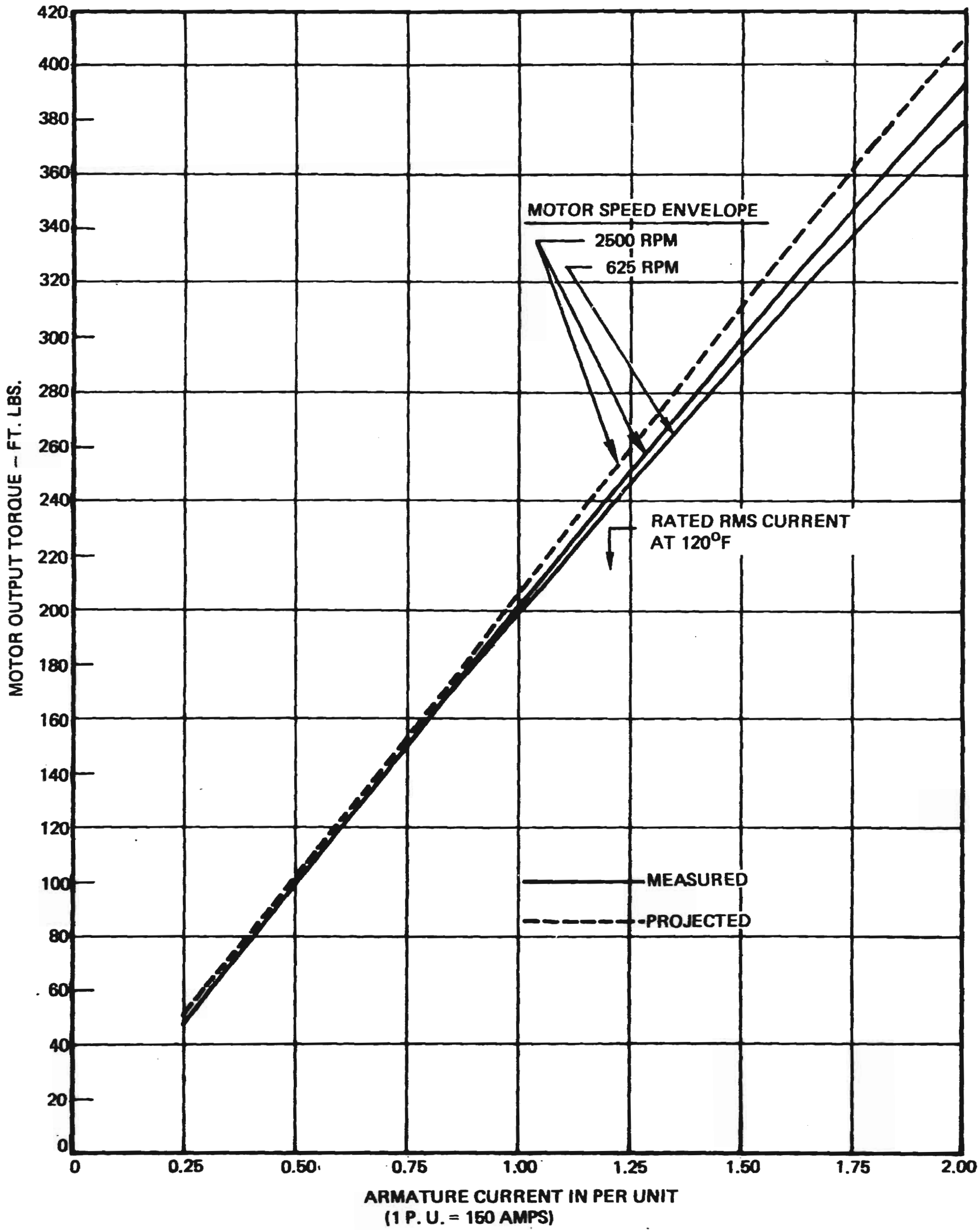


FIGURE 2–27 MOTOR TORQUE CHARACTERISTICS

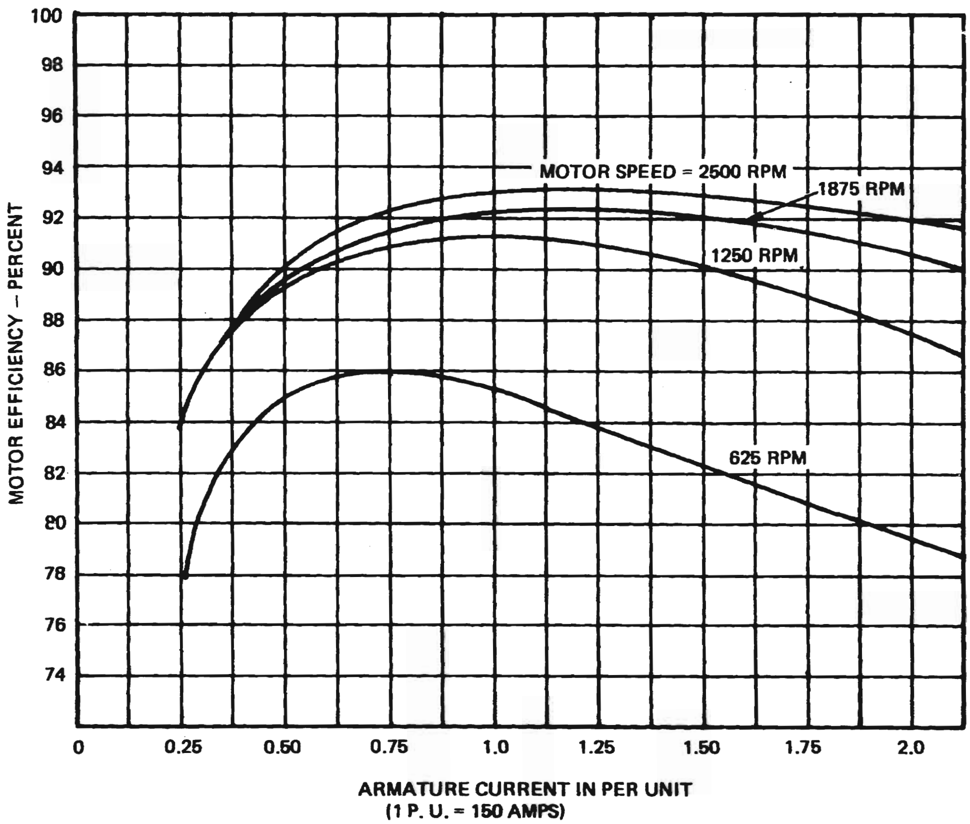


FIGURE 2–28 MOTOR EFFICIENCY

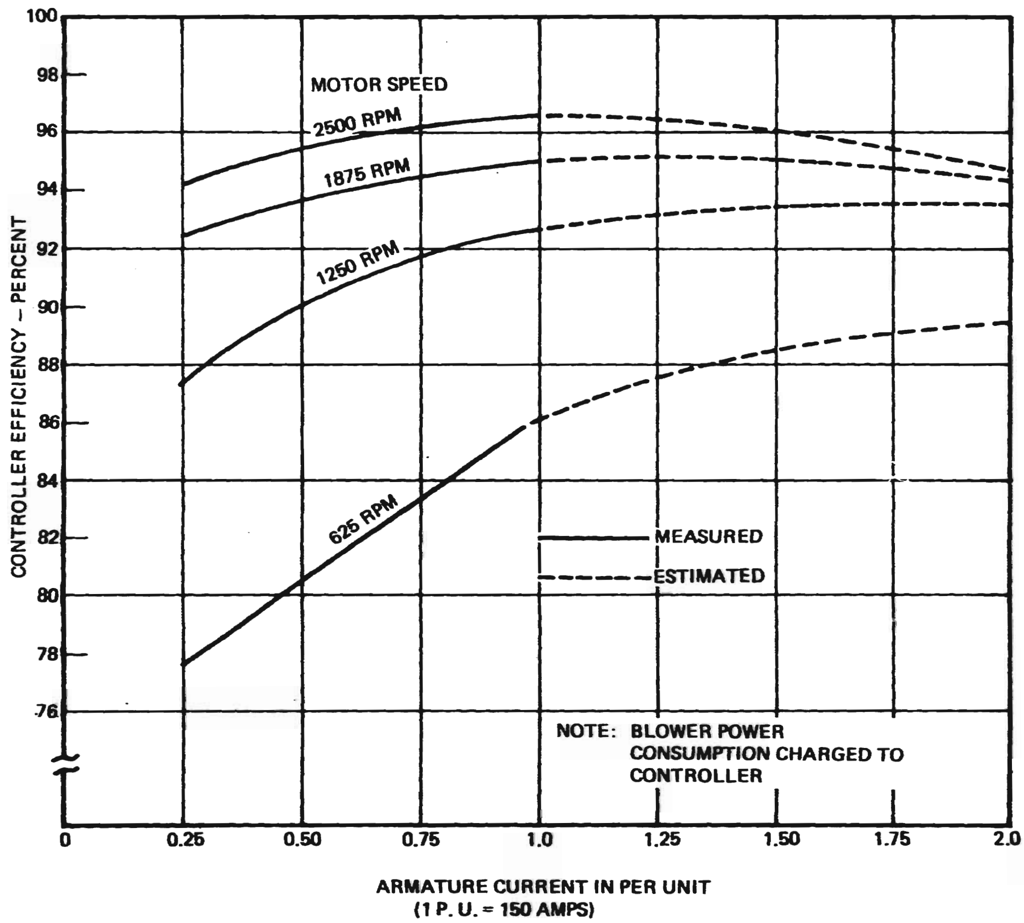


FIGURE 2–29 CONTROLLER EFFICIENCY

p p

(2) Rebuilding the drive axle, changing the gear ratio from 17.44 to 7.8 to 1 and converting the forward undriven axle to powered axle with gear ratio of 7.8 to 1 (Although the motors were selected for operation with a gear ratio of 10.1 to 1, the 7.8 to 1 gear ratio was selected for these running tests because of compatibility with the existing axles. The motor drive shafts were lengthened and increased in size.

(3) Building the power metering and battery compartments inside the vehicle. Moving the storage battery from undercar to the interior. Rebuilding the AC and DC power panel support shelves. Rebuilding the auxiliary power compartment and shelf.

(4) Installing the two AUTP motors, controllers and drive shafts. Installing propulsion power, control and diagnostic wiring.

(5) Designing, fabricating and installing a propulsion control panel inside the vehicle. Revising the vehicle command and control system to interface with the AUTP propulsion system.

(6) Designing, fabricating and installing a diagnostic/ instrumentation patch panel inside the vehicle.

(7) Installing propulsion power metering equipment under and inside the vehicle. Fabricating and installing the power/energy display panels.

(8) Rebuilding and rerouting forward-to-aft steering linkage.

2.6.2.2 Propulsion Test Equipment - Test equipment used in the AUTP propulsion running tests included:

(1) Digital voltmeter - Hewlett-Packard Model HP3455A,

(2) Visicorder - Minneapolis/Honewell Model 1848 (16 Channels), and

(3) Oscilloscope - Hwelett-Packard Model 1741A.

The above equipment is mounted within the vehicle. Additional portable meters and scope cameras were also used. Figure 2-30 shows the Propulsion Control Panel and test equipment installation.

2.6.2.3 Instrumentation/Diagnostic Patch Panel - An 80-point instrumentation/diagnostic patch panel was fabricated and installed to permit patching of selected command/control and AUTP propulsion diagnostic signals. Table 2-6 lists the propulsion diagnostic and related signals available from this panel.

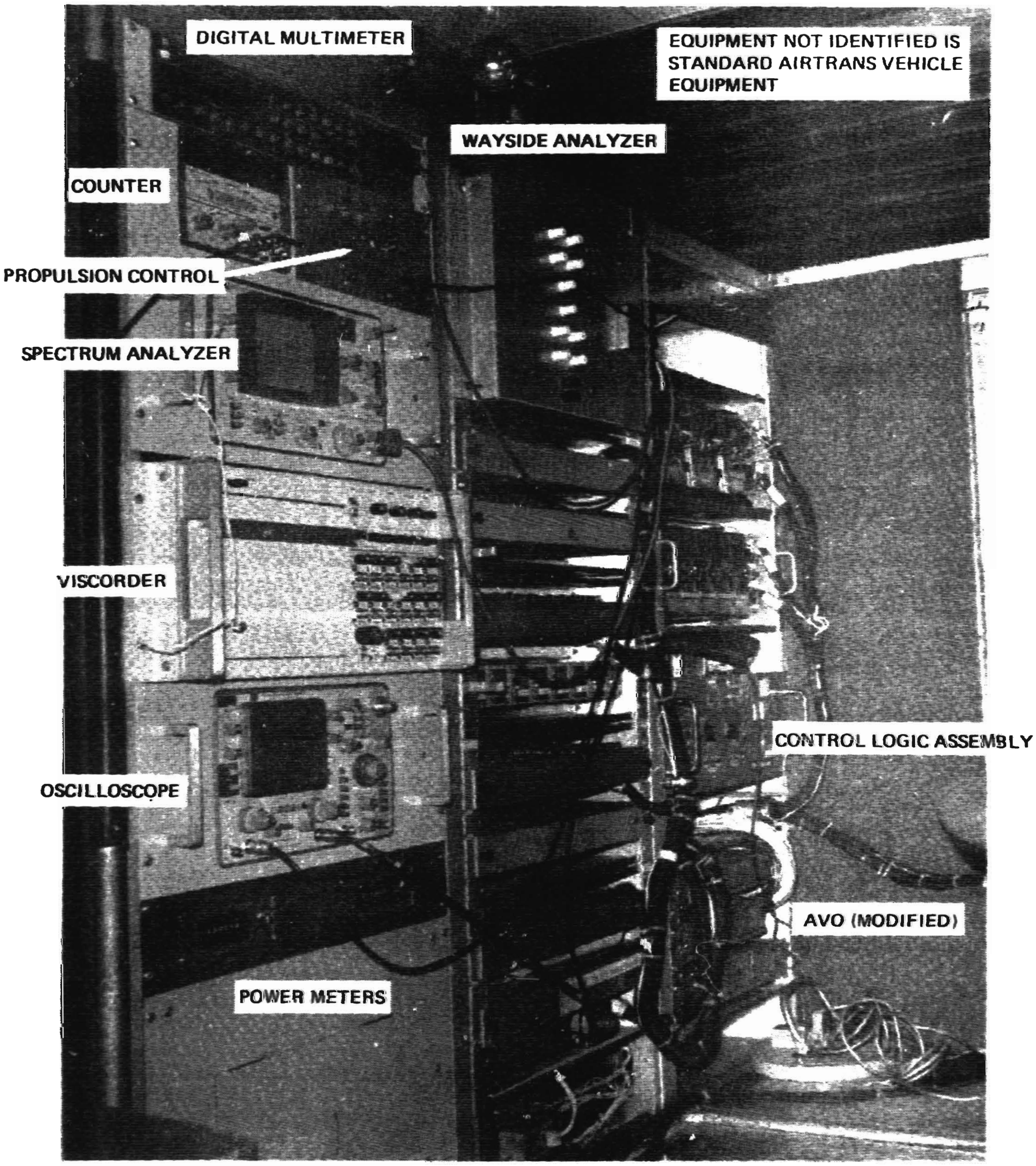


FIGURE 2–30 CONTROL PANEL AND TEST EQUIPMENT BAY

TABLE 2–6 PROPULSION DIAGNOSTIC SIGNALS ON INSTRUMENTATION/DIAGNOSTIC PATCH PANEL (NO. 1 IS FRONT MOTOR/CONTROLLER; NO. 2 IS REAR MOTOR/CONTROLLER)

ITEM	PATCH PANEL CONNECTOR	SIGNAL
1.	P21	No. 1 Regulated Power Supply (+24 Volts)
2.	P22	No. 1 Inlet Air Temperature (Inactive)
3.	P23	No. 1 Regulated Power Supply (+15 Volts)
4.	P24	No. 1 Regulated Power Supply (–15 Volts)
5.	P25	No. 1 Motor Analog Temperature
6.	P26	No. 1 Start/Stop Signal
7.	P27	No. 1 Reset Command Signal
8.	P28	No. 1 Forward Torque Direction Command
9.	P29	No. 1 Reverse Torque Direction Command
10.	P30	No. 1 Torque Command
11.	P31	No. 1 Armature Current Feedback
12.	P32	No. 1 Field Current Signal
13.	P33	No. 1 SCR Heat Sink Temperature (Inactive)
14.	P34	No. 1 Master Disenable Circuit (Inactive)
15.	P35	No. 1 Armature Current Shutdown Signal
16.	P36	No. 1 Counter EMF (V_G)
17.	P37	No. 1 Bypass Gate Enable (Inactive)
18.	P38	No. 1 Field Current Command
19.	P39	No. 1 Line Voltage Feedback
20.	P40	No. 1 Line Reactor Temperature (Inactive)
21.	P41	No. 2 Regulated Power Supply (+24 Volts)
22.	P42	No. 1 Controller Exit Air Temperature (Inactive)
23.	P43	No. 2 Regulated Power Supply (+15 Volts)
24.	P44	No. 2 Regulated Power Supply (–15 Volts)
25.	P45	No. 2 Motor Analog Temperature
26.	P46	No. 2 Start/Stop Signal
27.	P47	No. 2 Reset Command Signal
28.	P48	No. 2 Forward Torque Direction Command
29.	P49	No. 2 Reverse Torque Direction Command
30.	P50	No. 2 Torque Command
31.	P51	No. 2 Armature Current Feedback
32.	P52	No. 2 Field Current Signal
33.	P54	No. 2 Master Disenable Circuit (Inactive)
34.	P55	No. 2 Armature Current Shutdown
35.	P56	No. 2 Counter EMF (V_G)
36.	P57	No. 2 Bypass Gate Enable (Inactive)
37.	P58	No. 2 Field Current Command Signal
38.	P59	No. 2 Line Voltage Feedback
39.	P60	No. 1 or No. 2 Contactors Closed
40.	P61	No. 2 Forward Torque Direction Feedback
41.	P62	No. 2 Reverse Torque Direction Feedback
42.	P63	No. 1 and No. 2 Contactors Open
43.	P64	No. 1 Forward Forward Torque Direction Feedback
44.	P65	No. 1 Reverse Torque Direction Feedback
45.	P66	No. 1 Motor Exit Air Temperature
46.	P67	Propulsion Real Power (Kw)
47.	P68	Propulsion Reactive Power (Kvar)
48.	P73, P74, and P75	Line Voltage Potential Transformer (PT) Outputs (3ϕ)
49.	P76, P77, and P78	Propulsion Current Transformer (CT) Outputs (3ϕ)

NOTE: Inactive means that the circuit is presently inoperative due to the lack of a driving circuit or is presently being used for the monitoring of other internal controller test points. Since the D/FW AIRTRANS running tests can in no way approach the designed duty cycle for the AUT propulsion system, the expense of incorporation driving circuits for many temperature measurements were not made during the Phase I tests.

2.6.2.4 Diagnostic/Checkout Test Runs - AUTP propulsion and checkout testing was performed simultaneously with vehicle steering tests. A total of 50 test loop runs were made during this phase with 17 of these runs maintaining or obtaining speeds of 30 MPH in the high speed test section. An additional 9 runs were made around the 6W maintenance section for an estimated total mileage of 240 miles in this phase. Propulsion diagnostic parameters were monitored during these runs.

The propulsion system performed well. The rear (#2) motor controller occasionally experienced shut down and/or failure to build up armature current in sections of the guideway that experienced weak wayside power and unusually heavy traffic flow. Upon completion of the steering running tests, several additional runs were devoted to tuning and adjusting the propulsion system. The undervoltage shutdown settings were reduced on both controllers and component changes were made to smooth out low voltage transients and reduce effects of line voltage harmonic distortion. The adjustments have eliminated all nuisance tripping or cycling.

2.6.2.5 Test Runs - Eight additional test runs were made to gather propulsion system data at various speeds. These runs resulted in an additional 40 miles for an accumulated total of 280 miles on the system. These runs were devoted to a study of system response and line voltage/current waveforms.

Figure 2-31 shows responses to a manual acceleration on a grade to a speed of 30 MPH. Figure 2-32 illustrates typical responses in accelerating to 17 MPH while operating in the automatic control mode. It can be noted that excellent response of armature current (torque) was achieved in following the torque command signal. In the non-regenerative braking tests, an armature current bias of 15 amperes at zero torque command has been incorporated to prevent rollback during starting on grades.

Figure 2-33 shows that typical deep notching and line voltage waveform distortion encountered in weaker sections of guideway power during vehicle acceleration or hill climbing. Figure 2-34 depicts typical propulsion current waveform while Figure 2-35 illustrates voltage and current waveforms on the same photo. The latter photo is for a vehicle accelerating in a strong wayside power area. Although the AUTP propulsion and other vehicle systems can tolerate the worst of these waveforms, reliability and operational integrity can be insured by use of a strong and closely regulated wayside power system.

2.7 CONCLUSIONS

The prototype AUTP propulsion system development program is considered a success. All major milestones of the program were satisfied and the equipment met all requirements with minor exceptions.

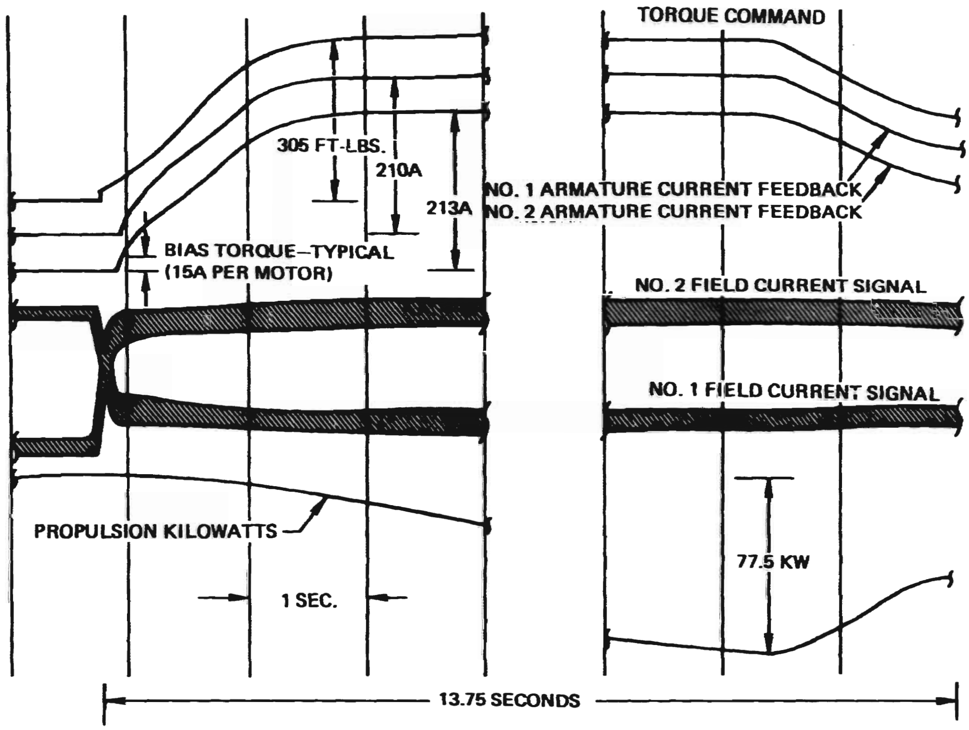


FIGURE 2–31 MANUAL ACCELERATION TO 30 MPH UP A GRADE

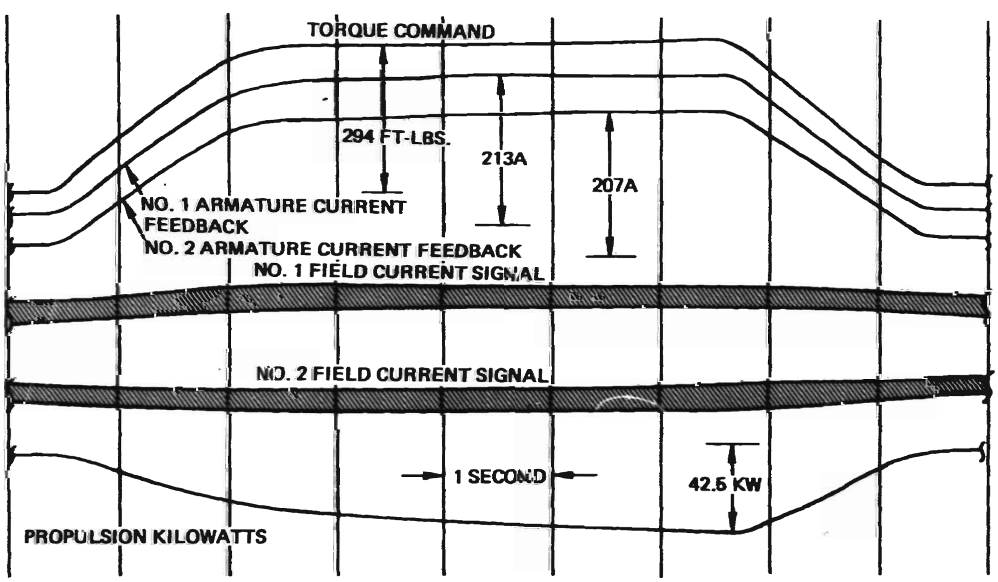


FIGURE 2–32 TYPICAL RUNNING UNDER AUTOMATIC CONTROL AT 17 MPH

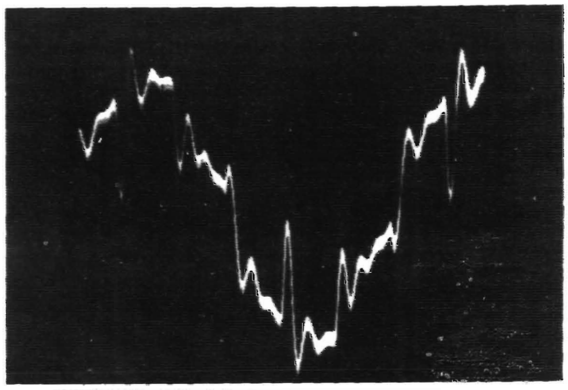


FIGURE 2–33 LINE VOLTAGE WAVEFORM (WEAK POWER AREA)

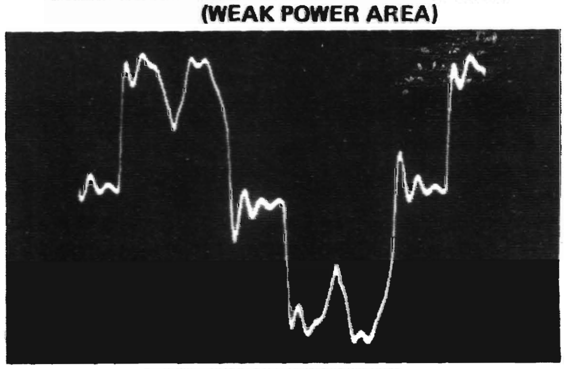


FIGURE 2–34 LINE CURRENT WAVEFORM (WEAK POWER AREA)

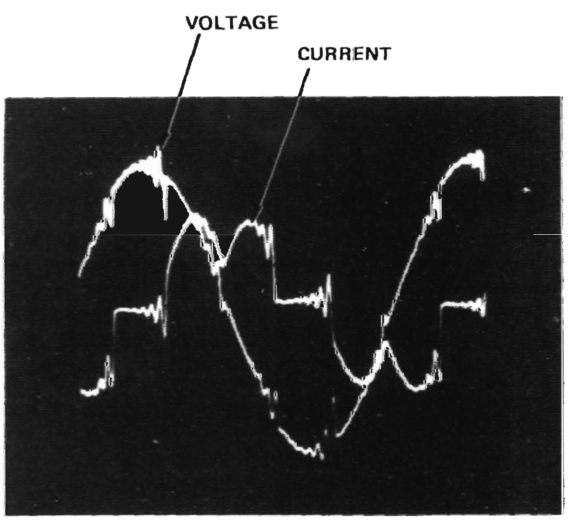


FIGURE 2–35 LINE VOLTAGE AND CURRENT WAVEFORMS (STRONG POWER AREA)

3.0 COLLECTOR SYSTEM

Successful operation of AIRTRANS relies heavily upon the vehicle control signal, the three phase electric power and the electrical ground collection equipment to provide adequate electrical contacts between the vehicle and the wayside conductor system. Within the environment of the Dallas/Fort Worth Airport the AIRTRANS collection equipment satisfactorily performs these functions. However, application of this equipment to a different environment, particularily one involving higher vehicle speeds, requires an evaluation of the equipment to assure acceptable performance. This section presents performance evaluations for both the AIRTRANS and newly-conceived collector and conductor system equipment when subjected to the operating conditions associated with an urban environment. Descriptions of the various designs, tests objectives and procedures, test results and corresponding analyses, conclusions, and recommendations are provided.

3.1 DESCRIPTION OF THE AIRTRANS CONDUCTOR AND COLLECTOR SYSTEMS AND STATEMENT OF THE PROBLEM

The provision of electrical ground and the transfer of control signal and three phase electric power from the guideway-mounted conductor system to the AIRTRANS vehicles are accomplished by vehicle-mounted collectors. The shoe of each collector is preloaded against and operates in sliding contact with the individual conductors. The functional relationship of the collectors and conductor system is shown by Figure 3-1. The primary purpose of the collection equipment is to maintain electrical contact between the vehicle and conductor system so that:

(1) The required level of vehicle control data transmission is maintained,

(2) Uninterrupted flow of electric current to the vehicle propulsion and auxiliary systems is provided, and

(3) Electrical ground contact is maintained.

To fulfill this purpose the collectors must maintain mechanical contact at the shoe/conductor interface.

The AIRTRANS conductor system is composed of three side-running conductor subsystems (vehicle control signal, three phase electric power and electrical ground), intermittently spaced insulator/supports which attach the conductors to the guideway wall and collector approach and depart ramps; nominal spacing of the insulator/supports along the guideway is 7.5 feet. Each conductor element is a steel tee to which is swaged a copper running surface. The standard length of each element is 30 feet. The signal subsystem and power subsystem are formed by end-to-end attachment of conductor elements at bolted splice, expansion or isolation joints. Splice joints provide rigid support and electrical continuity between adjoining conductor elements. Expansion joints compensate for thermal effects on conductor length and maintain electrical continuity across the joint. In the signal subsystem, the function of the isolation joint is to maintain electrical separateness of the vehicle control signal blocks and to provide a smooth running surface and rigid support at conductor element joints. In the power subsystem, isolation joints are the electrical insulation between the various power zone blocks within the guideway network. Splice and expansion joints are used to join all the conductor elements of the electrical ground subsystem making this subsystem electrically continuous at all conductor element joints.

The vehicle switching method of AIRTRANS requires that the conductor system be installed in overlapping segments to the left or right of the vehicle throughout the guideway network. The vehicles are equipped to collect control signal and electric power, and maintain electrical ground contact from either side of the guideway. Collector ramps are installed at each end of all conductor system segments. A visual description of the collector ramping method used by AIRTRANS is shown by Figure 3-2. Approach ramps are nonmetallic elements which are sloped toward and attached to the end of the conductor system segment. These serve to "scoop up" and compress the extended collectors of the passing vehicle and laterally align the collector shoes with the conductors. Depart ramps are used at the opposite end of the conductor segment to prevent rapid extension of the collectors. The geometry of the depart ramp is, in general, symmetrical to that of the approach ramp.

The running surface profile of the production AIRTRANS approach ramps is composed of a straight section and a parabolic transition section similar to that shown by Figure 3-3. The slope of the straight section is gentle enough so that, at the maximum operating speed of 17 MPH, impact loads do not damage the collectors. The parabolic section provides curvature necessary to ensure that the centrifugal force imposed at the shoe during ramping does not exceed the collector preload force. Operating over the AIRTRANS ramp profile at speeds in excess of 17 MPH will, however, impose abnormal impact loads and centrifugal forces on the collection equipment. The effects of higher speed ramping were investigated in this study.

Figure 3-4 illustrates the AIRTRANS collection equipment installation. This installation occurs symmetrically at each side of the vehicle. All four ground collectors are connected in electrical parallel on board the vehicle. Electrical grounding of the vehicles is provided a degree of redundancy since two collectors are theoretical in contact with the ground conductor at all times. Each of the four like-phase power collectors are connected in electrical parallel which, like the vehicle grounding subsystem, provides redundant collector/conductor contact. The two leading signal collectors are connected in electrical parallel as are the two trailing signal collectors.

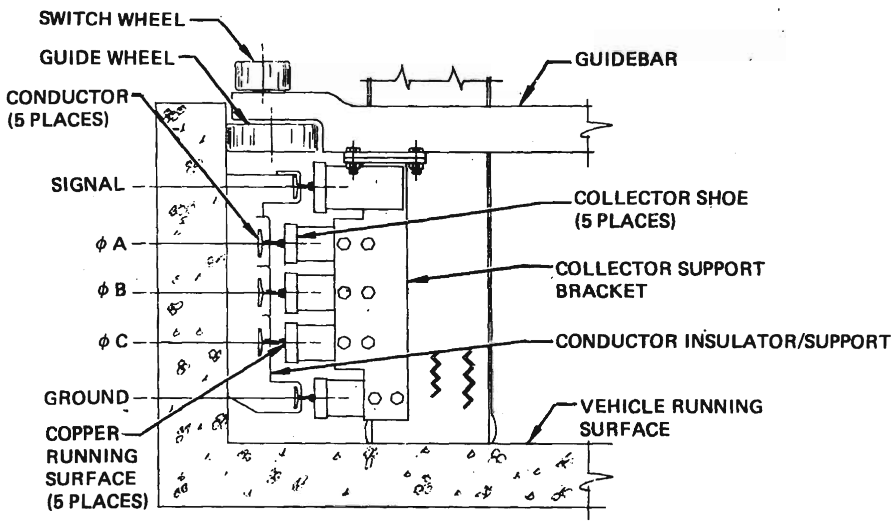


FIGURE 3–1 RELATIONSHIP OF AIRTRANS COLLECTOR AND CONDUCTOR SYSTEMS

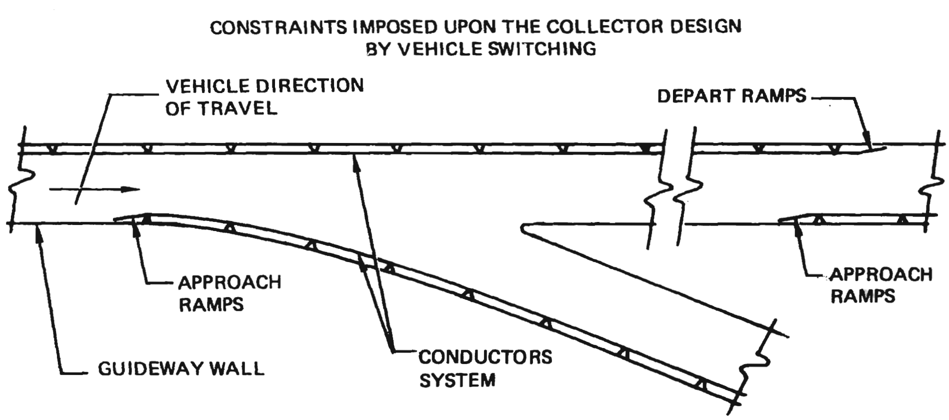


FIGURE 3–2 AIRTRANS COLLECTOR RAMPING METHOD (PLAN VIEW)

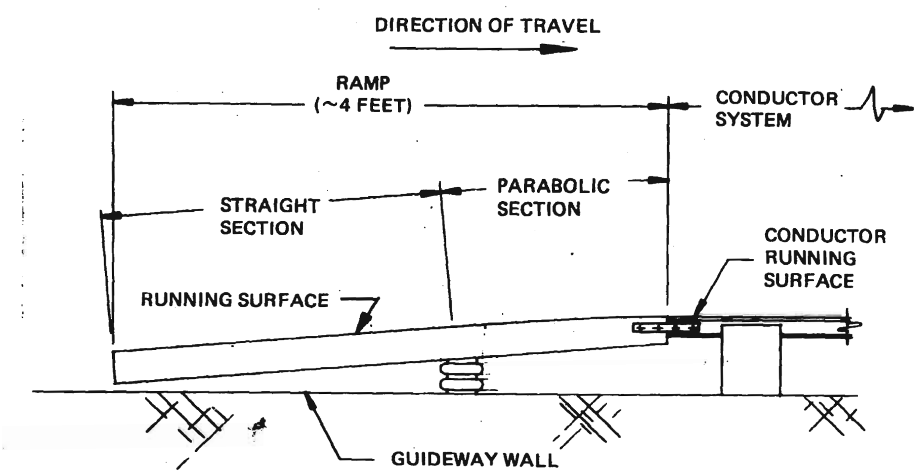


FIGURE 3–3 AIRTRANS APPROACH RAMP (PLAN VIEW)

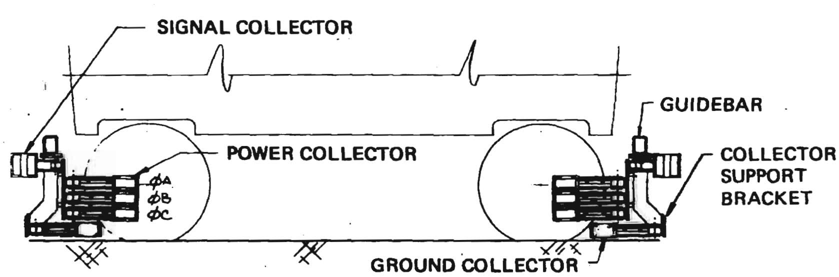


FIGURE 3–4 AIRTRANS COLLECTION EQUIPMENT

There is no on board electrical connection between the leading and trailing signal collectors; therefore, the vehicle control signal subsystem does not possess redundant collector/conductor contact. The purpose of the lead signal collectors is to link the on board vehicle control equipment with the wayside equipment; i.e., all vehicle control signal data is transmitted through the lead signal collectors. The trail signal collectors are used in conjunction with the lead signal collectors to facilitate vehicle alignment with station doors and cargo docks, and provide a "vehicle present" signal in the occupied control signal block.

Being mounted on the guidebar, the collection equipment is exposed to an environment of translational and rotational movement and vibration affected by vehicle suspension system characteristics, vehicle speed and irregularities, or roughnesses, of the guideway running surfaces. When traversing the guideway the collectors are also subjected to vibration caused by irregularities present at the running surfaces of the conductors. During operation these vehicle movements and irregularities cause the positions of the collector shoes to continually change at random velocities and accelerations. The preloads exerted by the shoes on the conductor running surfaces also change in response to these accelerations. Generally, for a given conductor irregularity spectrum, these accelerations increase with increasing vehicle velocity. To maintain the shoes in mechanical contact with the conductor running surfaces, the collectors must have sufficient "g-capability" to withstand these accelerations at all vehicle speeds.

3.2 PROGRAM OBJECTIVES

The principal objective of this study is to provide collector and conductor system equipment whose performances meet the electrical and mechanical requirements of an AIRTRANS-type system operated to 45 MPH operation in an urban environment. Providing acceptable collector contact with the conductor system is of utmost importance to passenger safety and the safety of the on board traction power and auxiliary equipment. It is for these reasons that the electrical contact quality, or electrical continuity, at the conductor/collector interfaces is selected as the criterion on which collector performance is judged. This is not to say that other parameters such as shoe and conductor wear, mechanical stress imposed on the various collector parts, reliability and maintainability are unimportant...these are fundamental to good design and are considered when appraising the overall performance of the several collector designs.

For the AUTP the following quantitative requirements are set forth for the control signal, three phase power and electrical ground collectors regarding contact quality at the shoe/conductor interfaces:

(1) Vehicle Control Signal,

Signal transmission interruptions equal to or lasting longer than 300 milliseconds are unacceptable, and

At least 7 out of 10 valid messages (one valid message = one 25-bit message) shall be totally transmitted from the signal conductor to the lead signal collector for acceptable data transmission.

(2) Three Phase Power

Power transmission interruptions (per electrical phase) equal to or lasting longer than 500 milliseconds are unacceptable.

(3) Electrical Ground

Interruptions in ground continuity which are equal to or last longer than 500 milliseconds are unacceptable. (Note: Position signal from ground is transmitted through 2 ground collectors connected in parallel)

These continuity requirements are identical to those imposed on the AIRTRANS collection equipment. The numerical value associated with each requirement constitutes a limit from the standpoint of safety of passengers and electrical equipment.

An additional objective of this program is to define, fabricate and test an approach ramp profile which is suitable for 30 MPH operation.

3.3 CANDIDATE DESIGNS

The AIRTRANS production signal, power and ground collectors and collector ramp and newly-conceived collector and collector ramp designs were all demonstrated in the test phase of the AUTP. The following are brief descriptions of each design, comments regarding their installation, and analysis of the designs.

3.3.1 AIRTRANS SIGNAL COLLECTOR - The production signal collector is illustrated by Figure 3-5. The two replaceable carbon shoes are each fixed to a common shoe holder. The shoe holder is attached to an L-shaped fitting at the shoe pivot axis, and is allowed to rotate about this axis to accommodate vehicle yaw motion and conductor curvature. The L-shaped fitting, arms and support form a four-bar linkage which provides the shoe stroke needed to accommodate lateral excursion of the vehicle and lateral misalignment of the conductor. The shoe preload force is produced by two parallel-connected clock springs which are mounted within a support fitting. The collector is bolted to the vehicle at the support fitting. The shoe holder, L-shaped fitting, arms and support fitting are metallic elements. The electrical connection between the shoes and vehicle is formed by two flexible wire ropes.

3.3.2 AIRTRANS POWER AND GROUND COLLECTORS - The production power and ground collectors possess a common mechanical design shown by Figure 3-6. A replaceable carbon shoe is fixed to a shoe holder which, in turn, is pinned to the arm at the shoe pivot axis. The rotation center of the arm lies on the arm pivot axis. A clock spring housed within the support fitting at the arm pivot axis provides the shoe preload force. The collector is bolted to the vehicle at the support fitting. The shoe holder and arm are nonmetallic (electrical insulating) parts. The support fitting is constructed of metal. A flexible battery type strap is used to transfer electric current from the shoe to the vehicle.

Figure 3-7 is a photograph of the production collection equipment installation. Each collector is fastened to the collector support bracket which is bolted directly to the vehicle guidebar. This collector installation was tested to obtain baseline information.

3.3.3 AUTP - A newly-developed collector design, designated herein as the AUTP collector, is illustrated by Figure 3-8. This design was conceived by an employee of Vought Corporation during preparation of a Masters thesis (Reference 10). In this design, rotation of the shoe about its pivot axis is accomplished by rollers in contact with the cylindrical surface of the shoe holder. The rollers are mounted on shafts which are fixed to the arm. The shoe holder is retained on the arm by a pin. The slots in the shoe holder through which the pin is inserted are slightly oversize such that, when the collector preload force is applied, the pin moves free of the slots to allow unrestricted contact of the shoe holder and rollers. The rotation center of the arm lies on the arm pivot axis. The clock spring used to produce the preload force and the support fitting are identical to those of the AIRTRANS production power and ground collectors. The shoe holder and arm of the AUTP collector are nonmetallic (electrical insulating) elements.

The AUTP collector installation used during vehicle tests is identical to production system except for the signal and ground collection equipment. See Figure 3-9. During the test programs, the AUTP collector was operated as signal and ground collection equipment. In the signal configuration the electrical lead connecting the shoe and vehicle is a 3/32-inch diameter aircraft control cable. In the ground configuration the control cable is replaced by a larger, battery strap type lead to accommodate phase-to-ground faults should they occur. The AUTP collector was

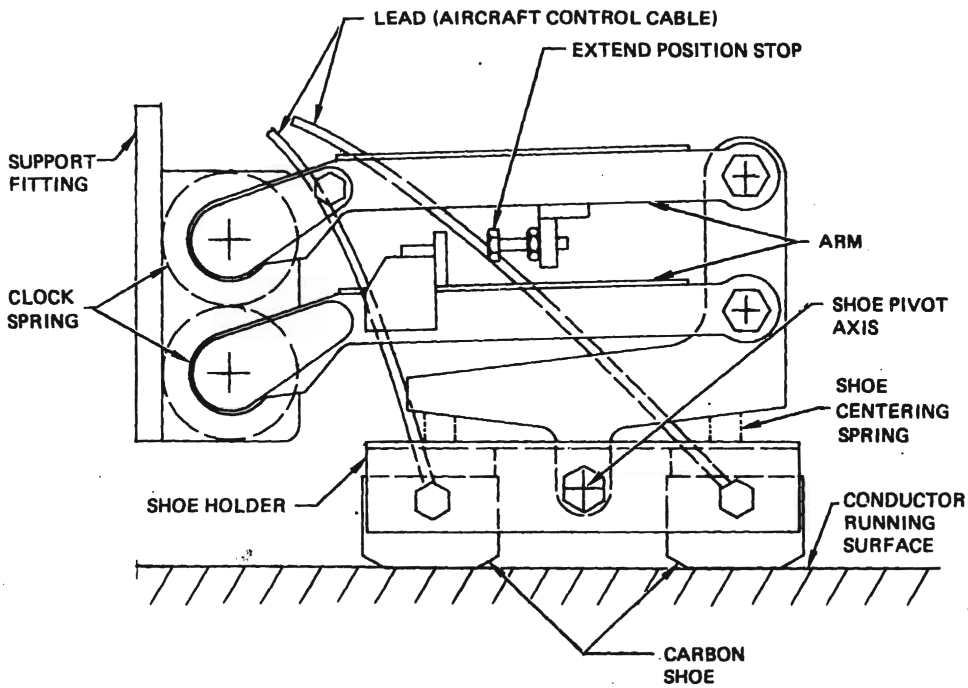


FIGURE 3–5 AIRTRANS SIGNAL COLLECTOR (PLAN VIEW)

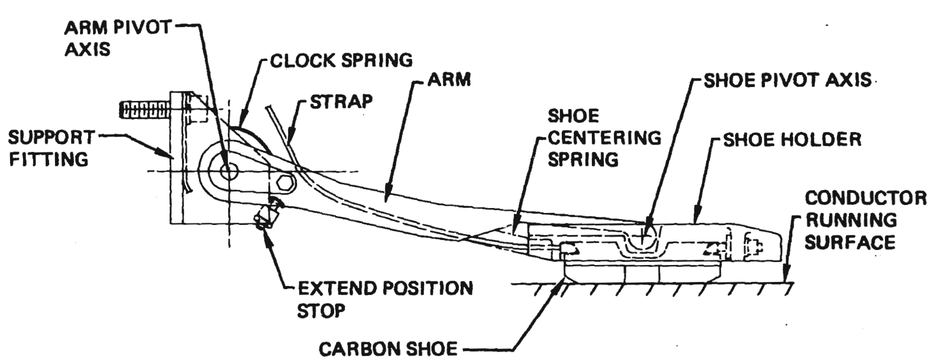


FIGURE 3–6 AIRTRANS POWER AND GROUND COLLECTOR (PLAN VIEW)

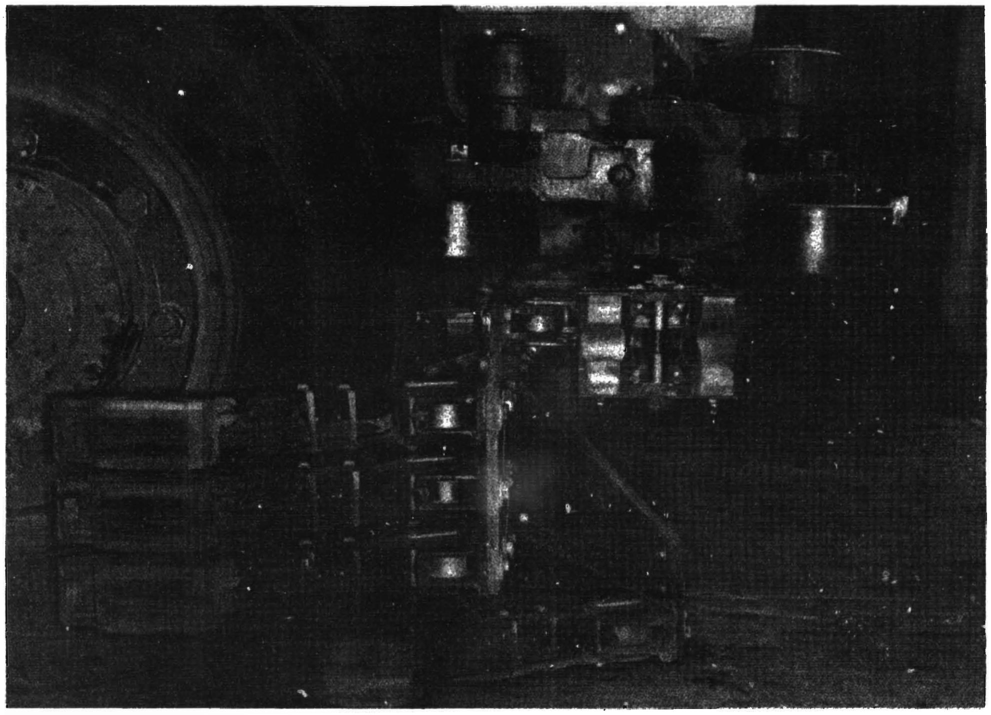


FIGURE 3--7 AIRTRANS COLLECTOR INSTALLATION

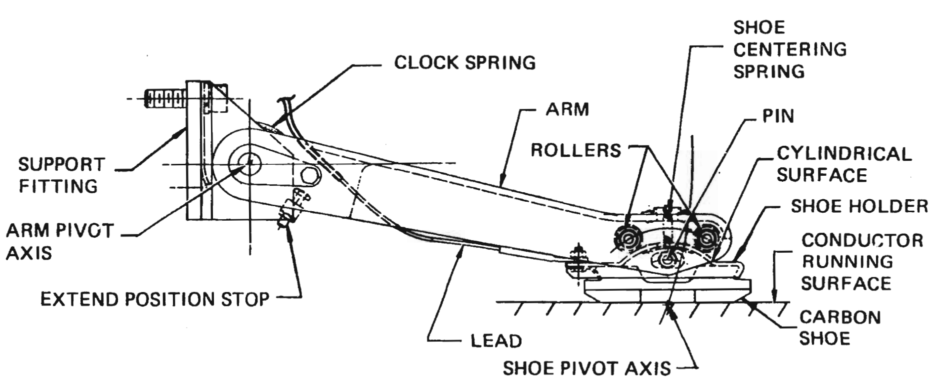


FIGURE 3–8 AUTP COLLECTOR (PLAN VIEW)

not vehicle-tested as power collection equipment due to small mechanical clearance between the shoe holder hardware of adjacent phases.

3.3.4 ANALYSIS OF CANDIDATE COLLECTOR DESIGNS - To maintain adequate contact with the conductor, the collection equipment must exhibit two basic characteristics:

(1) Sufficient "g-capability" to withstand the accelerations imposed by running surface roughness, and

(2) Stable shoe operation.

The collector's g-capability is a measure of its ability to overcome the adverse accelerations (those accelerations causing loss of contact with the conductor) produced by conductor irregularities. Herein, g-capability (z) is defined as:

$$Z = \frac{\text{SHOE PRELOAD FORCE (STATIC)}}{\text{EFFECTIVE SPRUNG WEIGHT OF COLLECTOR}}$$

where effective sprung weight, or the dynamically active weight, of each candidate collector is estimated as the summation of the shoe weight, shoe holder weight, weights of all hardware at the shoe/shoe holder/arm/lead interface, one-half the total weight of the arm and one-half the weight of the electrical lead. For a given shoe preload force, this expression implies that a lightweight collector will provide higher electrical contact quality than a heavier collector. Further, for a given effective sprung weight, a high preload force will produce better contact than a low preload. Increasing the collector's static preload to attain a higher g-capability is not necessarily the answer to acceptable collector operation. This brute force method could be used to enhance shoe/conductor contact, but at the risk of increased mechanical wear of the shoe and conductor running surfaces.

The g-capability of each collector candidate is inherently different due to the different effective weight associated with each design. Specifically, the AIRTRANS signal collector is the heaviest of the candidates. The AUTP collector has the least effective weight. The premise that the AUTP collector demonstrates the highest electrical contact quality of the three designs was verified by several tests. The test results, along with results obtained when using g-capability as a parameter (i.e., both the effective weight and preload force are allowed to vary) for each candidate design, are discussed later.

The location selected for the shoe pivot axis has a marked influence on the stable operation of the shoe. For example, the pivot axis location of Figure 3-10(a) will allow the shoe to rotate about its leading edge if

$$(F_{Friction})(d) > (F)(\ell/2).$$

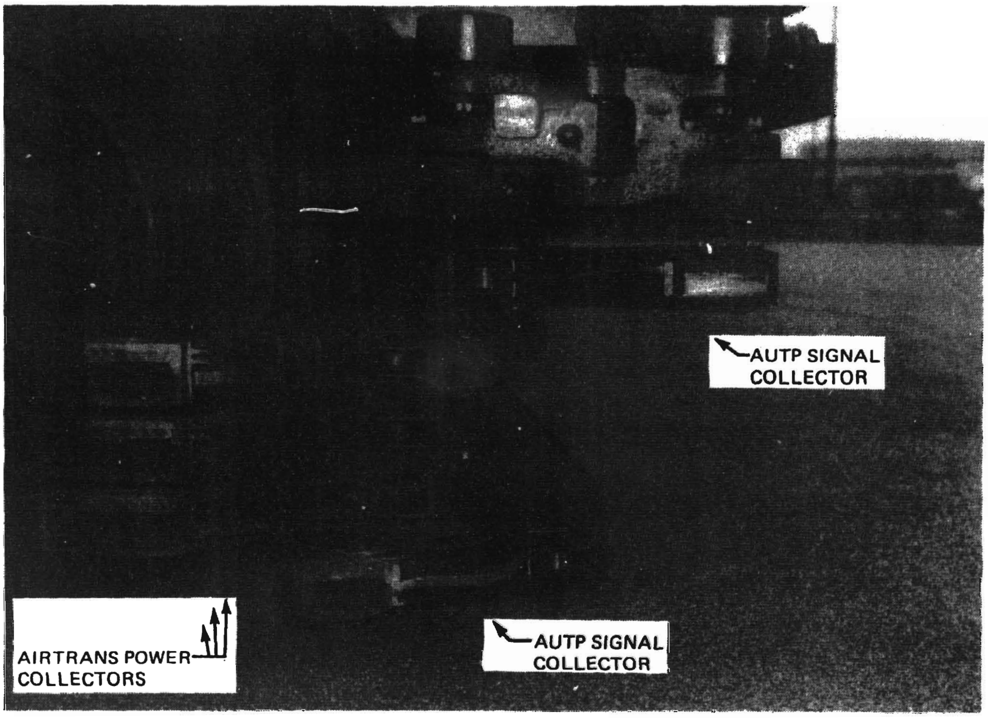
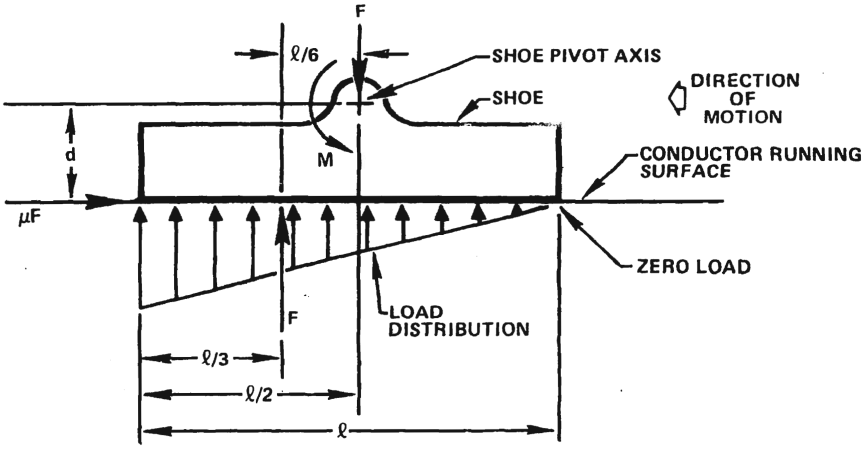


FIGURE 3–9 AUTP GROUND COLLECTOR

(a)

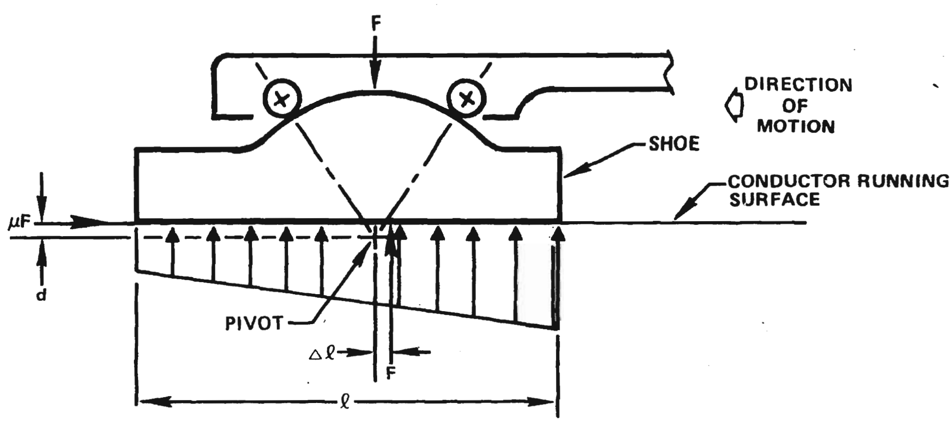


FRICTION CREATES MOMENT, $M = \mu Fd$
START OF INSTABILITY OCCURS WHEN TRAILING EDGE UNLOADS TO ZERO.
CENTROID OF FORCE IS THEN $\ell/2 - \ell/3 = \ell/6$ FROM PIVOT.
THEREFORE START OF INSTABILITY IS WHEN

$$\mu Fd = \ell/6F$$

$\therefore$ SHOE IS UNSTABLE WHEN $\mu > \ell/6d$

(b)



$$\mu Fd = \Delta\ell F$$

IN THIS CASE EVEN WITH LARGE COEFFICIENT OF FRICTION LIKE $\mu = 1$
$\Delta\ell$ WILL BE NO LARGER THAN d

FIGURE 3–10 EFFECT OF PIVOT AXIS LOCATION ON SHOE CONTROL

In addition to losing adequate mechanical contact with the conductor, the rotated shoe can take on a high frequency "heel-toe" motion as the vehicle moves along the guideway. This instability will cause accelerated wear of both the shoe and conductor. The shoe pivot axis location of Figure 3-10(a) is a design characteristic of the AIRTRANS production signal, power and ground collectors. Heel-toe instabilities were experienced with these designs during early (1974) AIRTRANS operation. This deficiency has been corrected by implementation of a shoe material havi[illegible] a low friction coefficient. Additionally, the friction coefficient of the AIRTRANS conductor running surfaces has been reduced through their continued use. These reductions in friction coefficient have reduced the shoe overturn moment $((F_{Friction})(d))$ such that the shoe instability problems encountered at the Dallas/Fort Worth Airport have been virturally eliminated.

Shoe instability can also be prevented by projecting the shoe pivot axis beyond the conductor running surface as illustrated by Figure 3-10(b). Here the interface friction force and the collector preload force are used to maintain the shoe in good mechanical contact with the conductor running surface. To demonstrate, assume that the shoe of Figure 3-10(b) is disturbed slightly such that only its leading edge is in contact with the conductor. The collector contact force and the interface friction force produce moments about the leading edge and pivot axis equal to $(F)(\ell/2)$ and $(F_{Friction})(e)$, respectively. Both moments act in directions to restore the shoe to its full contact position on the conductor. If the shoe is rotated about its leading edge such that the offset dimension, e, is negative (moved to the shoe side of the conductor running surface), the moment produced by the interface friction force about the pivot axis will act to rotate the shoe's trailing edge farther from the conductor. However, for the friction coefficients exhibited at the copper/carbon interface, the friction force should never exceed approximately one-half the valve of the collector preload force, and, since the magnitude of e can be designed smaller than $\ell/2$, the moment produced by F will restore the shoe to its correct running position. If, instead, the shoe of Figure 3-10(b) is disturbed slightly such that only its trailing edge is in contact with the conductor, the collector contact force again produces a restoring moment equal to $(F)(\ell/2)$. The moment produced by the interface friction force about the pivot axis will act to rotate the leading edge of the shoe farther from the conductor. However, as the shoe rotates about its trailing edge, the offset dimension becomes increasingly smaller thereby reducing the magnitude of this adverse moment. Negative values of e occuring when the shoe's trailing edge is in contact with the conductor will be accompanied by a moment caused by the friction force which acts to return the shoe to its correct running position.

A projected pivot axis like that of Figure 3-10(b) is implemented on the AUTP collector. During the several tests conducted on this design, no shoe instabilities occurred.

3.3.5 COLLECTOR RAMPS AND ANALYSIS - The parabolic section of the AIRTRANS approach ramp profile is described by the equation

$$Y = \frac{N}{2}\left(\frac{X}{V}\right)^2$$

(See Figure 3-11)

where X is the longitudinal distance from the conductor intersection, Y is the offset from the tangent to the ramp running surface, V is the collector approach velocity and N is the centrifugal acceleration (in g's) imparted to the shoe during the ramping operation. The AIRTRANS ramp is configured such that a collector with a 1g capability can just maintain contact with the parabolic section during a 17 MPH ramping operation. That is, the equation for the parabolic section of the AIRTRANS profile reflects N = 1.0g and V = 17 MPH. The g-capabilities of the production collectors are somewhat higher than one g, therefore, a margin of safety is provided against shoe "loft" away from the ramp and impact with the conductor. The parabolic section of the AIRTRANS approach ramp extends to approximately X = 18 inches. The profile is continued at this point to approximately X = 48 inches by a straight section whose slope, $\emptyset$, is $4^{\circ}17'$.

The equation used to define the parabolic section of the AIRTRANS ramp profile is used to design a 30 MPH profile for AUTP testing. The 30 MPH ramp retains the N = 1.0g feature of the production profile. The parabolic section of the new profile extends to X = 45 inches. The profile is continued at this point to its full length of X = 75 inches by a straight section whose slope, $\emptyset$, is $3^{\circ}34'$.

The AIRTRANS production approach ramps are constructed of cotton-based phenolic sheet. From the standpoint of preventing shoe loft, the production profile has performed well; however, investigation of the ramps installed at the Dallas/Fort Worth Airport and those used during in-plant tests show that phenolic cannot withstand the loads associated with shoe impact. Additionally, the airport ramps reveal that cotton phenolic is weather sensitive.

The 30 MPH ramps are fabricated from ultra-high molecular weight polyolefin sheet stock. This material is being used on an experimental basis at several approach ramp locations by the AIRTRANS Engineering Staff, and exhibits weather and impact resistance far surpassing that of phenolic.

3.4 TESTS AND RESULTS

The AIRTRANS and the AUTP collectors were tested both on and off the guideway. The off-guideway tests were conducted at Vought's rotating drum test facility and on-guideway tests were run at the Dallas/Fort Worth Airport utilizing the AUTP test vehicle.

3.4.1 OFF-GUIDEWAY TESTS

3.4.1.1 Description of Test Facility - Vought Corporation's 18-foot diameter rotating drum test facility, shown in Figure 3-12, was configured to mechanically simulate the signal, power and ground conductor installation used at the Dallas/Fort Worth Airport. The installation included approach and depart collector ramps for the signal and Phase A conductors. No positive (up) steps were permitted at the splice joints. The running surfaces at alternate splice joints were filled and ground smooth to simulate standard 30-foot conductor sections. The conductor surfaces were polished to remove oxides and residue. The system was run at both normal power line voltage (480 VAC, 100 amp) and at a level sufficient to check electrical continuity at the shoe/conductor interfaces (approximately 150 ma at 28 VDC). All testing on the rotating drum facility was performed at room temperature and relative humidity. Two electrohydraulic shakers were attached to the leading collector assembly such that vertical and lateral vibrations imposed by the vehicle at the collector support could be simulated. A plan view of the rotating drum with test collectors is shown by Figure 3-13.

3.4.1.2 Test Objectives/Procedures - The objective of the off-guideway test program was to evaluate the suitability of the AIRTRANS collector/conductor systems to:

(1) Operate at higher speeds under controlled conditions,

(2) Determine the signal collector for improving communication efficiency,

(3) Incorporate design improvements in the system, and

(4) Evaluate these improvements prior to actual guideway operation.

Performance of the production AIRTRANS signal collector, the production AIRTRANS power/ground collector used as a signal collector and the AUTP collector were evaluated for signal data transmission efficiency.

3.4.1.3 Collector Continuity Performance (Power, Signal and Ground) - Comparative evaluations of the production AIRTRANS signal collector, the AIRTRANS power/ground collector used as a signal collector, and the AUTP collector design were made. These evaluations were performed by use of a breadboard transceiver/signal generator which measured the quality of the vehicle input control signal. Basically, this equipment transmitted a signal with known characteristics to the lead collector and to recording equipment. The signal as received by the signal conductor is then transmitted to recording equipment for direct comparison with the known transmitted signal. Acceptable control

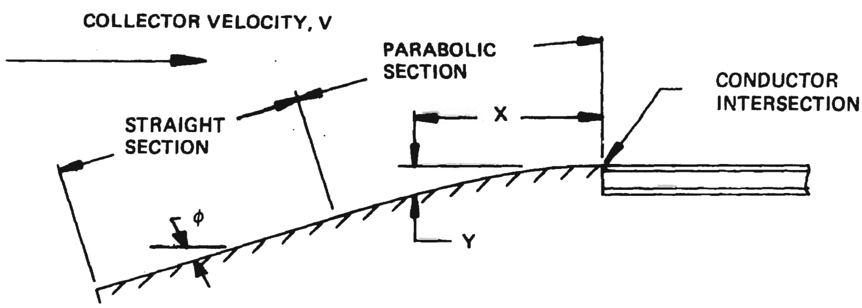


FIGURE 3–11 APPROACH RAMP PROFILE

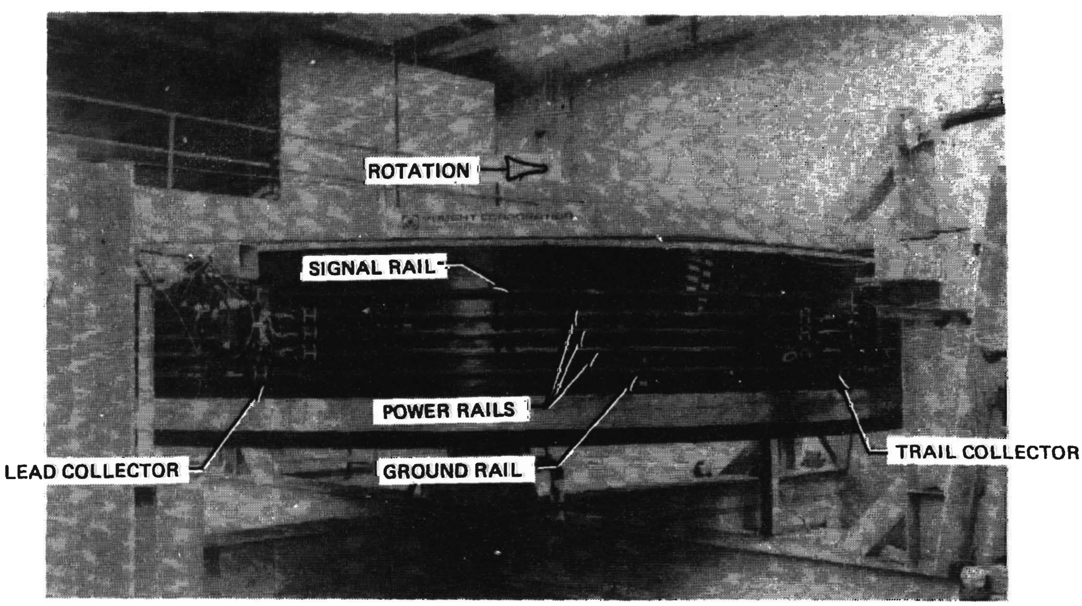


FIGURE 3–12 VOUGHT CORPORATION'S 18' DIAMETER ROTATING DRUM TEST FACILITY

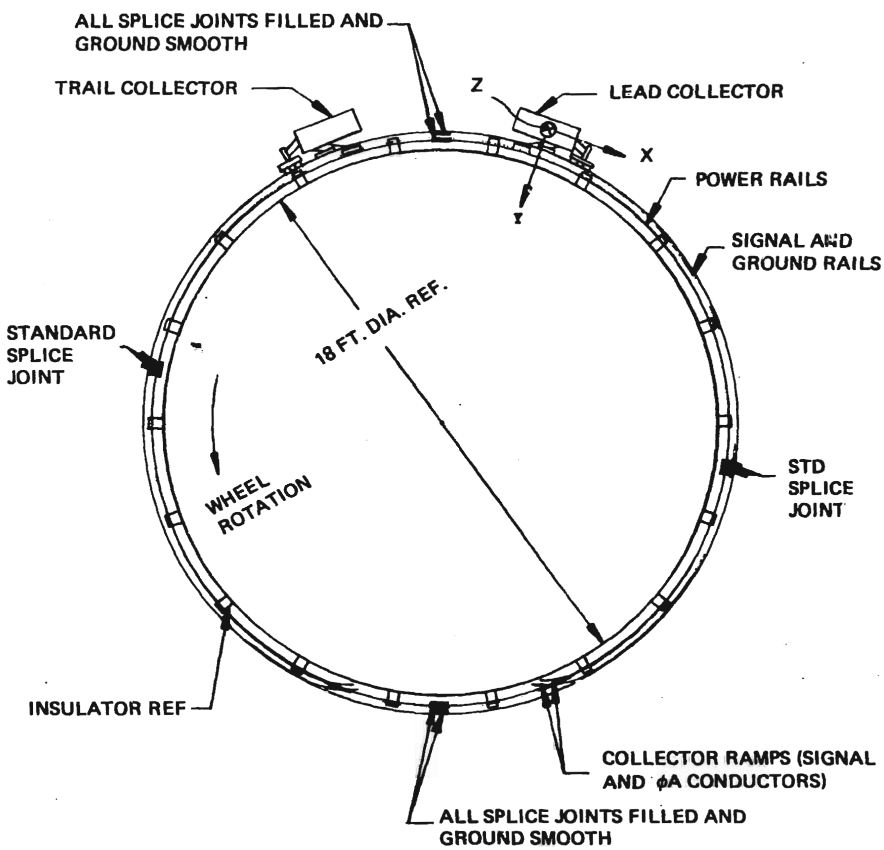


FIGURE 3–13 PLAN VIEW OF ROTATING DRUM WITH TEST COLLECTORS

data communications for AIRTRANS requires that the vehicle receive approximately 70% of the messages transmitted from the wayside. A block diagram of the electrical test setup used to measure the performance of the signal collection equipment is shown by Figure 3-14.

Figure 3-15 shows a comparison plot of the AIRTRANS signal collector, the AIRTRANS power/ground collector and the AUTP collector. Each collector was evaluated for its signal transmission capability, as described above, in 5 MPH increments. For direct comparison, each test was made using the same contact shoe material and approximately the same preload.

AIRTRANS signal collector - For a g-capability of 1.5, this collector shows a substantial drop off of transmission capability above 10 MPH. By replacing the P-55 shoes with the lighter weight shoes (carbon grade RC5660) used by AIRTRANS, 70% of the messages were received at 20 MPH.

AIRTRANS power/ground collector - Figure 3-15 shows acceptable data transmission to 21 MPH. Other tests show that by increasing the preload to 15.5 pounds (which increases Z to 6.38), acceptable data was received to approximately 40 MPH. Though the 15.5 pound preload is a "brute force" method to improve shoe contact, the corresponding improvement in data transmission demonstratates the influence of g-capability on collector performance.

AUTP collector - The AUTP signal collector was evaluated to 35 MPH. Extrapolation shows acceptable data transmission should continue at speeds up to 45 MPH.

Vibration effects - To evaluate the effects of vehicle motion, two hydraulic shakers were attached to the lead collector assembly such that it could be vibrated in the vertical and lateral directions. A photograph of the shaker/collector installation is shown by Figure 3-16. Testing was performed using the MIL-STD-810C vibration spectrum shown by Figure 3-17. The actual vibration spectrum measured during vehicle operation could not be used due to the unavailability of programmable shaking equipment. The 18-foot diameter test drum was rotated at constant simulated velocities of 10, 20, 30 and 35 MPH while the frequency of the shakers was swept from approximately 0 to 100 Hz at 1.5 "g". The constant 30 MPH test results are shown by Figure 3-18 comparing the AUTP collectors and the AIRTRANS power/ground collector. This plot shows unacceptable performance of the AIRTRANS power/ground collector and acceptable performance of the AUTP collector. The 10 and 20 MPH plots are not shown but have considerably better collector performance than at 30 MPH. They were all acceptable except the AIRTRANS power/ground collector at 20 MPH which was still unacceptable. Figure 3-19 shows that the AUTP collector has unsatisfactory transmission capability (below 70%) for a constant 35 MPH. On Figures 3-18 and 3-19, no data were taken between 0 and 18 Hz and between 30 and 65 Hz because a prior survey indicated no resonent frequencies existed in those ranges.

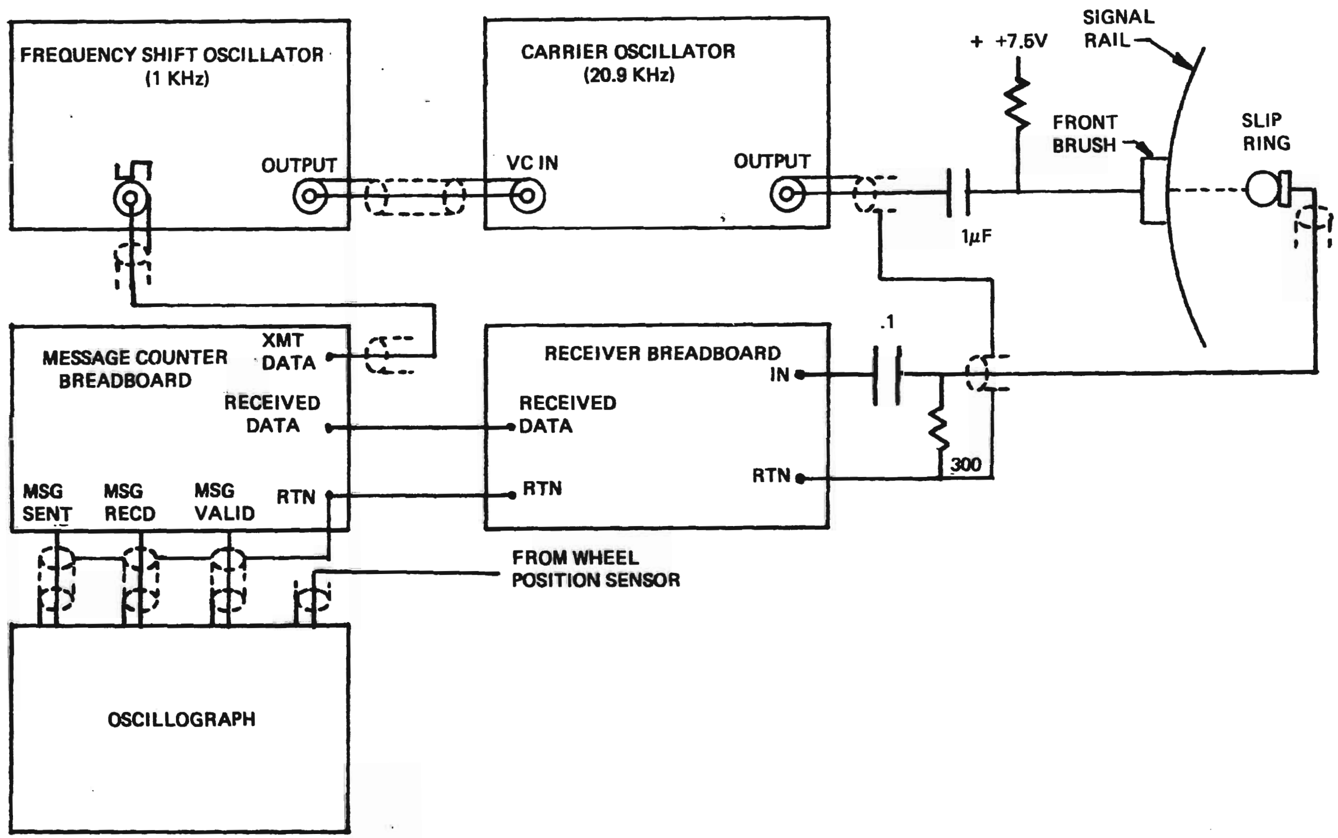


FIGURE 3–14 CIRCUIT DIAGRAM FOR SIGNAL TRANSMISSION EFFICIENCY TESTS, ROTATING DRUM FACILITY

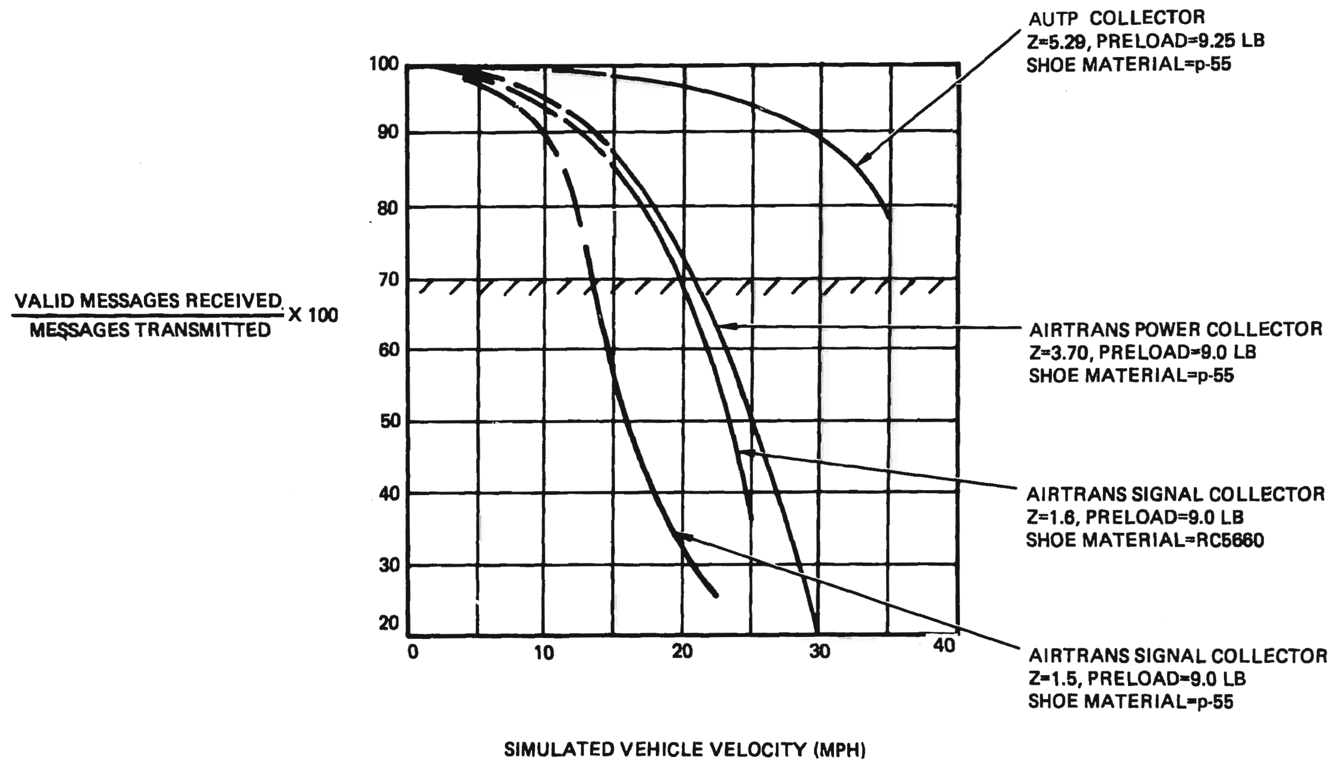


FIGURE 3–15 MESSAGE TRANSMISSION EFFICIENCY FOR AIRTRANS SIGNAL, POWER/GROUND, AND AUTP SIGNAL COLLECTORS

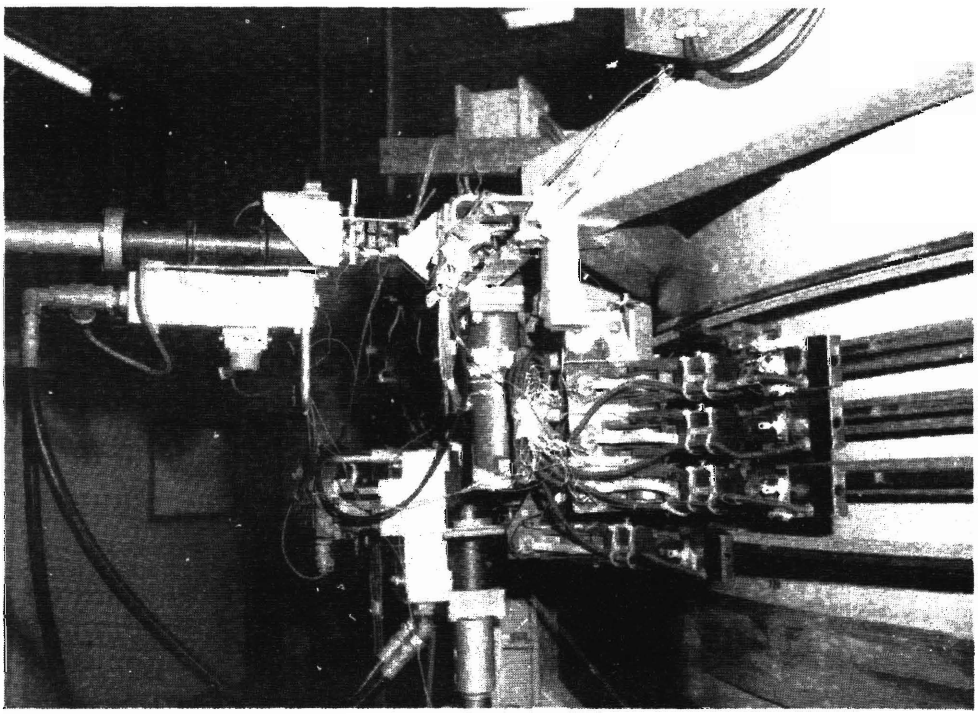


FIGURE 3–16 PHOTOGRAPH SHOWING HORIZONTAL AND VERTICAL HYDRAULIC SHAKERS INSTALLED ON COLLECTORS – 18' DIAMETER DRUM TEST

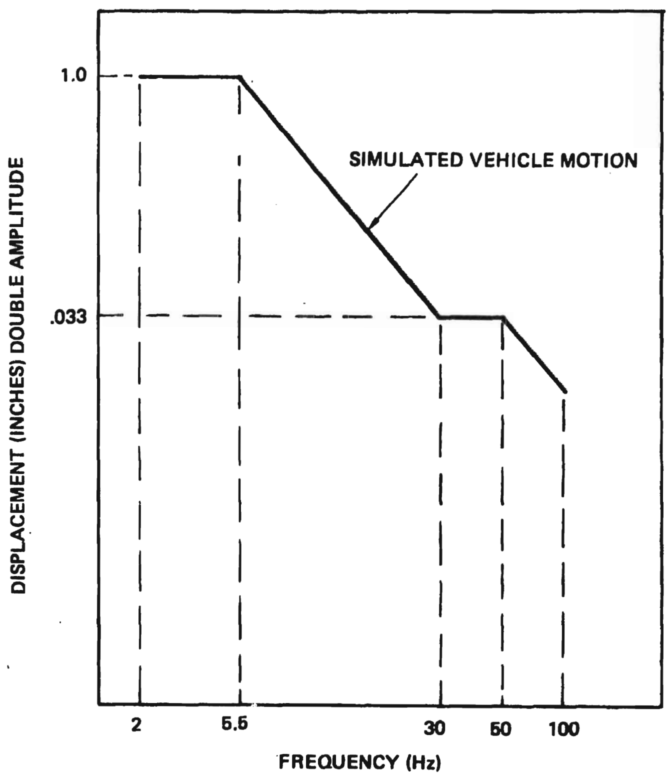


FIGURE 3–17 ENVIRONMENTAL VIBRATION LEVELS FROM MIL-STD-810C USED FOR AUTP COLLECTOR

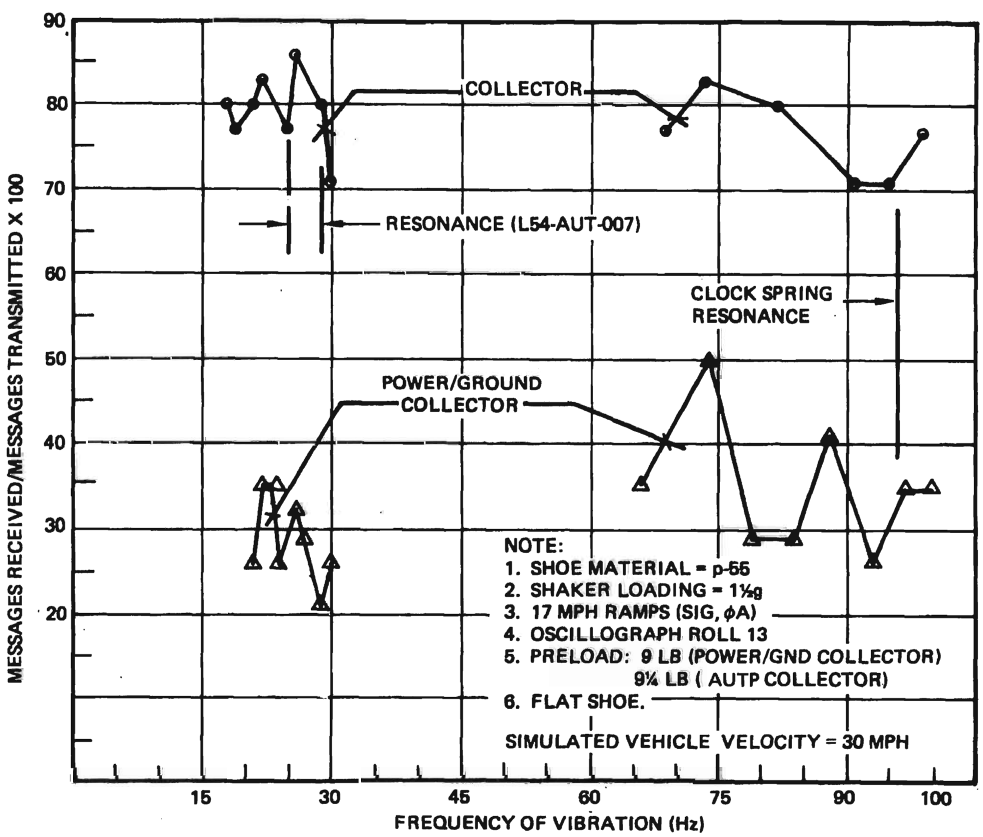


FIGURE 3–18 VEHICLE CONTROL SIGNAL TESTS, 18 FT. DIA. FACILITY AIRTRANS POWER/GROUND COLLECTOR, AUTP COLLECTOR – 30 MPH

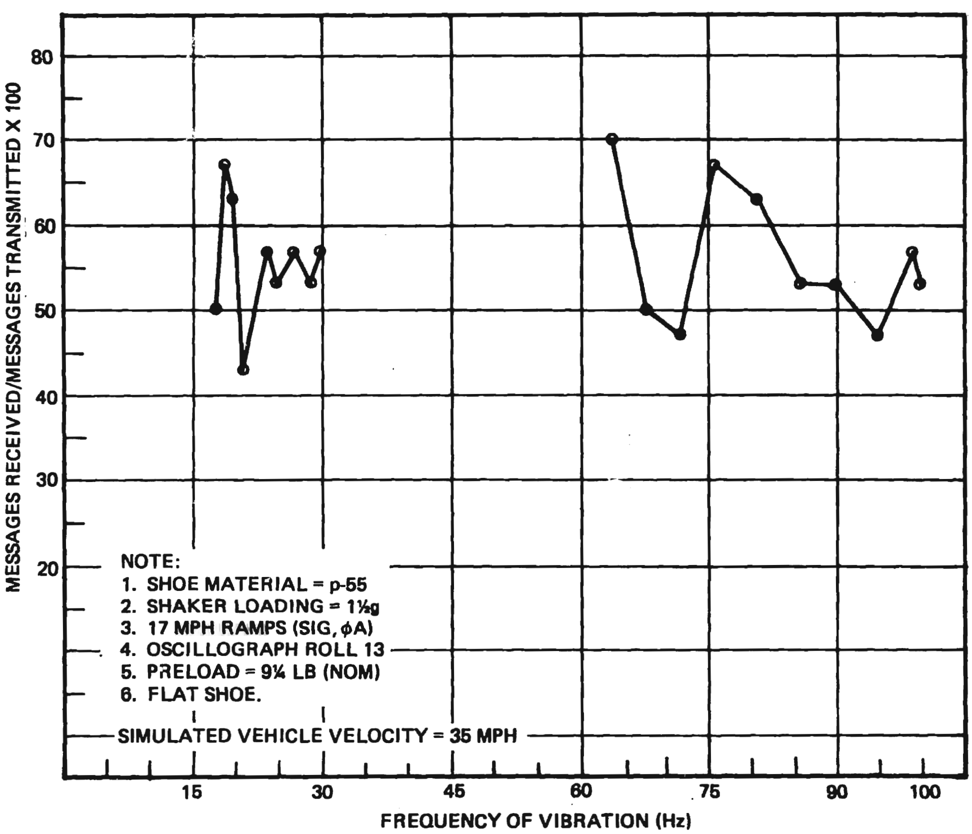


FIGURE 3–19 VEHICLE CONTROL SIGNAL TESTS, 18 FT. DIA. FACILITY AUTP COLLECTOR – 35 MPH

p p

3.4.1.4 Power and Ground Collector Tests - Power transmission tests of the AIRTRANS power collector were performed using the normal power line voltage of 480 VAC, 100 amps. Acceptable power transmission was established to be the maintenance of voltage continuity without simultaneous interruptions of more than 500 milliseconds on both lead and trail collectors of one power phase. The power transmission was measured by electrically connecting the ØB conductor, the ØC conductor, supplying power to the ØB collectors and recording the voltage picked up by the ØC collectors. The lead and trail collectors of each power phase are connected in parallel per the AIRTRANS design. Temperature sensitive paint (Tempilac) was applied to the contact surfaces of the lead and trail phase B and phase C shoes to monitor temperature rise from the normal system power and friction heating.

Continuity characteristics of the parallel-connected AIRTRANS power collectors are easily within the above tolerances for all speeds through 45 MPH. The maximum observed time of simultaneous discontinuity of both like-phase collectors was approximately 10 milliseconds. Temperature rise comparison, using P-55 shoe material, at 30 MPH with and without 480 VAC, 100 amp power applied showed no thermal or arcing problems. Maximum temperature increase was approximately 30°F above ambient.

The AIRTRANS ground collector was not tested on the 18-foot diameter drum since, mechanically, the power and ground collectors are identical. Since the lead and trail ground collectors are connected in parallel, the same as like phase power collectors, and the ground and power continuity requirements are the same, it was concluded that the ground collector transmission capability would be acceptable at speeds up to 45 MPH.

The AUTP collector was not tested as a power collector on the 18-foot diameter drum but was subjected to high electric potential tests because of its future application as a power collector. Dielectric strength tests were performed between various parts of the shoe and support. The voltage, frequency and electric current leakage allowables for the high potential tests were that current leakage shall not exceed one milliampere with an applied voltage of 2000 volts AC at 60 Hz for one minute across the shoe and support. These requirements apply to power collection equipment for Downtown People Mover Systems presently being studied. The leakage current did not exceed .01 milliampere during any of the high potential tests performed on the AUTP collector.

3.4.1.5 Stress Analysis - In order to determine the load environment of both the AIRTRANS collectors and the AUTP collector at higher speeds, stress tests on the 18' diameter drum were conducted. These tests not only aided to clear the AIRTRANS vehicle for higher speeds but will also aid in predicting design loads for future collector designs.

The following components of the production AIRTRANS collector assembly were instrumented with the following strain gages and accelerometers for the rotating drum test:

(1) Collector support post (strain gages - 2),

(2) Signal arm (strain gages),

(3) A, B, and C Ø arm (strain gages),

(4) Ground arm (strain gages),

(5) Signal arm (accelerometer),

(6) A Ø arm (accelerometer), and

(7) Ground arm (accelerometer).

The exact strain gage location on each component is presented by Figure 3-20.

The signal, power, and ground arms were each calibrated by applying a vertical load of 20# at the shoe centerline to obtain a load vs stress relation. During actual testing on the drum, strain measurements were taken at designated speeds of 10, 15, 17, 20, 25, and 30 MPH with no vibratory inputs, and at speeds of 10, 20, 30 and 35 MPH while being vibrated at 1 1/2g's in the 15Hz to 100Hz frequency range. The vibratory inputs were applied simultaneously in the vertical and lateral directions.

An equivalent peak "g" level acting at the shoe centerline was calculated using the arm calibration and the strain measurements from the drum tests. These peak "g" levels are presented in Table 3-1.

Also shown in Table 3-1 are stress levels measured at the base of the collector post which is a 3-1/4" diameter steel pipe with a .25" wall. No attempt was made to calibrate the post due to the complex interaction with the signal, power, and ground arms. The levels shown indicated no anticipated problem during guideway testing. After guideway testing, a comparison of the two tests was conducted.

3.4.1.6 Ramp Tests - During the test program at the drum facility, measurements of the accelerations associated with shoe/ramp impact were made. For these tests, accelerometers were installed on the lead AIRTRANS and AUTP collectors near the shoe centerline such that both vertical and lateral acceleration could be monitored. The trail AIRTRANS and AUTP collectors were also installed for testing, but were not instrumented.

Two different approach/depart ramp configurations were tested in the signal and ØA conductors. One simulated the 17 MPH profile used by AIRTRANS. The other simulated a ramp running

TABLE 3–1 DRUM TEST COLLECTOR LOAD ENVIRONMENTS

COMPONENT	MEASUREMENT	STRESS — PSI ACCELERATION — g's									
		SPEED ~MPH						SPEED(1) ~MPH(3)			
		10	15	17	20	25	30	10	20	30	35
Post-A Location	Stress	540	675	1,350	450	900	900	1,740	1,040	1,040	2,500
Post-B Location	Stress	450	900	1,350	675	900	1,440	1,450	1,250	1,450	2,500
Signal Arm(1)	g's	8.1	11.4	16.7	17.7	22.8	25.3	NO TEST PERFORMED			
"A" Phase Arm(2)	g's	20.1	14.4	15.5	16.8	20.1	22.5	18.7	27.5	32.4	39.0
Ground Arm	g's	3.0	4.1	5.5	4.8	5.5	6.9	11.7	12.1	13.0	19.0

Notes:

1. Signal data taken with AIRTRANS Signal Arm only.
2. "A" Phase Arm produced maximum levels ("B" and "C" Phase not shown)
3. Speeds conducted with 1½ "g" 15 Hz – 100 Hz sweeps.
4. "g" levels based on 5.5 LB. signal arm weight, and 1.4 LB. "A" Phase and ground arm weights.

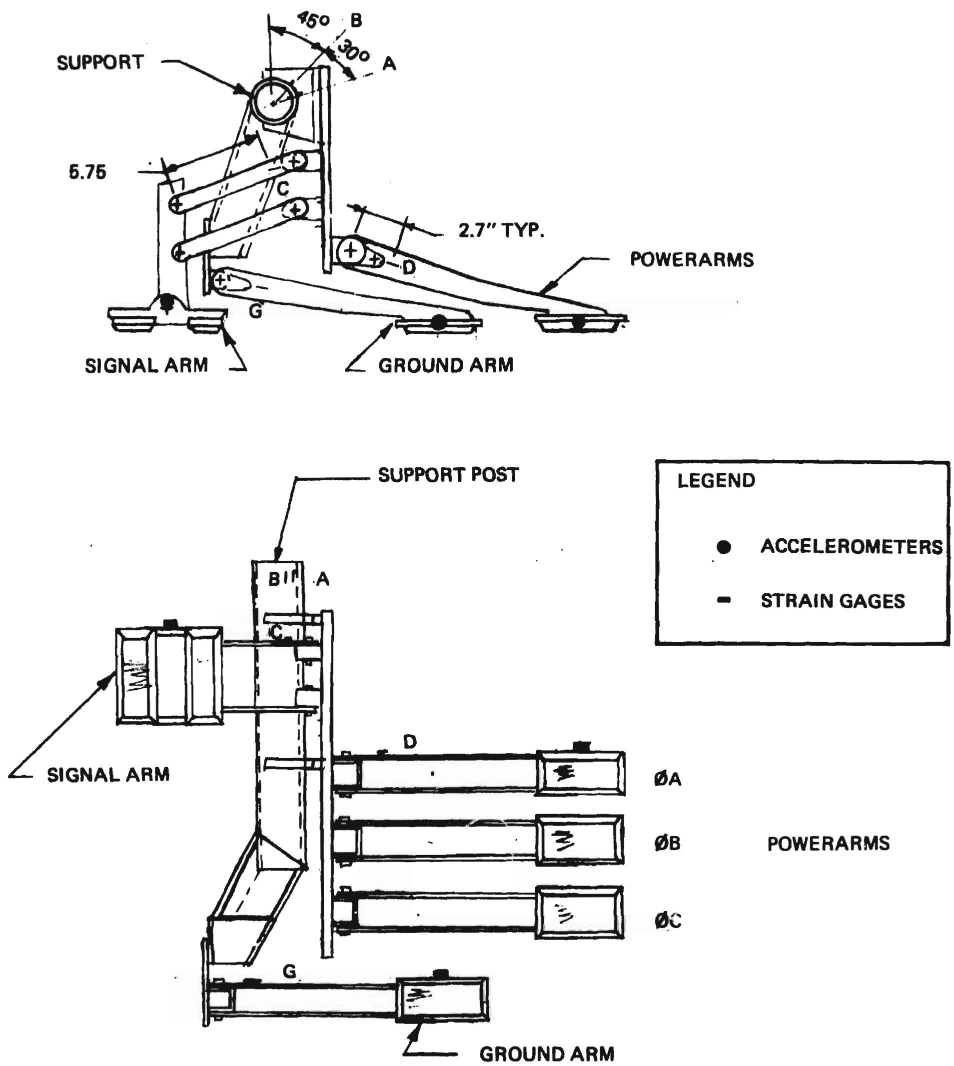


FIGURE 3–20 ACCELEROMETER AND STRAIN GAGE LOCATION FOR COLLECTORS

surface profile designed for 30 MPH operation. The simulated AIRTRANS ramps were constructed of cotton phenolic sheet; the 30 MPH configuration was fabricated from Polypenco 19 (an ultra-high molecular weight polyolefin).

Figures 3-21 and 3-22 display the lateral and vertical accelerations measured on the AUTP collector during impact with each of the ramp profiles. These "g" levels were obtained using an oscilloscope and were of extremely short duration (less than 5 milliseconds). Tests using the 17 MPH profile were terminated at 35 MPH due to the sudden increase in lateral acceleration. Lofting (shoe lift-off) of AUTP collector was not observed during tests involving the 17 MPH ramp. The 30 MPH profile showed a definite improvement in lateral impact loading but offered little in reducing vertical loading. Tests were continued up to 55 MPH using the 30 MPH ramps and were terminated at this velocity since, at 53 MPH, the trail AUTP collector began to loft. Loft of the lead AUTP collector did not occur.

Figures 3-23 and 3-24 are the lateral and vertical accelerations measured on the lead AIRTRANS ØA collector operating over the 30 MPH ramp profile. Note that this collector is installed in a trailing position. The "g" levels seen here cannot be compared directly with the 30 MPH ramp curves of Figures 3-21 and 3-22 since the AUTP collector was installed in a leading position. Both lead and trail AIRTRANS collectors were removed from the conductors after the 40 MPH velocity increment because the lead collector had begun to loft.

Upon completion of the ramp impact tests, a visual inspection was made of the lead and trail collectors, the ramps and the conductor running surfaces. The following is a summary of these observations:

Collectors:

AUTP - Wear was concentrated at center of shoe of both lead and trail collectors. The shoe wear depth was immeasurable. No chips or cracks were seen in shoes, shoe holders or arm. Arm pivot showed no sign of increased mechanical wear.

AIRTRANS - Wear was concentrated at leading and trailing edges of shoe of both lead and trail collectors. (Implies "heel-toe" motion of shoes). The shoe wear depth was approximately .02 to .03 inches. No chips or cracks were seen in shoes, shoe holder or arm. No increase in mechanical wear was seen in the arm pivot.

Conductor running surfaces:

Signal - No damage to conductor was noted.

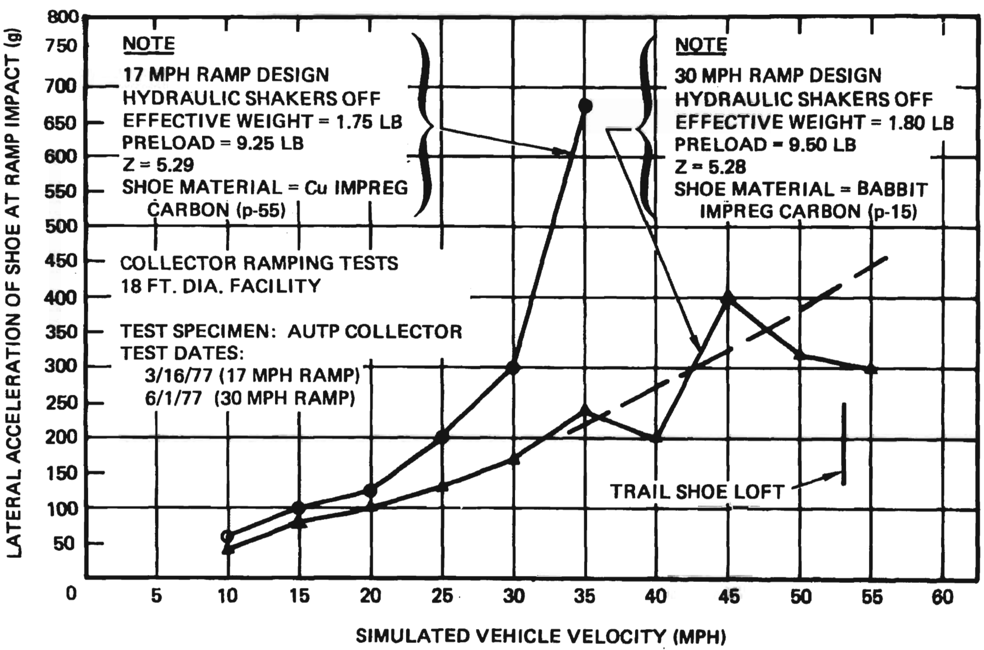


FIGURE 3–21 COLLECTOR RAMPING TESTS, 18 FT. DIA. FACILITY AUTP COLLECTOR

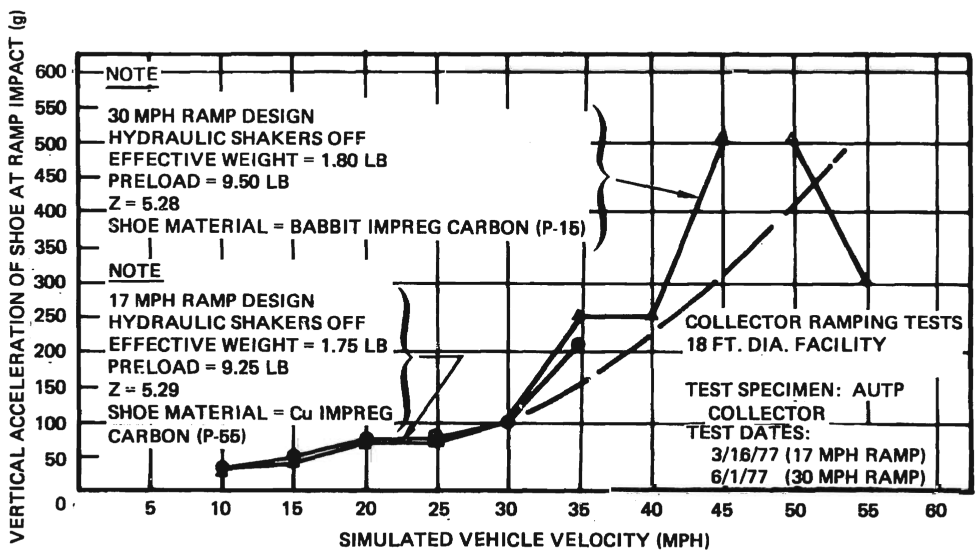


FIGURE 3–22 COLLECTOR RAMPING TESTS, 18 FT. DIA. FACILITY AUT COLLECTOR

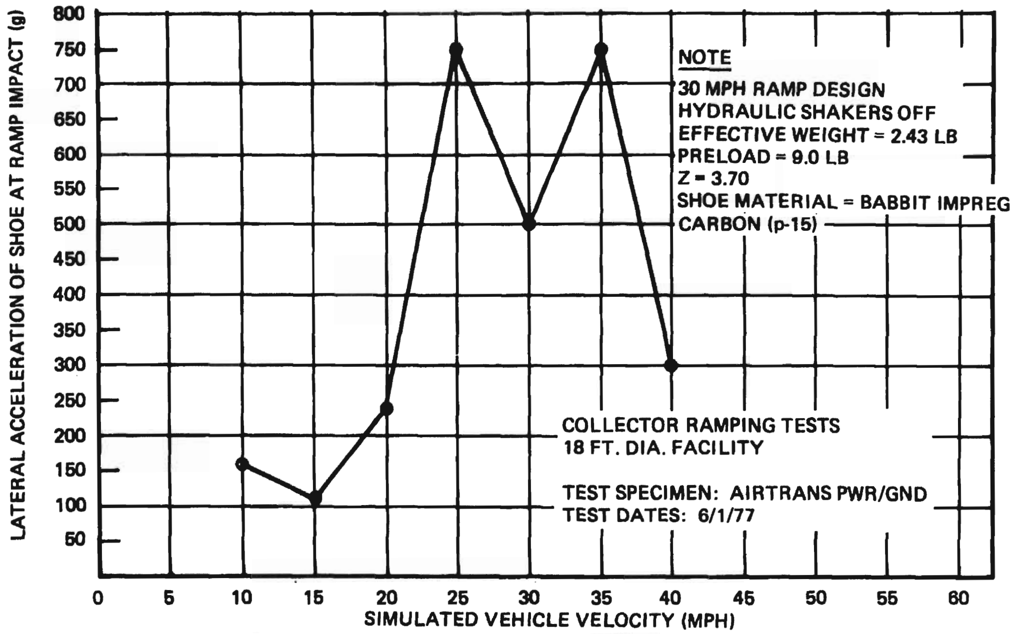


FIGURE 3–23 COLLECTOR RAMPING TESTS, 18 FT. DIA. FACILITY AIRTRANS PWR/GND

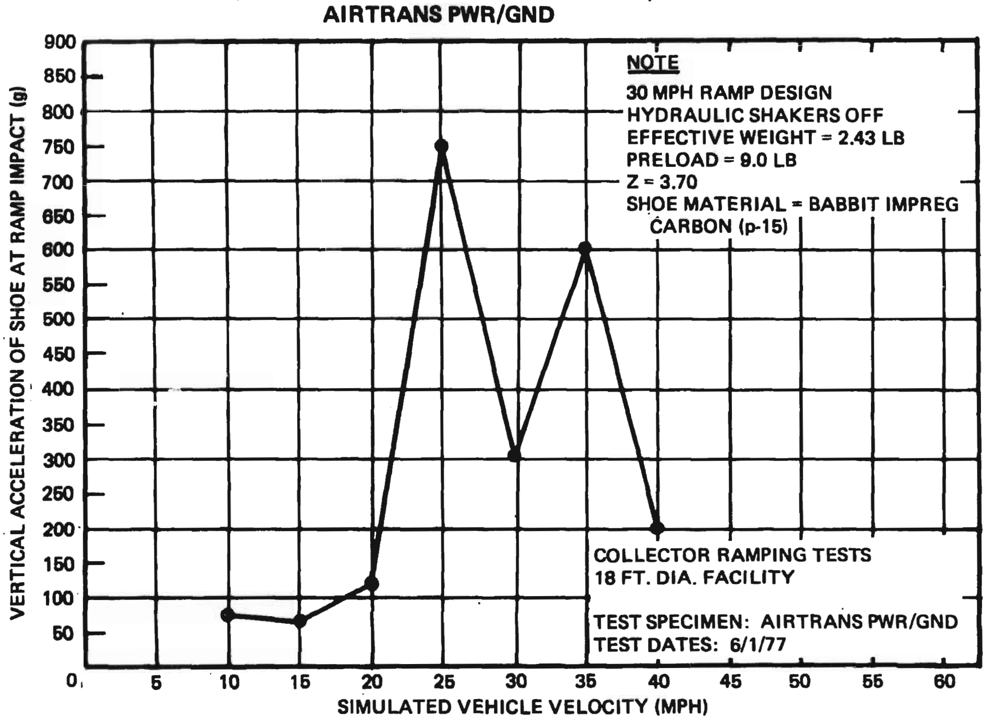


FIGURE 3–24 COLLECTOR RAMPING TESTS, 18 FT. DIA. FACILITY AIRTRANS PWR/GND

ØA - Impact marks were noted adjacent to the approach ramp. They probably occured during loft of AIRTRANS collector.

Ramps:

17 MPH ramp (phenolic) - Impact definitely degrades approach ramp running surface (both signal and ØA ramps). Inspection of approach ramps used at Dallas/Fort Worth Airport and those constructed for the rotating drum facility indicates that phenolic is not suitable for collector approach ramp applications.

30 MPH ramp (polyolefin) - Based upon the short time of exposure of this material to collector ramping at the rotating drum facility, Polypenco 19 can withstand impact loads much better than phenolic. Further, the Dallas/Fort Worth Airport Engineering Department has installed several 17 MPH ramps made of Polypenco 19 throughout the AIRTRANS guideway network; some of these ramp sets have been in service since September 1976, and show excellent resistance to weathering and impact loads. During tests at the drum facility, it was noted that the polyolefin material does smear onto the conductor running surfaces in small flakes which are easily removed. The source of this flaking could be loose material at the ramp running surface which was not removed after machining the ramp profile. It is expected that this flaking action would decrease after a "break-in" period which allows the ramp running surface to become covered with carbon.

Noise

Sound level measurements were made of the rotating drum and the lead AIRTRANS and AUTP collectors while in operation over the conductors and 30 MPH ramp profiles. These measurements were made using a B&K type 2204 impulse precision sound level meter at a horizontal distance of approximately 5 feet from the drum's outer surface. Table 3-2 is a record of the sound level measurements in decibels.

The slow meter readings may be regarded as an average of the sound generated by the drum and collector throughout 360° of drum rotation. The impulse readings are the sound levels associated with collector ramping.

3.4.2 ON-GUIDEWAY TESTS

3.4.2.1 Test Objective/Procedures _ As a result of the performance of the AUTP collector at the rotating drum facility, eight collectors were fabricated for demonstration on the AUTP

TABLE 3–2 COLLECTOR SOUND LEVEL MEASUREMENTS

SIMULATED VEHICLE VELOCITY	DRUM ALONE	AIRTRANS (LEAD, ϕA)	AUTP (LEAD, SIGNAL)
10	65	71–79 (Slow Meter) 97 Impulse	69–73.5 (Slow Meter) 89 Impulse
15	69	77–81.5 (Slow Meter) 99.5 Impulse	73.5–77 (Slow Meter) 91 Impulse
20	73	80–83 (Slow Meter) 100.5 Impulse	80–82 (Slow Meter) 95.5 Impulse
25	–	–	–
30	–	–	85–86 (Slow Meter) 101 Impulse

test vehicle. The object was to demonstrate the AUTP collector and compare its performance with the production AIRTRANS collectors under actual operational conditions.

Four of the eight AUTP collectors were identical to that used on the rotating drum and were used as signal collectors. The remaining four were used as electrical ground collectors. The power collectors used on the test vehicle were the production AIRTRANS equipment.

The test collector installation (shown in Figure 3-9) was made at the vehicle's forward right corner. Both signal collectors on the right side were instrumented to measure lateral and vertical acceleration at shoe level and the vehicle/collector interface voltage. Voltages and accelerations were recorded by magnetic tape equipment on board the AUTP test vehicle. The tapes were played back through Varian recording equipment to produce strip charts for visual interpretation of the data. Signal transmission quality was also monitored at the AIRTRANS Central Control Facility.

3.4.2.2 Test Route Segment - Approximately one mile of the AIRTRANS guideway was used for the high speed tests. About 3200 feet of this test section is straight and has the conductors mounted on the right side of the guideway. No collector ramps were installed in this section of the guideway, but a 17 MPH ramp, which was later replaced with a 30 MPH ramp, were both repeatedly and successfully negotiated at a turnout switch by the left side collectors (not instrumented) at vehicle speeds up to 30.7 MPH. A photograph of the new 30 MPH ramp is shown in Figure 3-25.

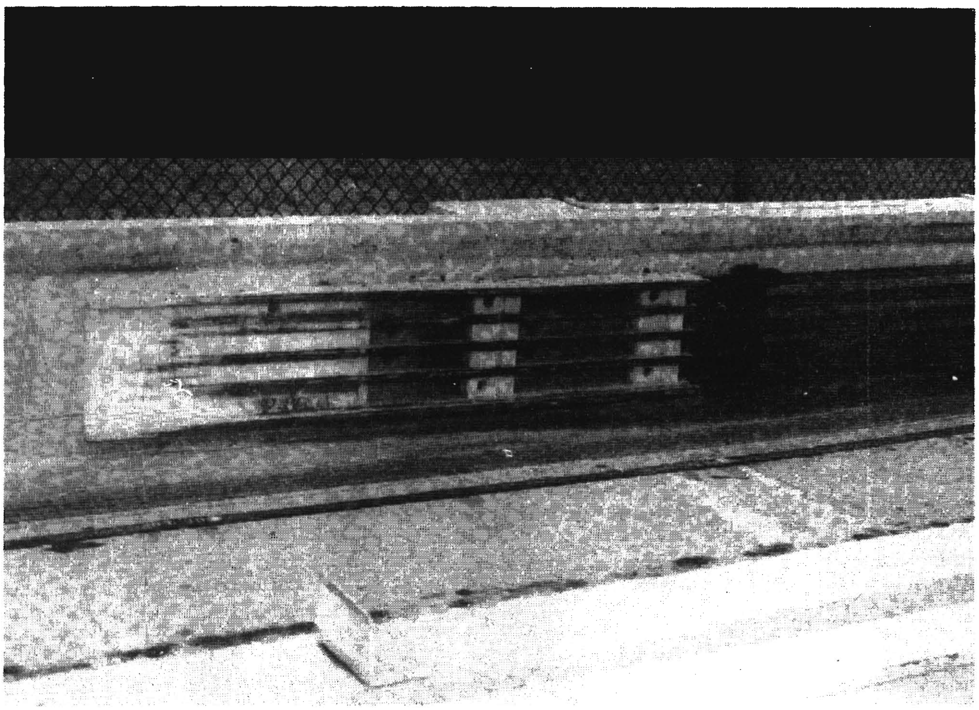


FIGURE 3–25 NEW 30 MPH RAMP INSTALLED IN AIRTRANS GUIDEWAY

3.4.2.3 Test Results - Fifteen signal conductor joints within the approximate 3200-feet test section were selected for investigation of the effects of vehicle velocity on collector shoe lateral acceleration and vehicle control signal transmission. Data from these fifteen joints were evaluated from the instrumentation traces for both the lead and trail AUTP signal collectors. A sample is shown by Figure 3-26. From this, the data was entered in Tables 3-3 and 3-4 for lead and trail AUTP signal collectors at two different lateral g-capabilities. A g-capability of 7.33 was obtained by using the lighter weight RC5660 shoe material and increasing the preload slightly by 12° additional windup of the clock spring. Joint type (I = isolation, E/S = expansion or splice) is given in Column 2. In these tables, positive accelerations act in a direction to increase shoe contact force and negative accelerations act in a direction to lift the shoe from the conductor. An asterisk at some of the negative values denotes signal transmission was lost. In every case where an interruption occured, the acceleration exceeded the collector g-capability. In fact, Table 3-3 corresponds closely with the calculated g-capability of 7.33 g's in that loss of the vehicle control signal occured only for negative accelerations whose absolute magnitudes were greater than or equal to 7.5g.

Average values of the lead and trail collector shoe lateral accelerations measured at the fifteen joints are plotted on Figure 3-27 and 3-28 to demonstrate the general increase in shoe lateral acceleration with increased vehicle speed. Note that both lead and trail collectors with the lower g-capability experienced higher positive and negative lateral accelerations than did the collectors of higher g-capability. These differences in accelerations are attributed to the different g-capabilities of the test collectors. The lower preload maintained the shoes in less controlled (looser) contact with the conductor than did the higher preload. The lower preloaded shoes were more disposed to bounce at conductor joints which effected higher accelerations. Also note that the magnitude of the lateral accelerations experienced by the lead collectors were less than those of the trail collectors. This is attributed to the relation of the friction force at the shoe/conductor running surfaces with the opposing geometry brought about by mounting the collectors in leading and trailing directions. More specifically, the friction force occurring at the lead collector shoe acts in a direction to rotate the collector arm toward the conductor running surface. Since the trail collector is mounted in the opposite direction, the interface friction force acts in a direction to rotate the collector arm away from the conductor and, thereby, aids the lateral acceleration acting to decrease the shoe contact force. Being opposed by the friction force, the trail collector is further removed, or further "lofted," from the conductor running surface after impact with a joint than the lead collector. Upon recontacting the conductor, the trail collector encounters higher positive accelerations than those of the lead collector.

The maximum time durations of signal voltage interruptions

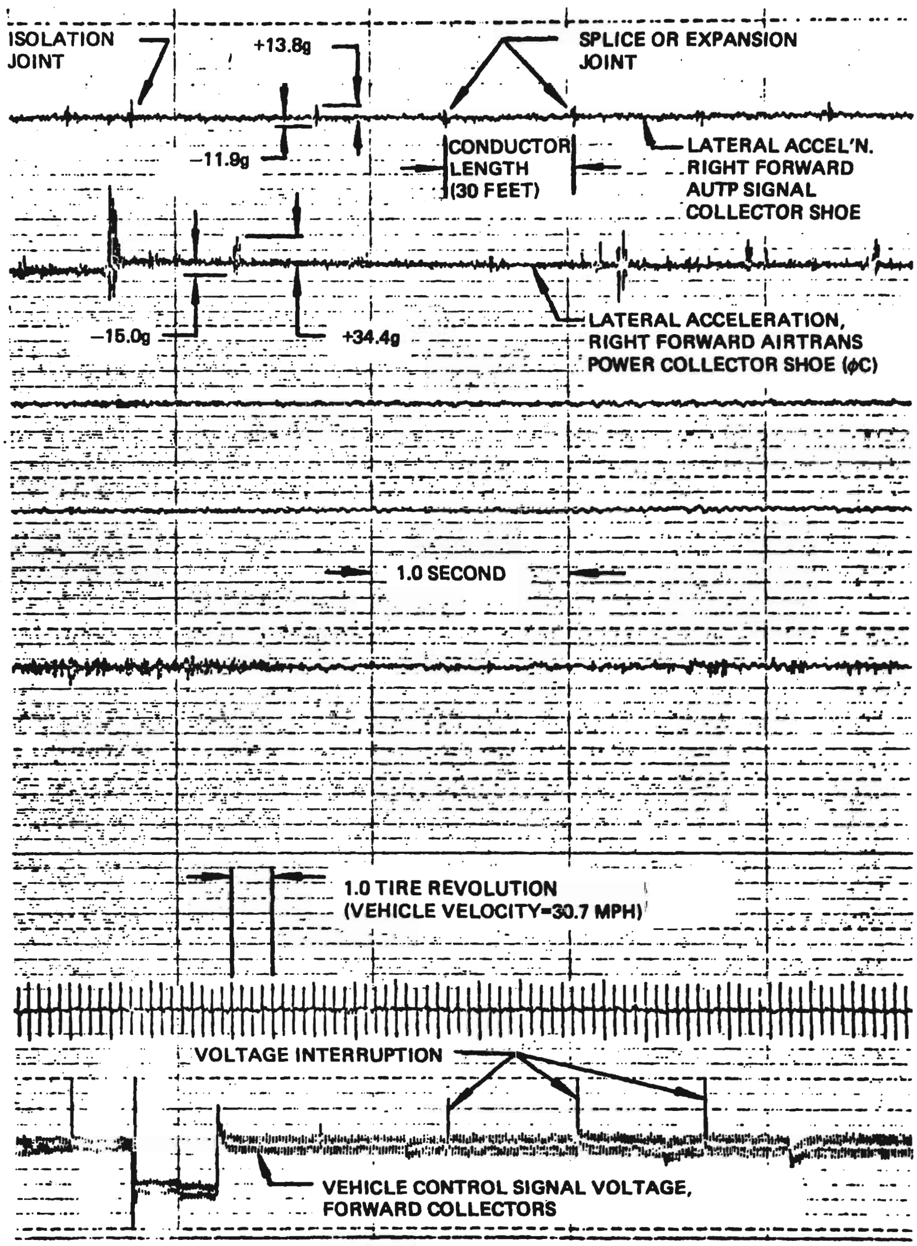


FIGURE 3–26 SIGNAL TRANSMISSION DATA SAMPLE – TRACE TAKEN FROM VEHICLE T365

TABLE 3–3 LATERAL ACCELERATION OF RH LEAD AND TRAIL AUTP SIGNAL COLLECTORS AT SELECTED CONDUCTOR JOINTS BETWEEN ROUTE DATA POINTS 21 AND 22, D/FW AIRPORT – Z = 7.33

JOINT	JOINT TYPE	ACCELERATION (g)							
		17.54 MPH		23.03 MPH		28.51 MPH		30.72 MPH	
		LEAD	TRAIL	LEAD	TRAIL	LEAD	TRAIL	LEAD	TRAIL
1	I	10.0, -3.8	15.0, -7.5	12.5, -10.0	16.2, -10.0	18.8, -10.0	18.8, -15.0	16.2, -10.0	17.5, -12.5
2	E, S	20.0, -12.5*	41.2, -20.0	25.0, -12.5*	50.0, -16.2*	28.8, -12.5*	43.8, -13.8*	30.0, -11.2*	47.5, -21.2*
3	E, S	15.0, -7.5*	27.5, -13.8	21.2, -15.0*	30.0, -11.9*	28.8, -12.5*	36.2, -12.5*	26.2, 17.5*	36.2, -17.5*
4	I	16.2, -7.5	16.2, -8.8	18.8, -10.0	22.5, -10.0	18.8, -10.0	27.5, -10.0	17.5, -11.2	23.8, -16.2
5	E, S	10.0, -7.5*	35.0, 11.2*	18.8, -12.5*	32.5, -10.0*	25.0, -12.5*	32.5, -20.0*	23.8, -15.0*	32.5, -11.2*
6	I	13.8, -8.8	20.0, -6.2	17.5, -12.5	20.0, -11.2	16.2, -12.5	22.5, -11.9	13.8, -8.8	17.5, -13.8
7	I	13.8, -8.8	20.0, -6.2	16.2, -12.5	20.0, -11.2	15.0, -7.5	25.0, -12.5	12.5, -16.2	26.2, -11.9
8	E, S	12.5, -6.2	21.2, -7.5*	12.5, -11.2*	17.5, -7.5*	11.2, -11.2*	28.8, -15.0*	12.5, -11.2*	33.8, -13.8*
9	I	15.0, -8.8	16.2, -8.8	22.5, -10.0	20.0, -10.0	26.2, -12.2	23.8, -13.8	22.5, -12.5	18.8, -12.5
10	E, S	15.0, -6.2	25.0, -7.5*	20.0, -11.2	30.0, -10.0*	20.0, -10.0*	31.2, -10.0*	16.2, -7.5*	27.5, -12.5*
11	E, S	13.8, -8.8	12.5, -6.2	22.5, -8.8	16.2, -10.0	18.8, -10.0*	18.8, -15.0*	25.0, -16.2*	17.5, -16.2*
12	E, S	16.2, -7.5	18.8, -6.2	18.8, -13.8	21.2, -11.2	18.8, -12.5*	22.5, -10.0*	22.5, -10.0*	23.8, -12.5*
13	E, S	11.2, -11.2	5.0, -6.2	12.5, -10.0*	8.8, -8.8	15.0, -12.5*	13.8, -7.5	11.2, -11.2*	15.0, -12.5
14	I	8.8, -8.8	13.8, -8.8	11.2, -10.0	22.5, -11.2	12.5, -7.5	22.5, -13.8	18.8, -12.5	22.5, -20.0
15	I	11.2, -6.2	22.5, -11.2	12.5, -8.8	26.2, -15.0	20.0, -7.5	32.5, -20.0	17.5, -16.2	25.0, -15.0
AVERAGE		13.5, -8.0	20.7, -9.1	17.5, -11.2	23.6, -10.9	19.6, -10.7	26.7, -13.4	19.1, -12.5	25.7, -14.6

* SIGNAL TRANSMISSION LOST

TABLE 3–4 LATERAL ACCELERATION OF RH LEAD AND TRAIL AUTP SIGNAL COLLECTORS AT SELECTED CONDUCTOR JOINTS BETWEEN ROUTE DATA POINTS 21 AND 22, D/FW AIRPORT – Z = 5.29

JOINT	JOINT TYPE	ACCELERATION (g)							
		17.21 MPH		23.58 MPH		24.92 MPH		29.07 MPH	
		LEAD	TRAIL	LEAD	TRAIL	LEAD	TRAIL	LEAD	TRAIL
1	I	18.6, -8.3	23.0, -10.7	13.9, -9.5	21.1, -14.3	19.8, -8.7	22.3, -17.1	15.8, -7.5	30.6, -11.5
2	E, S	36.8, -23.0*	43.7, -23.0*	25.7, -15.8*	24.6, -8.7*	50.7, -20.2*	76.3, 25.4*	23.8, -13.9*	38.2, -20.3*
3	E, S	21.4, -12.7*	16.7, -14.3*	35.6, -16.6*	21.1, -14.3*	34.1, -16.6*	39.0, -24.2*	27.7, -15.8*	46.9, -15.5*
4	I	17.8, -14.2	19.5, -8.0	22.2, -9.5	22.7, -12.3	24.2, -12.3	23.4, -14.7	16.6, -10.7	26.6, -11.1
5	E, S	26.5, -6.7*	13.5, -8.7*	35.6, -18.2*	28.2, -17.9*	33.3, -25.0*	31.8, -17.9*	22.2, -10.7*	21.5, -16.7*
6	I	21.4, -15.8	23.0, -15.1	9.1, -7.1	15.5, -8.0	10.3, -4.8	18.3, -9.9	16.6, -11.5	29.4, -16.7
7	I	13.5, -6.3	19.9, -15.5	17.0, -8.3	22.7, -15.1	18.2, -8.7	23.4, -13.5	17.4, -11.5	21.1, -9.5
8	E, S	14.3, -8.7*	27.8, -13.9*	26.1, 10.7*	29.0, -19.9*	23.0, -15.0*	50.5, -15.1*	31.3, -13.5*	29.0, -14.7*
9	I	21.8, -9.9	15.9, -7.6	17.8, -11.5	17.9, -11.5	9.8, -7.9	17.1, -13.1	14.3, -13.1	21.9, -12.3
10	E, S	38.8, -9.5*	38.2, -15.1*	10.7, -13.1*	32.6, -16.7*	21.4, -14.7*	39.4, -18.7*	47.1, 36.4*	48.5, -35.8*
11	E, S	19.8, -13.9*	15.1, -10.7*	25.0, -15.4*	20.3, -13.5*	27.3, -17.8*	17.9, -13.9*	#	#
12	E, S	22.6, -10.3*	37.4, -19.1*	24.6, -15.8*	37.8, -15.9*	28.5, -13.5*	39.8, -13.1*	#	#
13	E, S	11.1, -7.9*	6.8, -6.4*	6.3, -6.7*	7.6, -9.9*	†	†	#	#
14	I	14.3, -7.5	13.5, -8.7	11.9, -7.9	20.3, -11.1	†	†	#	#
15	I	18.6, -13.1	23.4, -9.1	9.1, -12.7	18.7, -13.1	†	†	#	#
AVERAGE		21.2, -11.2	22.5, -12.4	19.4, -11.9	22.7, -13.5	25.1, -13.8	33.3, -16.4	23.3, -14.5	31.4, -16.4

† RECORDS ARE NOT AVAILABLE
# VEHICLE SPEED BELOW 30 MPH NOMINAL
* SIGNAL TRANSMISSION LOST

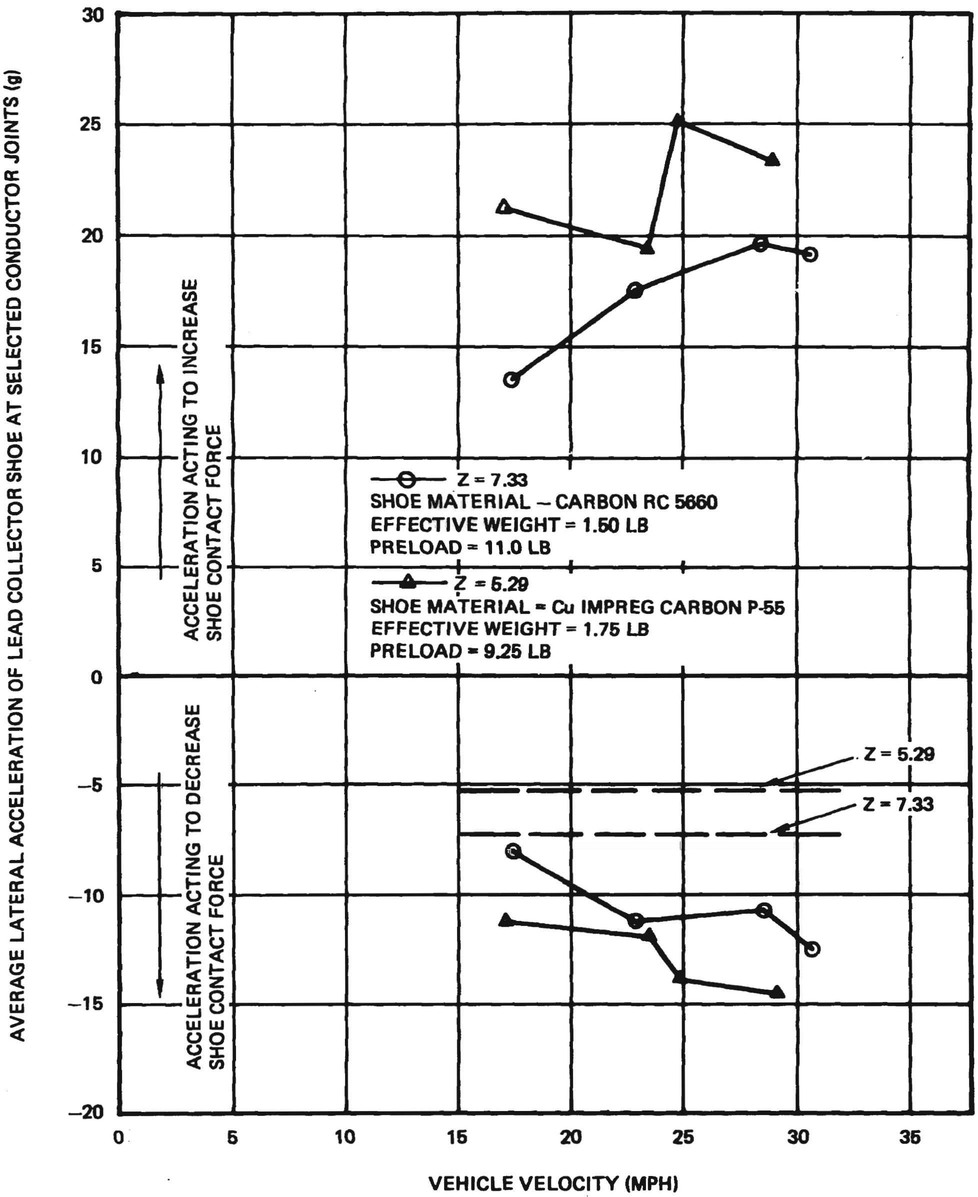


FIGURE 3–27 LATERAL ACCELERATIONS OF LEAD AUTP SIGNAL COLLECTOR MEASURED ON VEHICLE T365

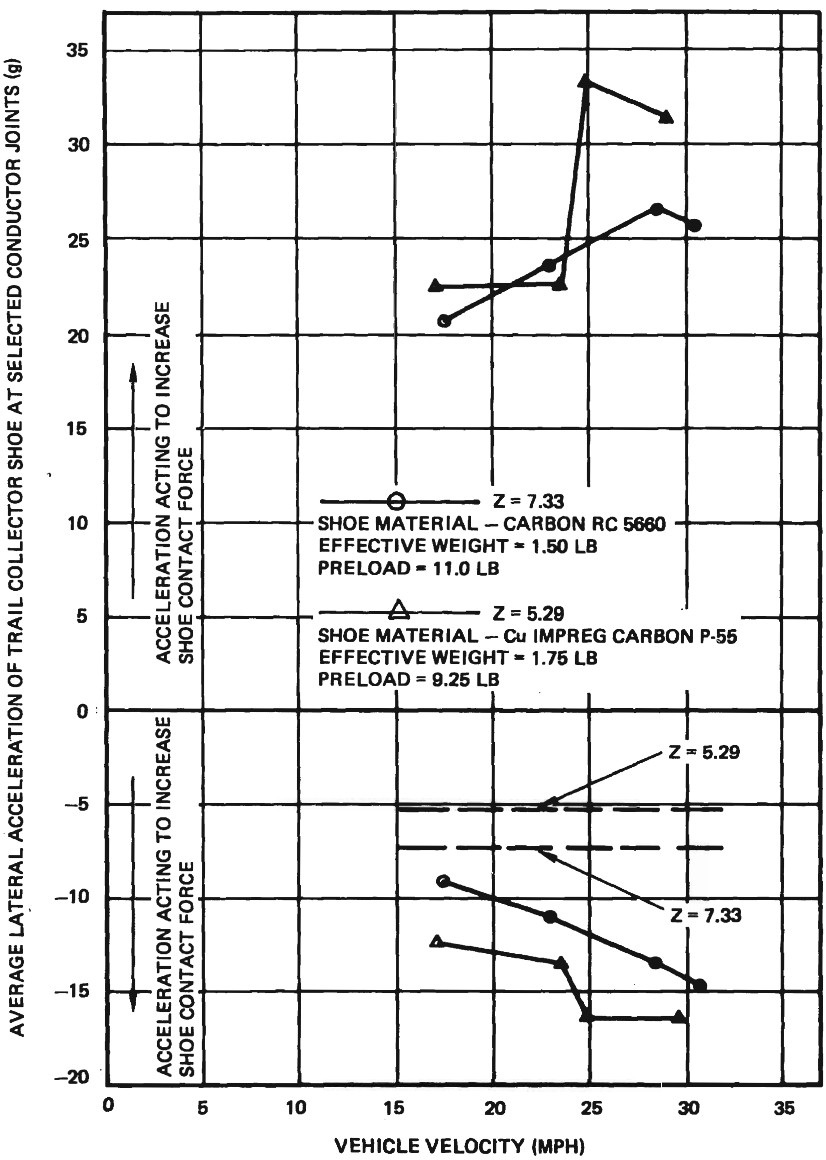


FIGURE 3–28 LATERAL ACCELERATIONS OF TRAIL AUTP SIGNAL COLLECTOR MEASURED ON VEHICLE T365

for the AUTP collectors occurred during 30 MPH operation. These durations are listed below for the lead collectors at two different g-capabilities, and are the "worst case" interruptions observed throughout the 3,200-foot test section.

(1) At Z = 7.33 the worst case interruption was 36 MSEC.

(2) At Z = 5.29 the worst case interruption was 44 MSEC.

That is, in reducing the g-capability of the AUTP collector from 7.33 to 5.29, the worst case interruption duration was increased approximately 22 percent. Though these durations are far less than the 300-millisecond interruption allowable for testing, they are presented to show the influence of g-capability on shoe/conductor contact quality.

The results of signal transmission tests performed on the AUTP collector and the production AIRTRANS collector by a monitor at the Central Control Facility are shown by Figure 3-29. These data also demonstrate the influence of collector g-capability on signal transmission, and, therefore, on the quality of mechanical contact at the shoe/conductor interface. This figure shows that the data transmission capability demonstrated by the AUTP collectors far surpass the 70 percent valid messages received/messages sent criterion set forth for the test program.

Records taken during high speed tests indicate that vertical accelerations of the collector shoes are, like their lateral accelerations, more pronounced at conductor joints. The fifteen conductor joints of Tables 3-3 and 3-4 were also selected for investigation of the effects of vehicle velocity on collector shoe vertical acceleration. The data taken at these joints are entered in Table 3-5. In this table positive- and negative-signed accelerations act upward and downward at shoe level, respectively. Average values of the lead and trail collector shoe vertical accelerations occurring at the fifteen joints are plotted on Figure 3-30. Note the approximate symmetry of the accelerations about the zero g level, i.e., the respective positive and negative accelerations of the lead and trail collectors are approximately equal. At 23.58 MPH, there was a general decrease in vertical acceleration of the shoes. This is attributed to a corresponding decrease in vertical acceleration measured at the guidance system at approximately the same vehicle velocity. The data received at 24.92 MPH and 29.07 MPH show that the shoe vertical accelerations are increasing with increased vehicle velocity.

The production AIRTRANS power collection equipment was used throughout the test period for power pickup. Lead and trail Phase C collectors were instrumented such that lateral acceleratons imposed at the collector shoes could be monitored; additionally, a continuous record of Phase C voltage continuity was made. The largest lateral accelerations experienced by the power collectors occurred at conductor splice, expansion and power zone

TABLE 3–5 VERTICAL ACCELERATION OF RH LEAD AND TRAIL AUTP SIGNAL COLLECTORS AT SELECTED CONDUCTOR JOINTS BETWEEN ROUTE DATA POINTS 21 AND 22, D/FW AIRPORT

JOINT	JOINT TYPE	ACCELERATION (g) 17.21 MPH LEAD	17.21 MPH TRAIL	23.58 MPH LEAD	23.58 MPH TRAIL	24.92 MPH LEAD	24.92 MPH TRAIL	29.07 MPH LEAD	29.07 MPH TRAIL
1	I	3.6, -5.6	4.7, -7.2	5.6, -5.6	5.0, -5.7	7.2, -9.2	9.7, -9.0	9.7, -6.7	6.5, -7.5
2	E, S	4.1, -4.1	5.7, -7.5	10.8, -5.6	9.3, -16.9	5.6, -7.7	7.9, -10.8	12.3, -8.7	4.7, -7.9
3	E, S	6.1, -8.7	7.9, -7.2	7.2, -8.7	6.5, -4.7	13.3, -13.8	4.7, -4.7	11.8, -8.2	12.6, -15.8
4	I	6.1, -3.6	4.3, -7.9	7.2, -5.6	6.1, -6.1	7.2, -6.1	5.4, -7.5	4.1, -4.6	7.2, -8.3
5	E, S	5.1, -13.3	7.2, -19.8	8.7, -6.1	8.6, -5.4	6.1, -9.2	10.1, -12.2	5.6, -9.7	7.5, -9.0
6	I	6.1, -5.1	14.7, -10.8	3.6, -3.6	5.4, -7.5	5.1, -8.2	8.3, -10.1	6.1, -6.1	18.0, -14.0
7	I	15.4, -6.1	16.2, -15.4	9.7, -8.2	7.5, -9.7	6.7, -6.1	6.5, -7.5	11.8, -11.8	6.5, -6.5
8	E, S	8.2, -8.2	23.7, -10.4	8.7, -9.2	5.0, -5.0	9.2, -5.6	4.7, -6.1	7.2, -5.1	13.6, -6.8
9	I	4.1, -3.1	12.6, -6.8	5.6, -5.6	7.5, -6.1	7.2, -7.2	10.8, -7.9	9.7, -7.7	10.4, -7.9
10	E, S	3.1, -5.1	5.4, -11.5	9.2, -7.2	5.4, -8.6	9.2, -10.7	13.3, -10.8	19.0, -11.8	12.2, -12.2
11	E, S	4.1, -4.6	7.5, -4.3	7.2, -5.1	5.0, -5.0	7.2, -7.7	5.7, -5.7	#	#
12	E,S	8.2, -6.1	10.8, -12.2	3.1, -4.1	5.4, -7.5	6.7, -9.2	6.8, -5.4	#	#
13	E, S	9.2, -9.2	4.7, -5.7	3.6, -3.6	3.6, -2.9	†	†	#	#
14	I	8.2, -6.6	6.1, -3.6	5.1, -5.1	5.4, -5.4	†	†	#	#
15	I	8.2, -7.7	8.6, -10.8	6.7, -7.7	4.7, -5.4	†	†	#	#
AVERAGE		6.6, -6.5	9.3, -9.4	6.8, -6.1	6.0, -6.8	7.6, -8.4	7.8, -8.1	9.7, -8.0	9.9, -9.6

† RECORDS ARE NOT AVAILABLE
# VEHICLE SPEED BELOW 30 MPH NOMINAL

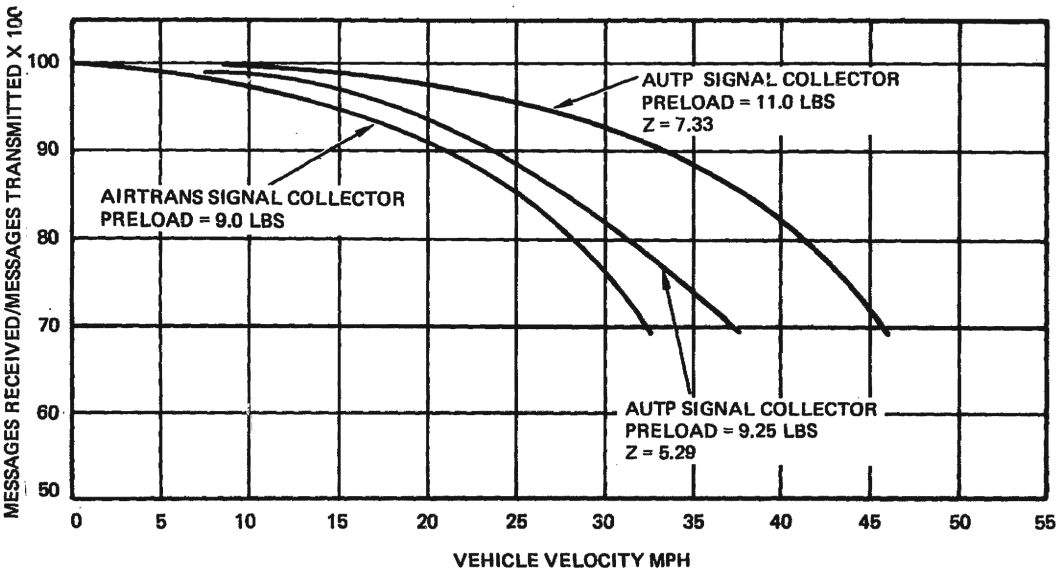


FIGURE 3–29 VEHICLE T365 TESTS OF MESSAGE TRANSMISSION EFFICIENCY OF AUTP COLLECTOR AND AIRTRANS SIGNAL COLLECTOR

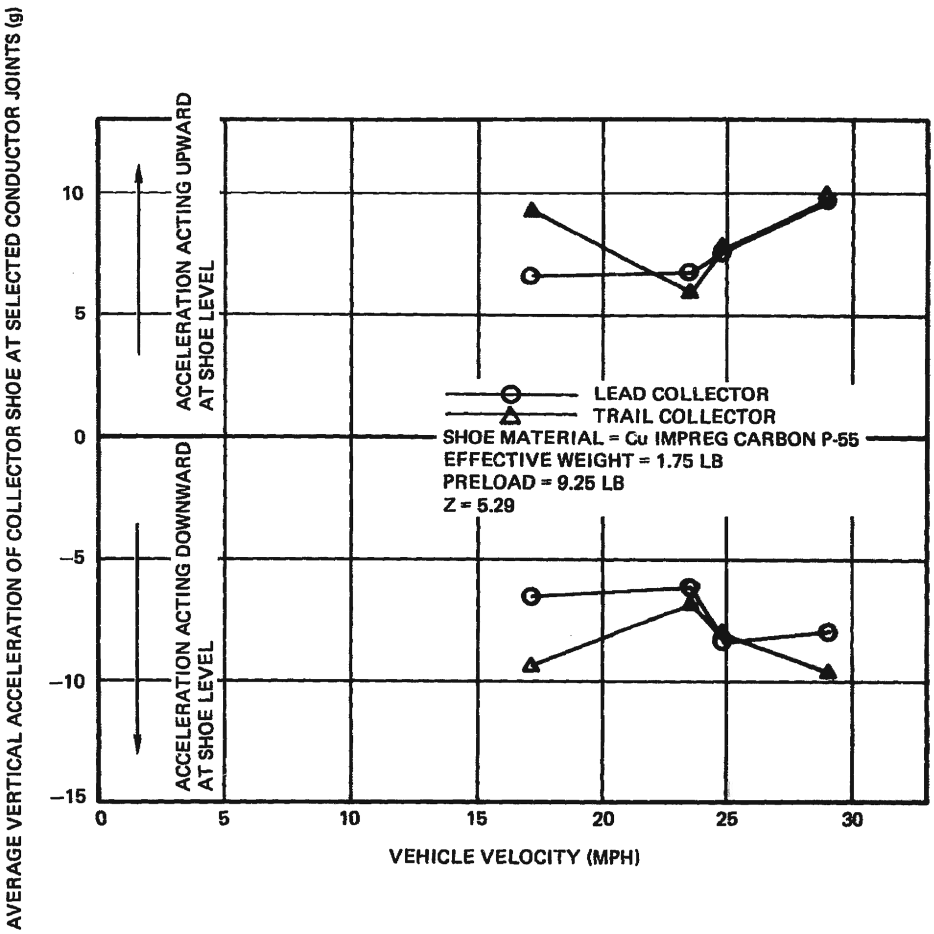


FIGURE 3–30 LEAD AND TRAIL AUTP SIGNAL COLLECTOR VERTICAL ACCELERATIONS MEASURED ON VEHICLE T365

isolaton joints. No interruption in Phase C voltage was indicated by the continuity records during any of the speeds. Continuous power transfer to the vehicle is attributed to the redundancy of the power collection equipment, that is, two collectors per electrical phase are in contact with the power conductors at all times.

3.5 CONCLUSIONS

On- and off-guideway test programs revealed the primary causes of interruption in conductor/collector contact to be the discontinuities present at conductor joints. Maintenance of adequate contact at the conductor/collector interfaces is not only a matter of good collection equipment design, but is also a matter of providing and maintaining smooth conductor running surfaces. These test programs also demonstrated the performance of the AUTP collector to be superior to the production collection equipment. This is attributed to the higher g-capability and stabler shoe operation of the AUTP design. Noise level measurements made at the rotating drum facility indicate that the AUTP collector operates quieter than the production power collector.

Within Phase I of the AIRTRANS Urban Technology Program the AUTP collector was operated as signal and ground collection equipment. This design will, however, be modified during AUTP Phase II to accomodate the signal, ground and power collection requirements of the urban vehicle. It was concluded that this design concept has the capability to operate successfully in all applications at speeds up to 45 MPH.

Collector ramping tests demonstrated the effect of ramp profile geometry on shoe impact acceleration and shoe loft. During these tests it was found that the collection equipment could negotiate the various ramp profiles at speeds up to 55 MPH without being damaged. Additionally, a ramp running surface material was found which is less sensitive to impact loads and the effects of weather than the production ramp material.

To gain additional data in the areas of reliability, structural fatigue and wear, a vehicle set of AUTP signal collectors were fabricated and installed on AIRTRANS passenger vehicle. The operation of these collectors was monitored from October 8, 1977 through November 23, 1977. After 1053 operating hours and 8553 vehicle miles visual inspection of the collectors indicate that all components are in very good operating condition. No increased mechanical freedom, or joint wear, was evident. The shoe material used in this test period is copper impregnated carbon (carbon grade P-55). The average wear rate of the four shoes is 8.4766×10^{-6} inches per mile. For the allowable shoe wear depth of .25 inches, the projected AUTP shoe life is 29,493 miles. AIRTRANS shoe wear information is based on the overall shoe replacement requirement per vehicle, i.e., this data includes not only shoe replacement due to normal wear, but replacement associated with lost or broken shoes. Best estimate for AIRTRANS shoe life is 10,000 to 22,000 miles depending on location. Therefore, it is reasonable to assume a significant shoe wear rate improvement with the new collector design when fully developed.

4.0 STEERING

This section describes the design and testing of changes in the steering system to improve the design and permit operation at higher speeds. The problem is stated, goals are discussed, candidate solutions are described, test results are presented, and conclusions drawn.

4.1 STATEMENT OF PROBLEM

The AIRTRANS steering system was designed to suit the requirements of the Dallas/Fort Worth Airport. The 17 mph speed requirement of the system is inadequate to meet the needs of many urban applications. Development of the AIRTRANS mechanical system to operate at some higher speeds was obviously possible. It was also apparent that practical limitations of guidesurface quality would limit top speed, probably to some speed less than the 45 mph objective established for AUTP.

The Dallas/Fort Worth operating experience indicates the need to improve the AIRTRANS steering system for urban applications. The projected speed limitation of mechanical steering suggested that some form of power steering should be developed for the high speed applications. The guidewheel loads are known to be excessive, requiring a high maintenance on the steering system and parapet walls. Thus redesign of the system was necessary for three reasons:

(1) To reduce loads on parapet walls and guidewheels,

(2) To increase speed while maintaining acceptable lateral ride quality, and

(3) To reduce weight and complexity to achieve cost savings and maintainability gains.

The original AIRTRANS design program omitted design iterations in the interest of cost and schedule. As a consequence a good potential for simplification and weight savings by redesign existed. Gains in this area were expected to aid directly in reducing loads on the parapet walls. Reduction in loads is mandatory to permit greater speed because guidewheel loads are known to increase with increasing speed.

4.2 PROGRAM GOALS

A quantified goal for steering system improvement was not set. However the objectives of load reduction and improved maintainability were used as requirements. Another unstated goal in the guidewheel load area was to develop a power steering concept which would steer the vehicle contactlessly thereby reducing the function of the mechanical steering system to a backup, and reducing the normal loads in the guidewheels to virtually zero.

Ride quality measurement was used as an evaluation parameter in comparing the changes made with the original baseline design at 17 MPH and the higher 30 MPH. It was determined that some degradation of ride quality at speeds over the baseline 17 MPH speed would be acceptable as improved lateral ride quality will be obtained in Phase II AUTP through a redesign of the lateral suspension system.

4.3 BASELINE AND CANDIDATE SYSTEMS DESCRIPTION

Candidate design improvements were selected by trade off studies. They were:

(1) An improved mechanical system,

(2) A power boost system, and

(3) A contactless ferrous strip following system with electro-hydraulic servo drive. (Hereinafter called contactless steering).

As noted in Section 4.1, substantial improvements in the mechanical steering system could be made by redesign. These improvements would also augment the performance of the powered steering systems. Thus improved mechanical steering was selected as both a stand alone candidate and as an integral part of alternate candidate systems.

A second candidate, power boost, was selected as an intermediate cost effective approach for power steering. Off the shelf components developed by the automotive industry were used to construct this system.

The contactless steering concept was based on a successful Vought program to develop a steered steel wheeled prototype vehicle. This system utilized an electro-magnetic sensor which tracked the steel rail and electro-hydraulically positioned a steerable steel wheel to follow the rail. The purpose of the program was to develop a steering and suspension system that would replace the standard steel wheel trucks now used on light rail vehicles. The objectives were to reduce cost and weight through reduction of parts, and to reduce noise and wear by eliminating the wheel flange contact with the rail to detect the location of the steel rail and guide the steel wheels without "hunting" or flange contact. A natural follow on to this development was to adapt the system to follow a steel strip placed in the AIRTRANS guideway and utilize the guideway parapets as limiting restraints in case of abnormal conditions. Several variations in arrangement and function were established based on this concept and were evaluated by trade studies to select the system described later in this section. This concept was the only one identified which could achieve the ideal of no wall contact.

4.3.1 BASELINE - The directional control of AIRTRANS is accomplished by a steering mechanism which follows the guideway parapets (guide walls). A drawing of the system and a cross-section through the guideway are shown in Figure 4-1. For normal operation, lateral loads are resisted primarily by cornering forces at the tire/pavement contact area, with only small forces being present in the small guidewheels which track the vertical walls. In abnormal conditions the small guidewheels provide all of the lateral forces to maintain the vehicle safely in the guideway.

The running gear of AIRTRANS consists of two steerable axles, front and rear. Normally the front axle is active, but the vehicle can be operated in reverse by adjusting the reversing mechanism. Each axle has a tie rod with conventional Ackerman geometry to coordinate motions of left and right wheels. To help coordinate steering motions between front and rear axles an interconnect linkage is provided. A break out spring is provided in this linkage to allow steering motions to occur independently front and rear as required from the primary steering mechanism, which is the guidebar mechanism.

Mounted on the front and rear of the vehicle are identical guidebar mechanisms. The guidebars are bent tubular members mounted on arms which allow them to swing laterally in either direction. The motion is limited by solid stops to ± 2 inches either side of center. Mounted at each end of a guide bar are a fixed guidewheel and a fixed switch wheel, and a spring loaded guidewheel and switch wheel. The spring loaded wheels are mounted on a movable link which mounts on the guidebar and a spring mechanism forces the wheels outward until they rest on the guide-walls or on their individual limiting stops. The spacing of the fixed wheels left and right is to approximately match the guideway width to cause the guidebar always to follow the guideway with little or no side to side motion. The function of the springloaded guidewheels in straight guideway is to track both guide walls and cause the guidebar to approximate an average path between the two guide walls. When variations occur in curves the guidebar will tend to track the inside wall with a fixed wheel and an outside wall with a spring loaded wheel. The guidebar is linked to a reversal mechanism which is in turn linked to an arm on the wheel axle. The two inch motion of the guidebar will thus cause the wheel to turn approximately 4.7° in either direction (9.3° lock to lock).

To properly guide the vehicle the rear guidebar must move the wheels in the opposite direction from the motion provided by the front guidebar. The function of the reversal mechanism is to permit this mechanism to be properly set for the desired operational direction of the vehicle. In Figure 4-1, note the respective positions of the "steering link (rigid)" at the front and rear with positions for reverse operation indicated by the phantom lines.

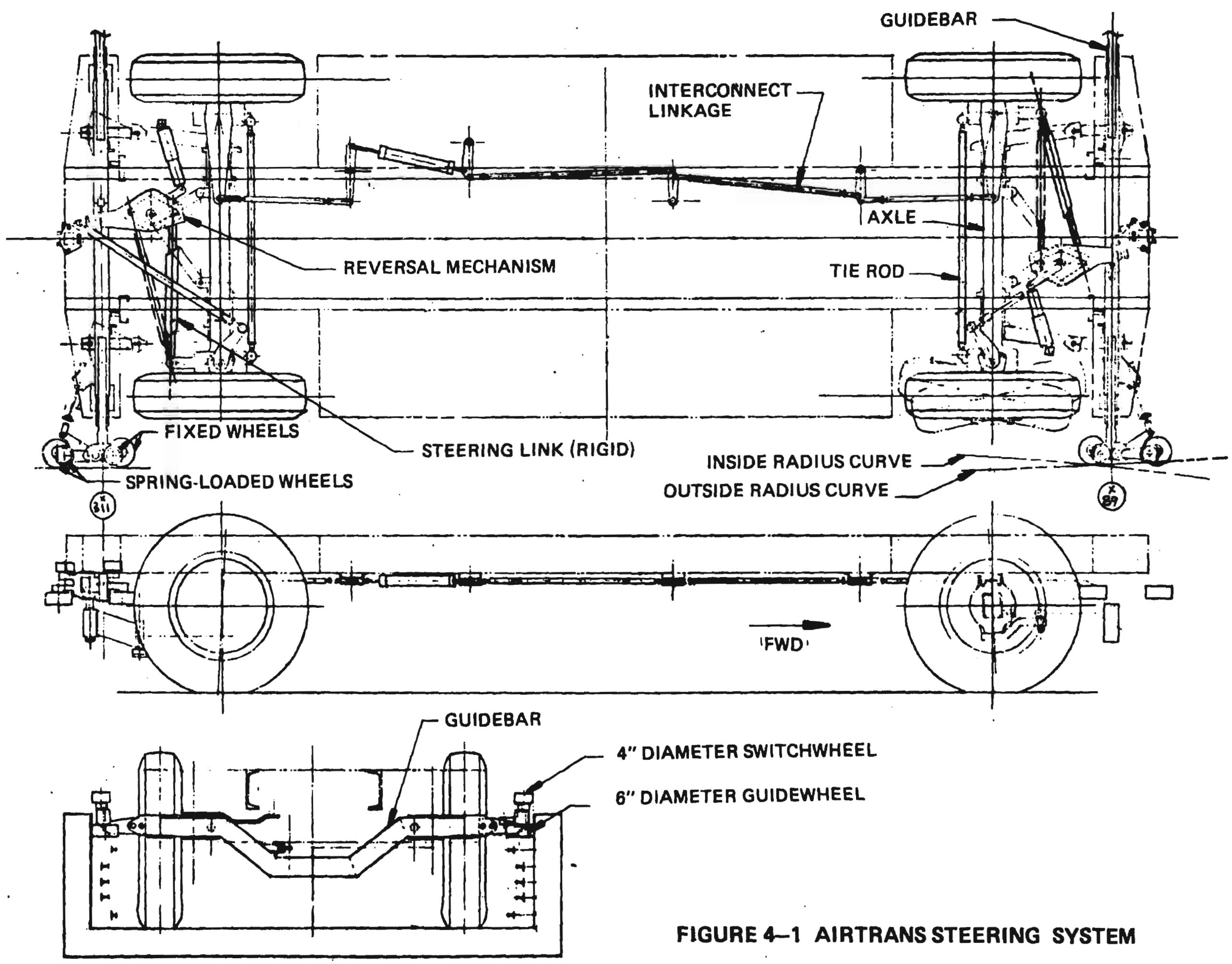


FIGURE 4–1 AIRTRANS STEERING SYSTEM

At switches the guidewalls are continuous only on one side of the vehicle. To make the vehicle follow a single wall, a trap rail is provided which engages the smaller switch wheels on their inside to force the guidebar to track the one wall. To determine which wall of the switch is followed a guideway switching mechanism positions a movable section of the trap rail.

A damper is attached to the reversal mechanism to help damp out undesirable motions of the steering system.

4.3.2 IMPROVED MECHANICAL - The improved mechanical steering operates basically the same as AIRTRANS with the followup changes and modifications.

AUTP	AIRTRANS
Larger guidewheel (8" dia.)	6" dia.
Spring loaded guide/switch wheels	fixed and spring loaded guidewheels
8 guide/switch wheels total per vehicle	16 total per vehicle
Lightweight guidebar (straight tubular section)	Joggled sections welded
Rotary steerdamper	Axial steerdamper
Anti-friction kingpin bearing	Journal bearings
Steering link spring	Rigid steering link
Wheel loss detection and mechanical entrapment	Redundant wheel

The overall steering arrangement is shown in Figure 4-2. The components of the improved mechanical system at each end of the vehicle are the guidewheels, guidebar, reversal mechanism, rotary damper and steering rod with an interconnect linkage tying each end together. The AUTP 8" diameter guidewheel and 4" diameter switch wheel on each end of the guidebar are mounted to a spring loaded support at a common pivot. An enlarged view of the guidewheels, Figure 4-3, shows the pivoted wheels and their relation to the switch/entrapment rail and guidewall.

In operation, the important differences which were expected to lessen loads, were the reduced mass, the rubber springs which absorb the impact loads from wall irregularities as the guidewheel strokes, and the single guidewheel configuration.

A rotary damper connected to the reversal mechanism provides damping with minimum friction. The damping rate is adjustable and the sealed unit is temperature compensated. A damping rate

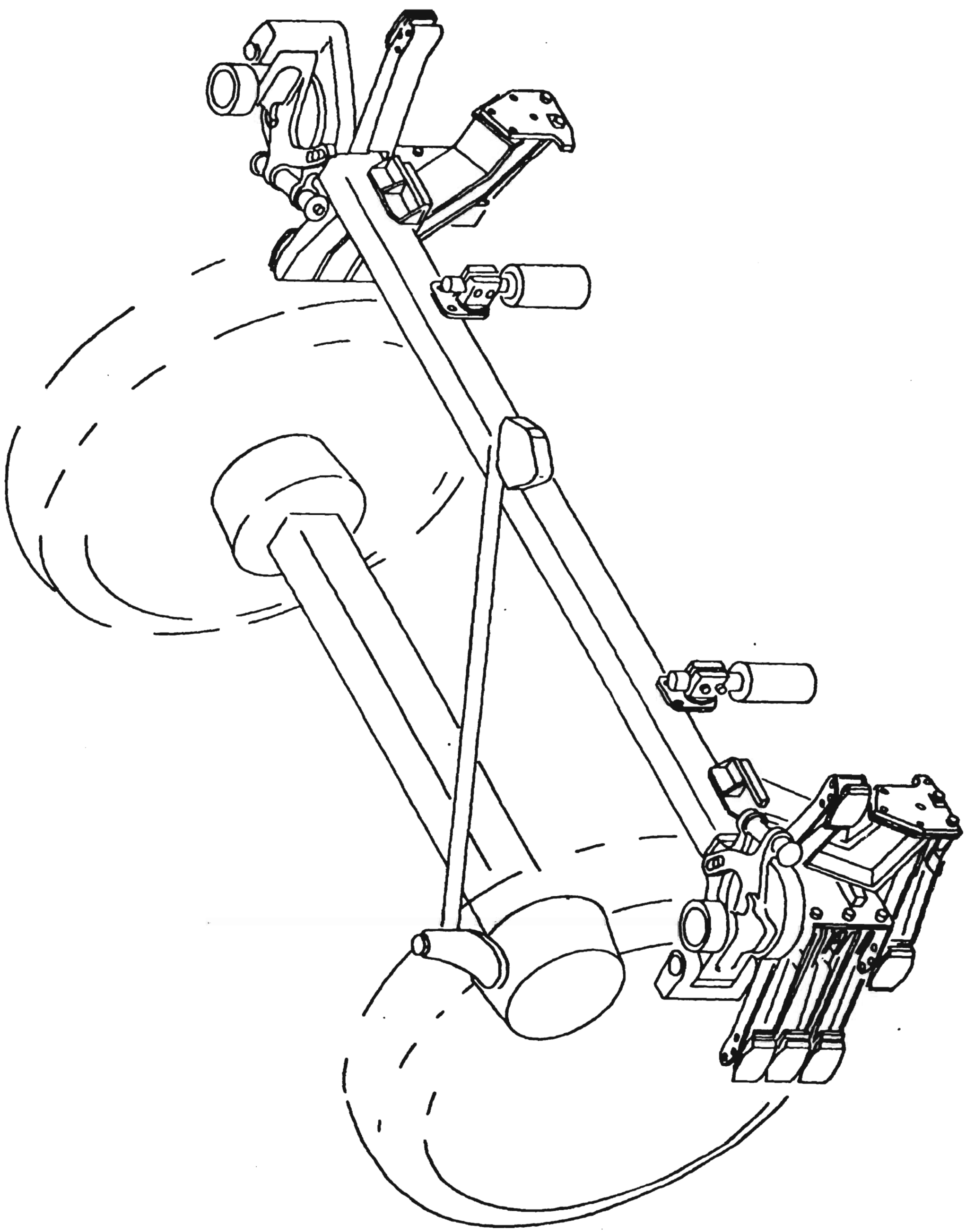


FIGURE 4–2 IMPROVED MECHANICAL STEERING AND COLLECTORS

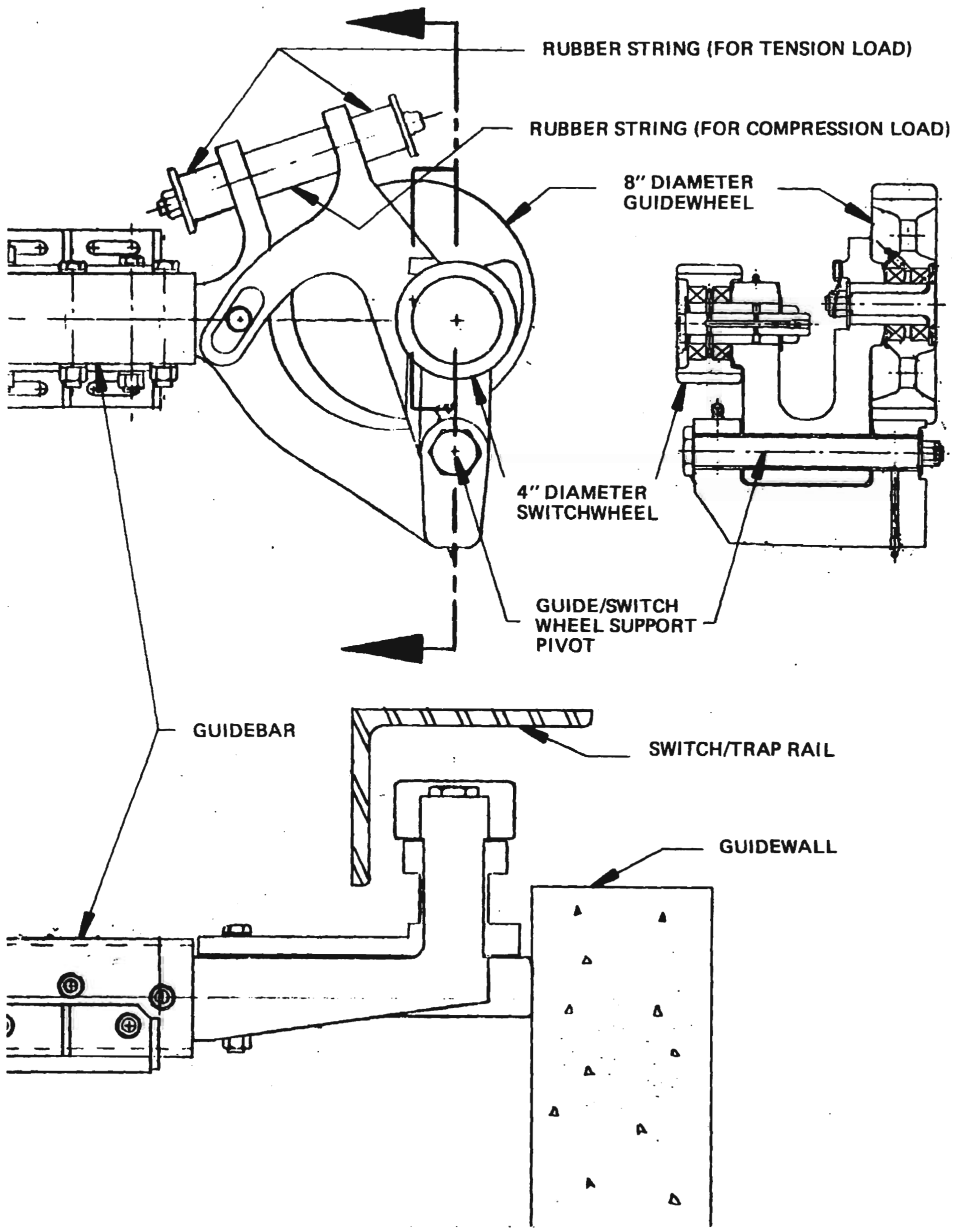


FIGURE 4-3 AUTO GUIDEWHEEL INSTALLATION

of 20 pounds per inch per second at the guidebar was selected as a nominal test value.

In an effort to further reduce the steering forces, anti-friction kingpin bearings were installed on the axles in place of the journal bushings used on AIRTRANS. This reduction in friction should not only lower the guidebar loads but also improve the overall steering system life.

A special steering link (pneumatic spring) was used in the test but was not intended to be a part of a production system. In case more stroke was required after the rubber springs bottomed, this link with its pneumatic spring was provided. The spring strut is used in the mechanical system to provide an adjustable breakout force in the linkage between the guidebar and the steered wheels. Regulated nitrogen pressure from the onboard high pressure cylinder is applied to the strut to provide the required breakout force level. The pressure is adjustable over the full range of cylinder pressures from 0 to 2000 psig, thereby providing a breakout force of 0 to 4960 pounds. In operation, the pressure is adjusted to provide a breakout force equal to the bottoming force of the spring loaded guidewheel. Operation of this system is schematically shown in Figure 4-4. A rubber spring would be used in production if tests showed it was beneficial.

4.3.3 POWER BOOST - Another approach to improved steering is power boosting the mechanical steering system to achieve reduced loads and improve ride quality at higher operating speeds. This system uses standard commerical hardware added to the improved mechanical steering system to provide the added capability.

The overall system arrangement is presented by Figure 4-5. In addition to the mechanical elements discussed in Section 4.3.2, the system consists of an onboard hydraulic system, two power boost valves and two hydraulic actuators. The hydraulic system, valves and actuators provide the power boost to the mechanical system. The hydraulic system is discussed in APPENDIX C. The power boost valves are standard truck type "valve-in-link" spool valves of the open centered configuration. The spool travel is mechanically limited to ± 0.055 inches thereby providing a direct mechnaical link between the guidebar and axle in the event of a hydraulic system malfunction.

Any steering input from the guidewall strokes the guidebar, and through the linkage, the power boost valve. As the valve strokes (± 0.055 inch maximum), the fluid path through the valve is changed such that the actuator is pressurized in the direction to neutralize the valve stroke and aid guidebar motion. As the wheels respond, the guidebar input is neutralized and the valve returns to the centered position thereby returning the actuator and valve to a balanced condition at a new wheel steering angle.

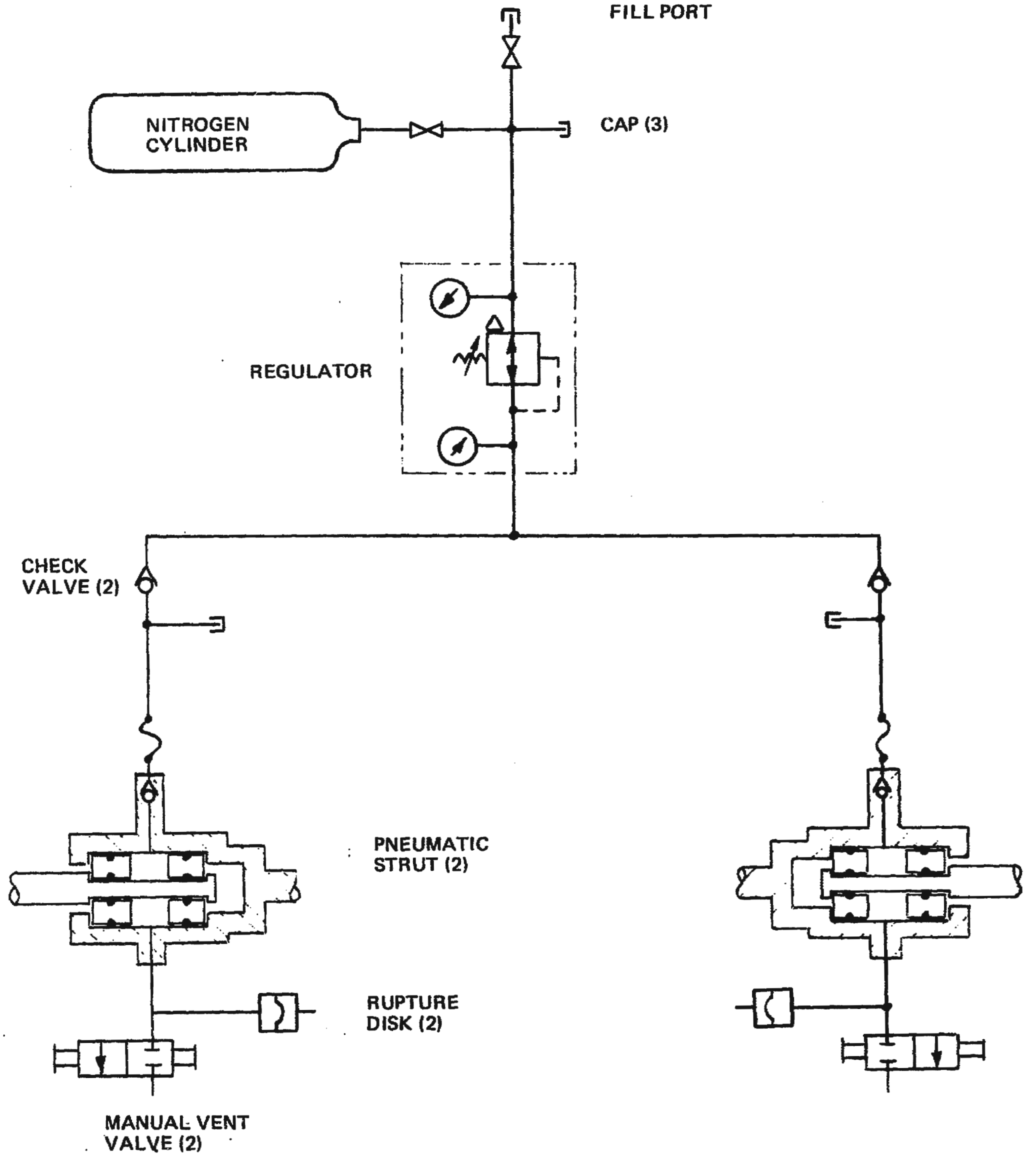


FIGURE 4-4 IMPROVED MECHANICAL STEERING HIGH PRESSURE NITROGEN SYSTEM

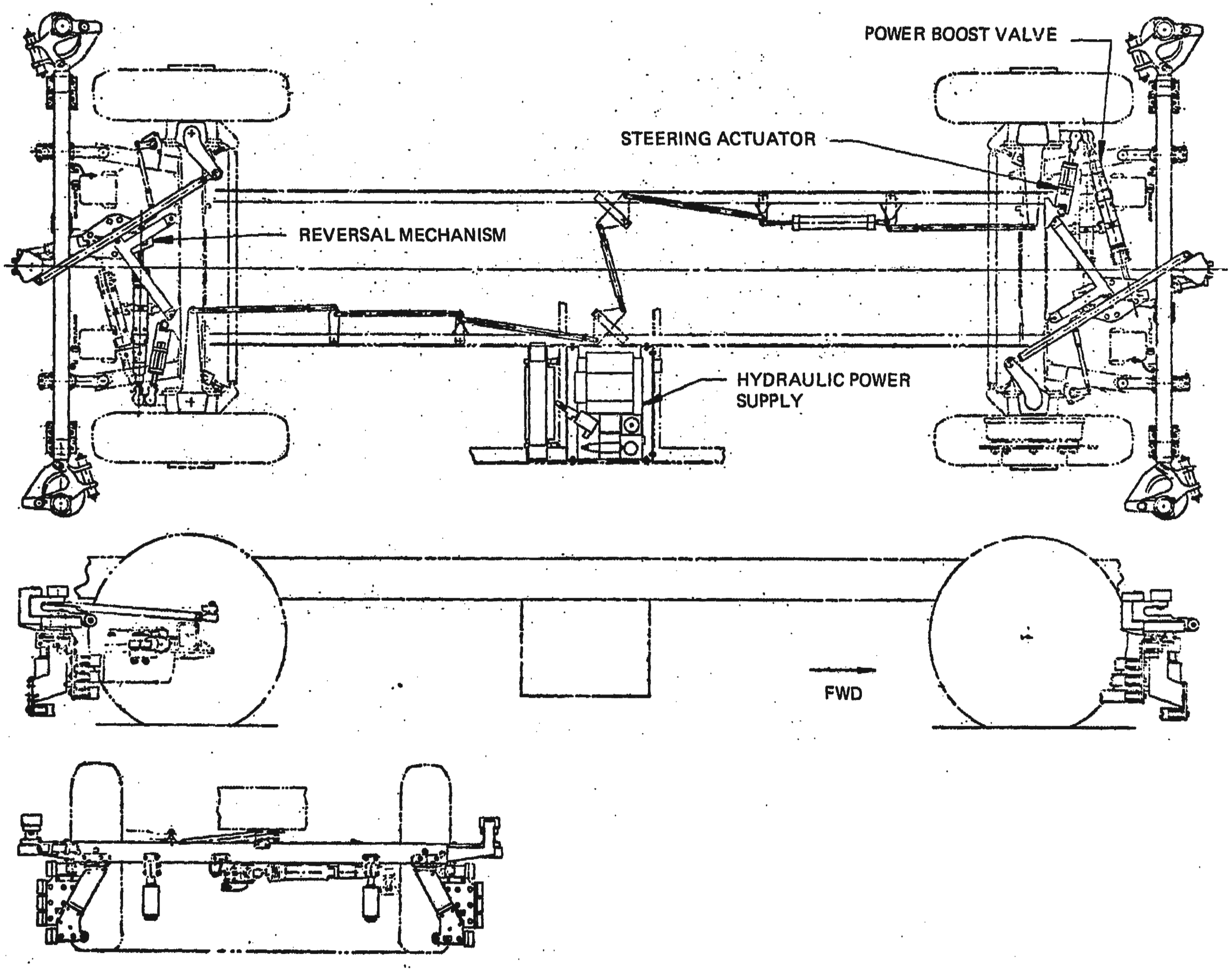


FIGURE 4–5 POWER BOOST STEERING SYSTEM

4.3.4 CONTACTLESS STEERING - A complete departure from the mechanical steering system is the contactless steering system. This concept uses a passive iron guidestrip located on the floor of the guideway to serve as a path for the vehicle to follow. The guidestrip cross section dimensions are 2 inches wide by 1/8 inch thick. Electro-magnetic sensors mounted on the front and rear axles of the vehicle measure the position of the vehicle with respect to the guide strip. The output of the sensors controls a servo system which steers the wheels. The system commands the vehicle to follow the center line of the guide strip. A second set of sensors on the opposite side is provided to allow electronic switching. A schematic of the contactless steering system is shown by Figure 4-6.

A major consideration in the design of the contactless steering system was vehicle safety. A fail-operational concept was designed. A redundant electronic model of the active steering channel is provided. An electronic monitor compares the outputs of the model and the active channel. If the difference of the two exceeds a fixed threshold, a failure is indicated. A failure indication operates a bypass valve which dumps hydraulic power. At the same time, a pneumatic mechanism connects the mechanical steering system to the wheels. This event is accomplished in forty milliseconds. If either the front or rear path follower steering system malfunctions, both revert to mechanical steering. In addition, a guidestrip detection circuit is provided. If either sensor does not detect the presence of a guidestrip, a malfunction is indicated. If the vehicle is in a switch area, two guidestrips are detected. If two guidestrips are detected and a switching tone is not detected, a malfunction is indicated. Finally, mechanical stops are provided between the mechanical guidebar and vehicle frame to limit the vehicle position to two inches either side of the center line of the guideway. The mechanical guidebar, guidewalls and entrapment rails are designed to hold the steering forces developed by a full travel of the wheels.

The overall system arrangement is presented on Figure 4-7. The system consists of guidestrips, sensors, steering control electronics, and the hydraulic power supply, servo valves and actuators of the power boosted system described previously. The special steering link (described in the mechanical system) is used as caging device which disengages the guidebar during full servo operations.

The pneumatic caging system utilizes an onboard high pressure nitrogen storage cylinder to pressurize the pneumatic strut to engage mechanical steering. Pressure application and removal is achieved through the use of fast response solenoid valves. The system is shown schematically on Figure 4-8.

The guidestrip center line is positioned twenty-five inches from the center line of the guideway. The guidestrip was fabricated from short sections of hot rolled steel strips, 1/8 thick

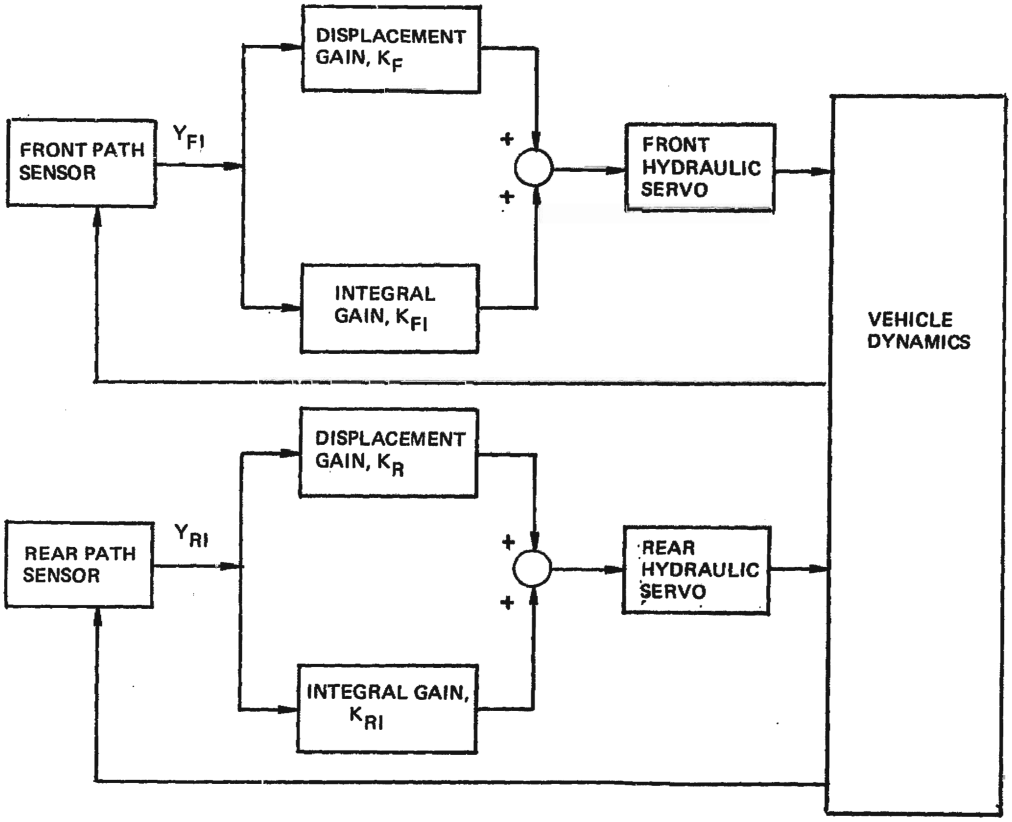


FIGURE 4–6 CONTACTLESS STEERING SYSTEM SCHEMATIC

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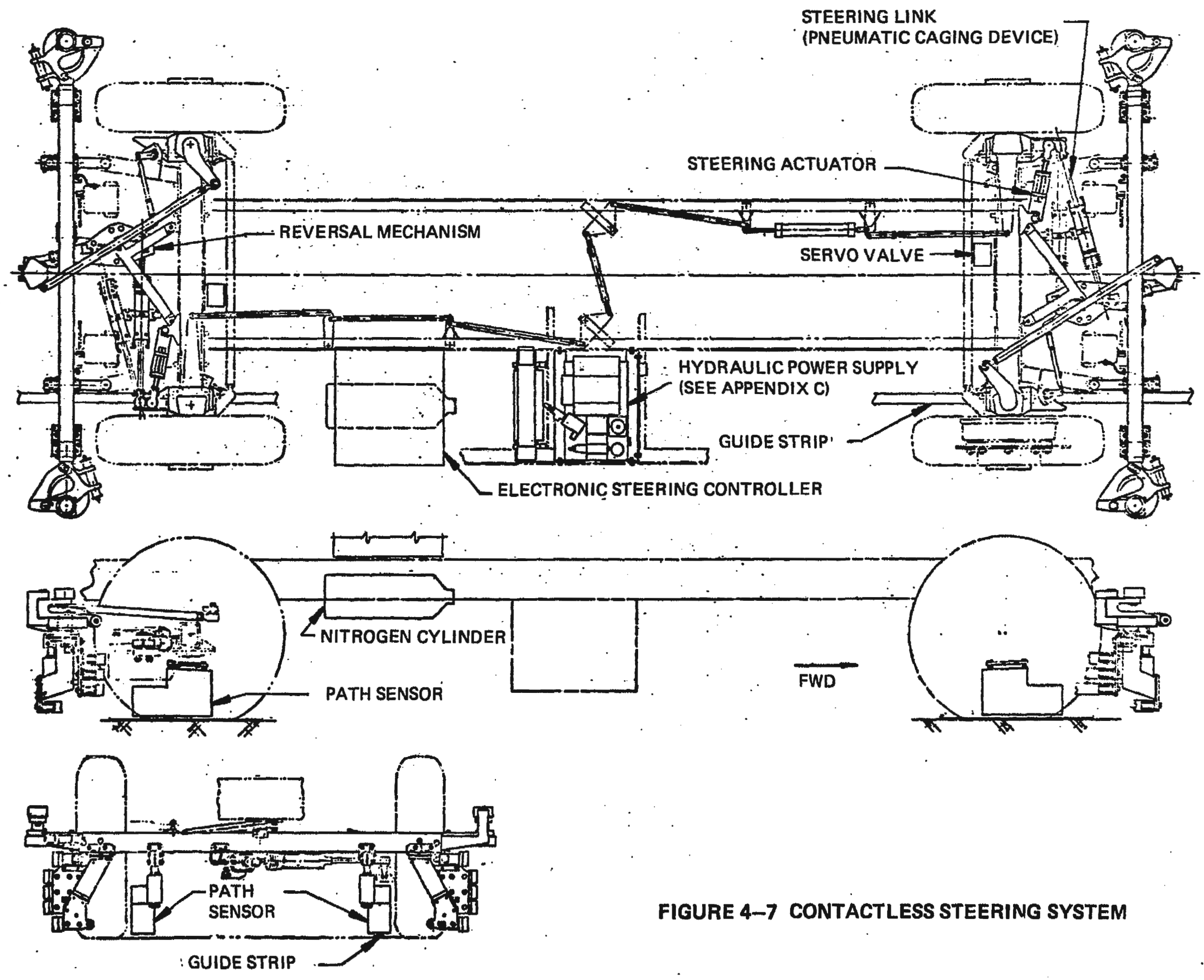

FIGURE 4–7 CONTACTLESS STEERING SYSTEM

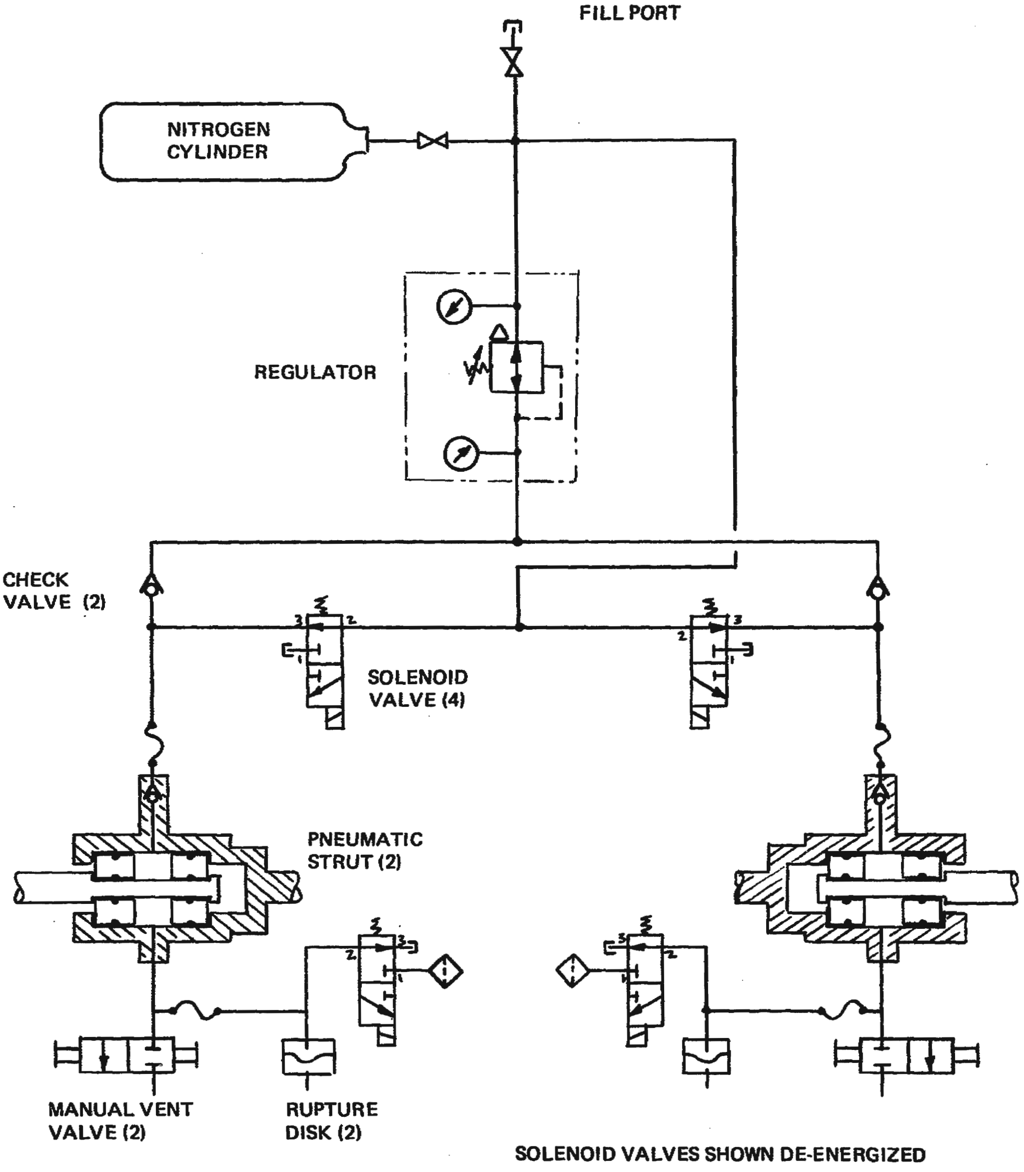

FIGURE 4–8 CONTACTLESS STEERING HIGH PRESSURE NITROGEN SYSTEM

by 2 inches wide which matches the required sensitivity of the sensor. The path through curves and switches follows the same tangent to spiral transitions that were employed in originally laying out the guideway. To make a temporary installation non-damaging to the guideway and adjustable, strips were held in place with Velcro patches cemented to the guideway. Previous experiments showed that it was not necessary to make any compensation for reinforcing or other steel in the guideway. This was verified during the tests.

Special provisions are necessary to guide the vehicle through a switch. In a switch area, a second guidestrip, located twenty-five inches from the center line of the guideway on the opposite side from the first, passes on through the switch. When the sensors on both sides of the vehicle detect the presence of guidestrips, a tone detection circuit is activated. A wayside signal generator puts a small AC current (tone) at 12.2 KHz through the iron strip. If the tone is on the right hand guidestrip and is detected by the right hand sensors, control is switched to the left hand sensors and the vehicle follows the left hand guidestrip. If the tone is on the left hand guidestrip and is detected by the left hand sensors, the vehicle continues to follow the right hand guidestrip.

4.4 TESTS

In order to evalute the improved mechanical, boosted and contactless steering system concepts, it was necessary to acquire baseline data for comparison. The baseline was established with the AIRTRANS mechanical steering system installed on the AIRTRANS passenger and cargo vehicles at Dallas/Fort Worth Airport. The T-365 test vehicle was instrumented and operated through a broad range of speeds and steering conditions with the AIRTRANS baseline system. Tests of the AUTP steering systems were then performed. Comparisons of each system with the baseline system were then made.

For qualitative comparisons among configurations, the overall G_{RMS} (acceleration) was used as a descriptive single index. The use of the G_{RMS} as a predictor of ride quality was investigated and recommended in the Research Report, "The Prediction of Passenger Riding Comfort from Acceleration Data", by Smith et.al., performed under the sponsorship of the Department of Transportation, Contract Number DOT OS 30093. The subsequent evaluation of the different vehicle changes used both the frequency analysis and the overall RMS levels.

The material describing the testing is detailed and lengthy because of the large number of important tests which were run. A summary of this section which explains the background and need for each test is presented in the following paragraphs.

SUMMARY

NOTE: The paragraph numbers in this summary are the same as in the detail text.

4.4.1 BASE LINE TESTS - Tests with the instrumented test vehicle were run with the steering in the AIRTRANS configuration to establish a base for comparison. Data were gathered in a full variety of AIRTRANS situations. This section lists the runs that were made and the type of data that were recorded.

4.4.1.1 Vehicle Steering Performance - The motions and loads in the steering system in a 150' radius turn were compared with analytical predictions and found to be in close agreement.

4.4.1.2 Special Steering Configuration Tests - The necessity of steering the rear wheels with both the rear guidebar and the interconnect linkage has often been questioned. Two tests were run:

(1) The rear guidebar disconnected and (2) the interconnect linkage disconnected. In the first test performance was acceptable in straights but degraded in the turns and at switches. In the second test the ride quality was also degraded in turns and switches.

4.4.1.3 Speed Effects On Vehicle Steering System - Increased speed test were run with the baseline system at 23, 27 and 30 MPH. The tests showed that loads in the guidebar increase linearally with speed, instead of geometrically with the square of the speed as might be expected. A mathematical model was generated, balancing impulses and momentums of the system components, which can predict with confidence loads for speeds higher than tested at Dallas/Fort Worth. Ride quality was shown to degrade with increasing speed as expected.

4.4.1.4 Fixed/Springloaded Guidewheel Interaction (Guidebar "Pounding") - An undesirable reasonance phenomenon known as guidebar "pounding" occurs during 150' radius turns. From the test records this phenomenon is identified as a 20 Hz oscillation of the guidebar between the solid wheel rolling on the inside wall and the springloaded wheel rolling on the outside wall.

4.4.1.5 Effect Of Kingpin Friction - AIRTRANS kingpins have plain bronze bearings which are a maintenance item. Comparisons with tests run with anti-friction kingpin bearings show that the load required at the guidebar due to steering the wheels is reduced from 360 pounds to 160 pounds. Ride quality is improved significantly overall but low frequency lateral excursions are increased due to the loss of damping due to friction.

4.4.2 IMPROVED MECHANICAL STEERING TESTS - The test runs with this system installed are listed in this paragraph and the data is summarized and presented.

4.4.2.1 Interconnect Linkage - Runs with and without the interconnect linkage were made with no difference or consequence noted.

4.4.2.2 Speed Effects On Vehicle Steering - As with the baseline, loads increase linearily with speed and the ride quality degrades rapidly with increasing speed.

4.4.2.3 Single Guidewheel Interaction - The tests showed no unfavorable interaction between guidewheels and the "pounding" present in 150' radius curves with the baseline is completely eliminated.

4.4.2.4 Guidewheel Spring Rate Evaluation - Runs were made with two different rubber springs controlling the guidewheels. The softer spring gave lower loads but allows more lateral motion to occur.

4.4.2.5 Additional Spring In Steering Link - Runs were made with the special steering link acting as a load limiting breakout spring at two different spring rates. No beneficial effect was obtained at either spring rate.

4.4.2.6 Steering Damper Disconnected - A run made with the damper disconnected proved the damper has a beneficial influence on ride quality.

4.4.3 POWER BOOST SYSTEM - One run was made under automatic train control in regular traffic. Three more runs at 22, 26, and 30 mph were made in the high speed area.

4.4.3.1 Performance - Ride quality performance is summarized in a table. A mild coupling between the body dynamics and the actuator occurred, most pronounced during the 26 mph run. Decoupling can be accomplished rather easily by a reduction in gain.

4.4.3.2 Speed - The actuator load was compared at various speeds thru the "S" turn area, and was found to increase slightly with speed, approximately linearly.

4.4.4 CONTACTLESS STEERING SYSTEM - Tests runs were made at 17, 22, and 27 miles per hour. Steering behavior obtained closely matched the predictions. A switch was negotiated at low speed to demonstrate electronic switching function.

4.4.4.1 Bench Tests - Simulation of the contactless steering system was made in the laboratory. Operation was demonstrated and resonances and responses determined. No changes were required.

4.4.4.2 Vehicle Integration Tests - With the contactless steering system installed on the vehicle this test was performed with the vehicle on jacks. The test confirmed that the system was operational and that the failure logic correctly caused reversion to the mechanical system.

4.4.4.3 Performance - Because the system could only be tested where the iron guidance strips were installed, data for comparison is limited. No essential difference in ride quality from the improved mechanical system could be discerned.

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4.4.4.4 Speed - Speed does not increase the magnitude of the guidewheel loads. Inadequate data exists for a ride quality trend to be determined.

4.4.5 COMPARISON OF STEERING SYSTEMS

4.4.5.1 Effects Of Speed - The test results at a 2o diverge switch were used for comparison. The switch wheel loads for the baseline and improved mechanical are very close to the same and increase linearly with speed. The power boost load was about half as large.

4.4.5.2 Effects Of Fixed Guide/Switchwheel Deletion - In 150' radius curves the guidebar "pounding" present in the baseline is completely absent in the improved mechanical. A dramatic 49% reduction in switch wheel load is attained, from a peak of 2357 to a peak of 1210 pounds.

4.4.5.3 Ride Quality Comparisons - Important differences between the four systems, baseline, improved, power boost, and contactless are discussed. The anti-friction king pin bearing change and improved mechanical system gave marked improvement. The improved mechanical system met UMTA guidelines (reference 11) at 30 miles per hour in straight guideway and was slightly better than the contactless or powerboost systems as tested. However, the later systems can be tuned to the application to provide better ride quality.

4.4.1 BASELINE TESTS - The baseline tests for the AUTP were performed to establish a base for comparison with improved steering concepts that were designed and tested in Phase I. Steering loads, inertial loads, and displacements in major steering system components of the vehicle were measured during the baseline testing. Accelerations on the interior floor of the vehicle were also measured for determination of the vehicle ride quality. These data will be used to evaluate the current AIRTRANS vehicle steering system parameters, evaluate the design for 30 MPH capabilities, and to aid in determining design improvement changes to the steering system for use in an urban environment.

A complete listing of measured data recorded is presented in Table 4-1. The instrumented components relative to the vehicle are shown in Figures 4-9 and 4-10. The test results from the instrumented components were plotted into time history curves.

Testing at Dallas/Fort Worth Airport was restricted to the 3, 4, 5 and 6 loops of the guideway with the 3 and 4 loops for the 17 MPH baseline tests, and the 5W section for the high speed testing. Switches, 150 ft. turns, 800 ft. turns, and straight sections were given encounter designation markers and labeled along the route. The test route and the designated encounters

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TABLE 4 - 1 STEERING SYSTEM INSTRUMENTATION LIST

COMPONENT	LOCATION	TYPE MEASUREMENT
Moment[1]	Lt, Rt, Fwd	Bending bridge calibrated for fixed guidewheel lateral load
Moment Z[1]	Lt, Rt, Fwd	Bending bridge calibrated for fixed switchwheel lateral load
Force Y[1]	Lt, Rt, Fwd	Axial bridge calibrated for fixed guidebar lateral load
Forces (Sum)[1]	Lt, Rt, Rear	Axial bridge calibrated for fixed guidebar lateral load
Eyebolt	Fwd, Rear	Axial Bridge
Spring Wheel	Lt, Rt, Fwd	Axial Bridge
Steering Link	Fwd Rear	Axial Bridge
Tie Rod	Fwd	Axial Bridge
Steering Interconnect		Axial Bridge
Wish Bone Links[1]	Fwd, Rear	Axial Bridge calibrated for axle lateral load
Kingpin Rotation	Lt. Fwd, Lt. Rear	Kingpin rotation relative to axle
Guidebar Disp.	Fwd, Rear	Lateral guidebar movement relative to axle
Springwheel Disp.	Lt. Fwd, Rt. Rear	Displacement of guide/switchwheel spring
Guidebar Accel.	Fwd	Vertical Guidebar accel.
Guidebar Accel.	Fwd	Lateral Guidebar accel.
G	Fwd	Vertical Axle accel.
Axle Accel.	Rear	Lateral Axle accel.
Interior Acceleration	Fwd and Rear	Vertical Accelerations front left and right; rear right; lateral accelerations front right and rear right.

1. Required machining to increase sensitivity.
2. Vehicle speed, time and guideway position recorded also.

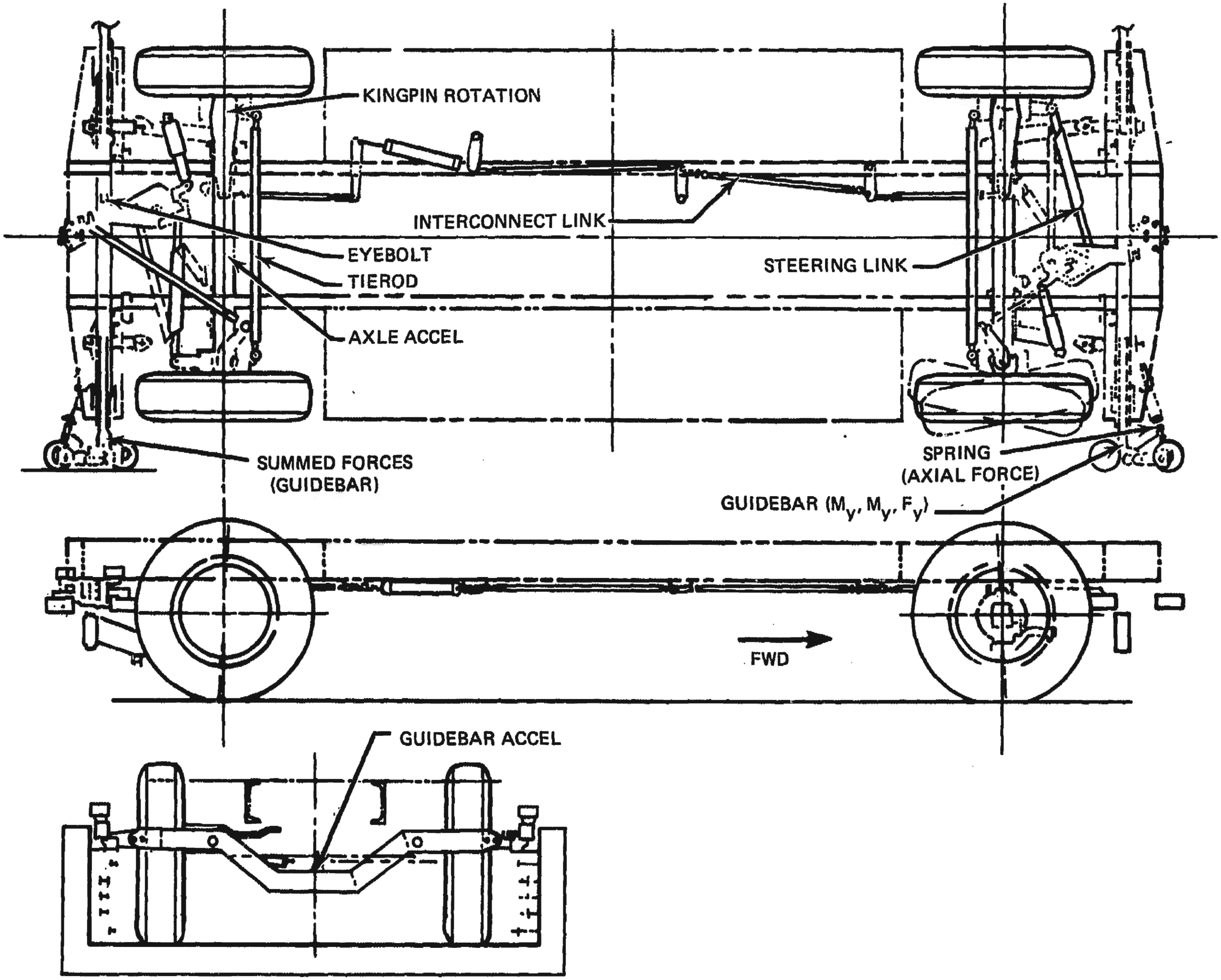


FIGURE 4–9 INSTRUMENTATION – BASELINE TEST

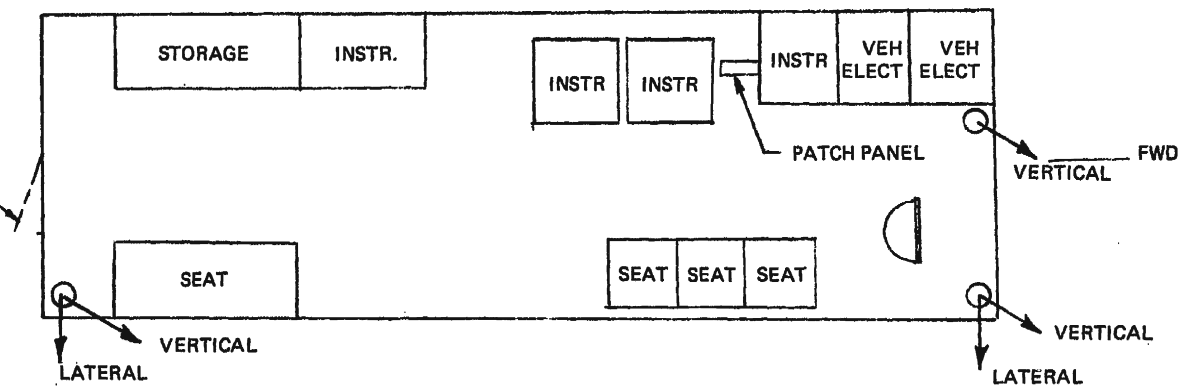


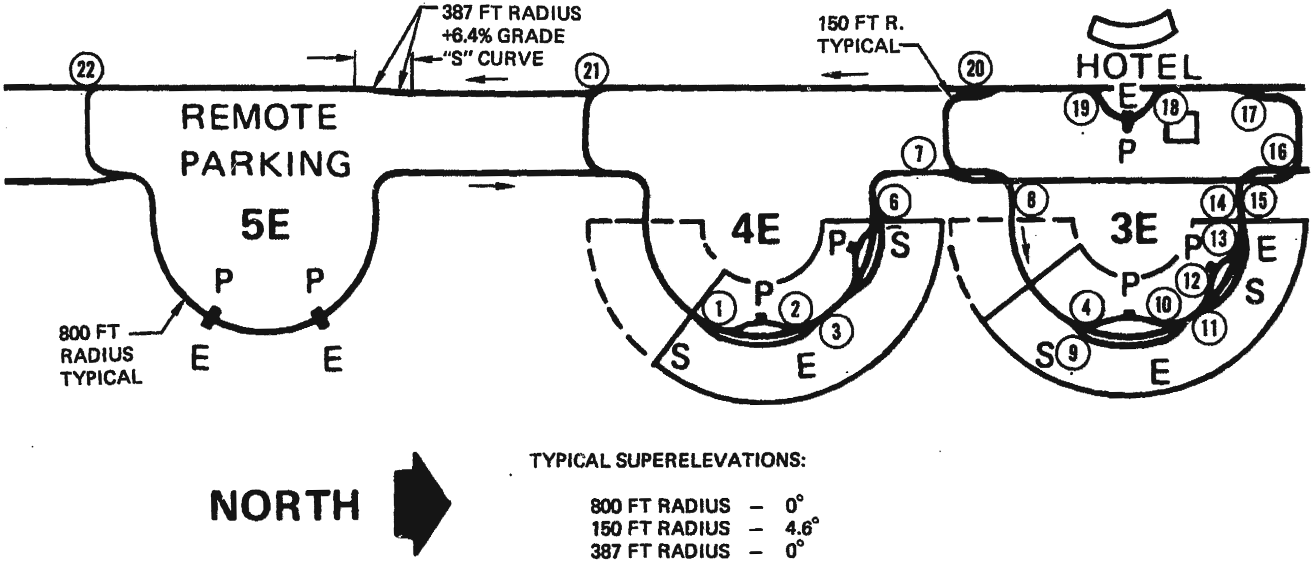
FIGURE 4–10 TEST VEHICLE INTERIOR LOCATION OF ACCELEROMETERS FOR RIDE QUALITY MEASUREMENTS

are presented in Figure 4-11.

The baseline tests for the steering system were conducted considering parameters such as speed, kingpin friction, and front/rear guidebar interactions. These parameters were investigated to determine their effects on the current AIRTRANS steering system. Table 4-2 presents a summary of the baseline test runs numbered and the significance of the run indicated. As indicated, the first four runs were made with the original journal bearing kingpins. Since these were known to increase the steering load significantly and were a cause of maintenance, no purpose would be served in testing the journal bearings at higher speeds. Therefore, when the car was modified for higher speeds, the anti-friction king-pin modification was also made and remained for all subsequent tests.

The baseline test results were examined to determine the vehicle's relationship to the guideway (loads, displacement of guidebar, steering angles, etc) and the effect of speed. This detail information will be used as an aid in determining future design changes to the AIRTRANS steering system.

Table 4-3 summarizes the G_{RMS} for the different conditions investigated under the baseline test series. These data are presented for different events as described and noted by the marker numbers on Figure 4-11.



TYPICAL SUPERELEVATIONS:

800 FT RADIUS – 0°
150 FT RADIUS – 4.6°
387 FT RADIUS – 0°

MAXIMUM GRADE: 8%

(1) = EVENT MARKERS (SEE RIDE QUALITY SUMMARY ANALYSIS TABLES)

FIGURE 4–11 BASELINE AND HIGH SPEED TEST ROUTE

TABLE 4–2 BASELINE RUN DEFINITION ATC – AUTOMATIC TRAIN CONTROL 17 MPH MAXIMUM SPEED

RUN NO.	SPEED (MPH)	REMARKS
5D	ATC	Baseline run, normal kingpin bushings, baseline route (all formats) original collectors.
11D	ATC	Baseline run, normal kingpin bushings, rear guidebar in neutral, baseline route (all formats), original collectors.
4D	82% ATC	Baseline run, normal kingpin bushings, baseline route, (all formats), original collectors.
3D	63% ATC	Baseline run, normal kingpin bushings, baseline route (all formats), original collectors.
101	ATC	Needle bearings in kingpin baseline route (all formats) original collectors.
102	19	Needle bearings in kingpin, high speed route (all formats) original collectors.
103	21	Needle bearings in kingpin, high speed route (no data reduced), original collectors.
104	23	Needle bearings in kingpin, high speed route (no data reduced), original collectors
105	25	Needle bearing in kingpin, high speed route (formats 1, 3, 4, 6, 8), original collectors.
106	27	Needle bearing in kingpin, high speed route (formats 1, 3, 4, 6), original collectors.
107	30	Needle bearing in kingpin, high speed route (all formats) new design collectors.
108	ATC	Needle bearing in kingpin, blade removal evaluation for Bill Stewart (format 1), new design collectors.
109	19	Run not made.
110	21	Run not made.
111	23	Needle bearings in kingpin, high speed route (all formats) new design collectors.
112	25	Run not made.
113	27	Needle bearings in kingpin, high speed route (all formats) new design collectors.
114	30	Run not made.
115	ATC	Needle bearings in kingpin, baseline run, video only. New design collectors.
12	ATC	Needle bearings in kingpin, interconnect free, baseline route (all formats), new design collectors.
6	63% ATC	Needle bearings in kingpin, baseline route, guideway roughness measurements only, new design collectors.
116		Run not made.
117A	21	Needle bearings in kingpin, emergency braking, high speed route except straight through 5S diverge, new design collectors.
117B	25	Needle bearings in kingpin, emergency braking, high speed route except straight through 5S diverge. New design collectors.
117C	30	Needle bearings in kingpin, emergency braking, high speed route except straight through 5S diverge. New design collectors.
118		Run not made.

TABLE 4–3 AUTP VEHICLE BASELINE TESTS RIDE QUALITY ANALYSIS SUMMARY, G_{RMS}

RUN NO.	DATA IDENTIFICATION (SPEED, fps; ACCEL, G_{RMS})	MARKER NO./EVENT									
		1. 4 EBU MERGE/ REV	6-7 4ENP 16 150' RAD TURN	8-9 3 ESL 800' RAD TURN	15 3ENB DIVERGE/ REV	15-16 3NB 150' RAD TURN	16-17 3NB 150' RAD TURN	20-21 4WCL STRAIGHT	21-22 4WSL– 5WCL STRAIGHT	22 5SB DIVERGE/ REV	22+ 5WSB 150' RAD TURN
5D	Average Speed	14.1	23.0	25.2	25.4	24.9	23.9	25.2	25.4	25.0	
(Baseline)	Lateral, Front Accel.	0.0300	0.0671	0.0481	0.0648	0.1023	0.0832	0.0610	0.0454	0.0588	
	Vertical, Front Accel.	0.0254	0.0597	0.0570	0.0884	0.0808	0.0774	0.0584	0.0550	0.0618	
	Lateral, Rear Accel.	0.0352	0.0609	0.0378	0.0518	0.0852	0.0777	0.0455	0.0401	0.0501	
	Vertical, Rear Accel.	0.0288	0.0899	0.0757	0.0858	0.1002	0.1022	0.0813	0.0775	0.0867	
11D	Average Speed	14.1	22.0	25.2	25.5	24.9	23.8	25.3	25. 4	25.0	
(Baseline,	Lateral, Front Accel.	0.0279	0.0550	0.0478	0.0673	0.1028	0.0920	0.0595	0.0462	0.0577	
Rear	Vertical, Front Accel.	0.0262	0.0374	0.0440	0.0638	0.1008	0.0909	0.0548	0.0501	0.0577	
Guidebar	Lateral, Rear Accel.	0.0245	0.0517	0.0365	0.0574	0.0958	0.0986	0.0460	0.0419	0.0495	
in Neutral)	Vertical, Rear Accel.	0.0248	0.0372	0.0676	0.0855	0.1008	0.1051	0.0800	0.0685	0.0850	
12	Average Speed	14.1	23.2	25.3	25.6	25.1	23.9	25.4	25.5	25.1	
(Baseline with	Lateral, Front Accel.	0.0387	0.0789	0.0529	0.0798	0.1376	0.1184	0.0764	0.0475	0.0596	
Needle Bearing	Vertical, Front Accel.	0.0282	0.0586	0.0318	0.0526	0.0737	0.0734	0.0432	0.0348	0.0392	
Kingpin and	Laterial, Rear Accel.	0.0364	0.0670	0.0375	0.0593	0.0926	0.0843	0.0503	0.0392	0.0486	
Interconnector Free)	Vertical, Rear Accel.	0.0279	0.0637	0.0387	0.0618	0.0894	0.0831	0.0531	0.0385	0.0472	
101 (Baseline with	Average,Speed	14.2	23.2	25.5	25.7	25.2	24.8	25.5	25.7	25.8	25.1
Needle Bearing King-	Lateral, Front Accel.	0.0141	0.0546	0.0183	0.0347	0.0589	0.0499	0.0330	0.0221	0.0342	0.0438
pin Normal ATC)	Vertical, Rear Accel.	0.0278	0.0614	0.0370	0.0553	0.0870	0.0815	0.0565	0.0371	0.0572	0.0766
102	Average Speed								28.8	28.4	28.0
(19 MPH)	Lateral, Front Accel.								0.0220	0.0341	0.0416
	Vertical, Rear Accel.								0.0404	0.0581	0.0712
103	Average Speed								30.8	30.7	30.2
(21 MPH)	Lateral, Front Accel.								0.0616	0.0978	0.0997
	Vertical, Rear Accel.								0.0435	0.0632	0.0711
104(A)	Average Speed								34.5	34.4	33.8
(23 MPH)	Lateral, Front Accel.								0.0580	0.1084	0.1110
	Vertical, Rear Accel.								0.0492	0.0689	0.0739
105	Average Speed								37.9	37.9	37.2
(25 MPH)	Lateral, Front Accel.								0.0785	0.1080	0.1494
	Vertical, Rear Accel.								0.0618	0.0816	0.0836
106	Average Speed								41.6	40.9	26.4
(27 MPH)	Lateral, Front Accel.								0.0842	0.1082	0.1082
	Vertical, Rear Accel.								0.0681	0.0853	0.0853
107	Average Speed								45.5	45.2	28.4
(30 MPH)	Lateral, Front Accel.								0.0989	0.1278	0.1065
	Vertical, Rear Accel.								0.0798	0.0917	0.0763

4.4.1.1 <u>Vehicle Steering System Performance</u> - The selected area for this study was the 150' radius right turn out of 4E (between data points 6 and 8). This section of the guideway was selected to study vehicle tracking primarily because no switch or trap rail exists in this area. The test results from Run 5D (Baseline, ATC) were compared with prior analytical results and show vehicle position does match the predicted displacements as shown in Figure 4-12. Using the recorded vehicle steering link force and tire data from Firestone, the required slip angles were calculated and they matched the recorded guidebar displacements (wheel angle) as shown in Figure 4-13. Of the .133 g's side force developed by going around 150' R turn at 25.3 ft/sec., superelevation accounts for .08g, the tires account for .037 g's and the remaining .016 g's are taken by the guidewheels on the guide wall.

4.4.1.2 <u>Special Steering Configurations Tests</u> - The necessity of steering the rear wheels with both the rear guidebar and the interconnect linkage has often been questioned. In order to resolve this question two special steering configurations were tested. These configurations were:

(1) The rear guidebar is floating; i.e., the guidebar continues to follow the guidewall but the movement is not transmitted to the wheels as turning angle; run number 11D reflects this vehicle configuration; the rear wheels are therefore steered by the force limited interconnect linkage but as limited by the guidebar steps;

(2) The interconnect linkage is disconnected such that there is no interaction between the front and rear steering. Here, the rear wheels are steered exclusively by the rear guidebar. Run number 12 reflects this vehicle configuration.

Using G_{RMS} as a ride index as discussed in paragraph 4.4, it is concluded that the rear guidebar floating and the AIRTRANS baseline are very similar with the general levels being slightly lower (better ride) for the rear guidebar floating. The AIRTRANS baseline does perform better in the demanding 150' radius curves and in the switch encounters, however. The interconnect link disconnected test was also performed with the new antifriction kingpin bearings. Nevertheless, it is evident that aside from the beneficial effect of the antifriction kingpin, the interconnect link disconnected results in a small degradation in the vehicle ride from the normal AIRTRANS configuration. An interesting note is that the data for the interconnect link disconnected shows in Table 4-3 a reduced vertical G_{RMS} for all events. This is felt to be attributed primarily to the improved kingpin bearings. To further compliment these results from the ride quality data analysis, a review of the test records; guidebar displacements, steering component loads, and vehicle accelerations, is instructive. Where quick correction to the rear vehicle position is required, steering through the interconnect as is the

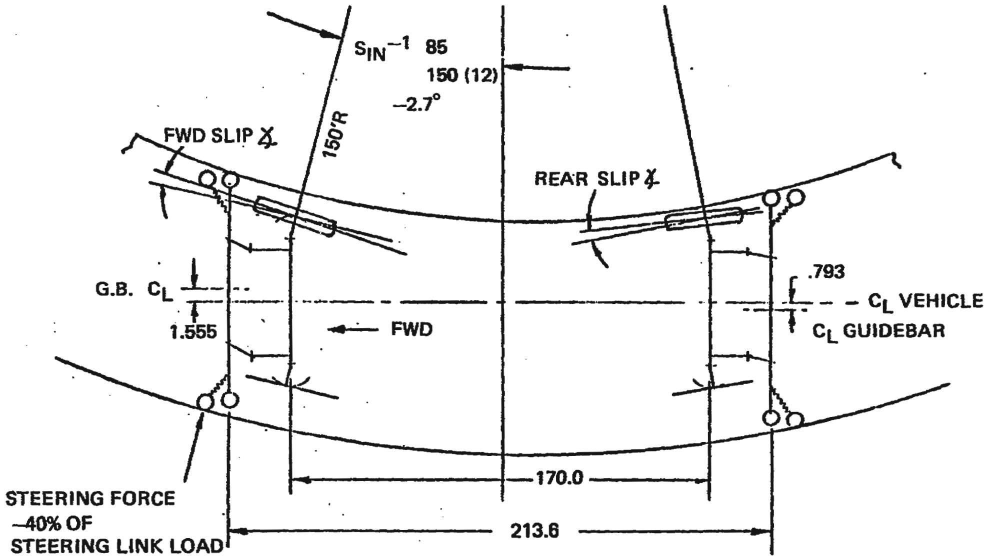


FIGURE 4–12 PREDICTED STEERING GEOMETRY ~ 150' TURN

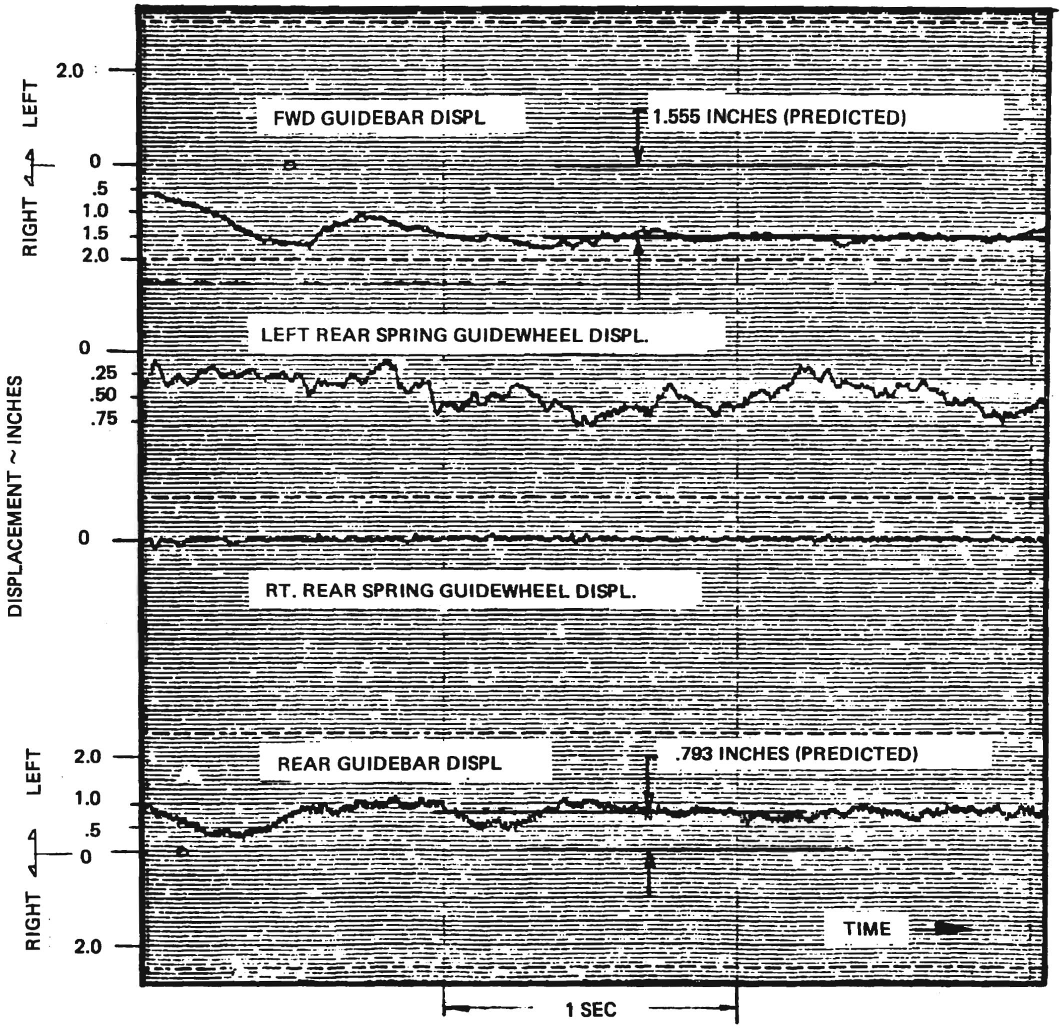


FIGURE 4–13 STEERING DISPLACEMENTS ~ 150' RIGHT TURN

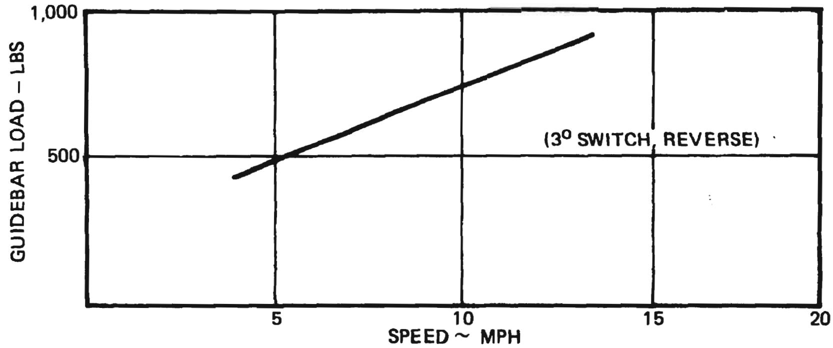
case for the floating rear guidebar is inadequate. This is a consequence of the force limiting breakout spring in the interconnect linkage. As evidence of this, the switch blade encounters show transient lateral acceleration increases of 3 or 4 times for floating rear guidebar over normal AIRTRANS or the interconnect link disconnected configurations. Also, when the floating rear guidebar bottoms against the motion limiting stop due to a diverge switch encounter, a high frequency shock is transmitted to the vehicle body that is noticeable in both the lateral and vertical directions. The floating rear guidebar does suppress the "pounding" effect of the rear guidebar in the 150' radius turns which is discussed in 4.4.1.4.

4.4.1.3 <u>Speed Effects On Vehicle Steering System</u> - Since increased speed capability is a major objective of the AUTP, how the vehicle reacts to this speed increase is important for improved steering system designs. Both merge and diverge switches were investigated for speed effects. Since the AIRTRANS guideway was designed for 17 mph, testing at higher speeds can only be safely accomplished in straight sections and a limited number of the more gentle turns and switches. The loads through switches data can only represent trends as a higher speed guideway would have longer spirals and larger radii and/or more superelevation. For this reason testing at higher speed was approached incrementally and terminated when safety or load limitations dictated.

The 4EBU diverge switch (data point 1) and the 5SB diverge switch (data point 22) are used to demonstrate speed effects on guidebar lateral loads. The following data runs were used.

SWITCH	RUN NUMBER	SPEED (MPH)
4EBU-DIV	3D	10.7
4EBU-DIV	4D	14.0
4EBU-DIV	5D	17.0
5SB-DIV	101	17
5SB-DIV	102	23
5SB-DIV	111	23
5SB-DIV	113	27
5SB-DIV	107	30

Figure 4-14 shows test results for the switchwheel load build up as the vehicle passes through the 4EBU and 5SB diverge switches in reverse. These diverge switch loads are consistent in magnitude from run to run and show a load that has a linear increase with speed. The 5SB switch has a 2° diverge angle where the 4EBU switch has a 3° diverge angle which accounts for the larger load at the 4EBU switch for the same vehicle speed. The



GUIDEBAR LOAD VS SPEED 4 EBU-DIV

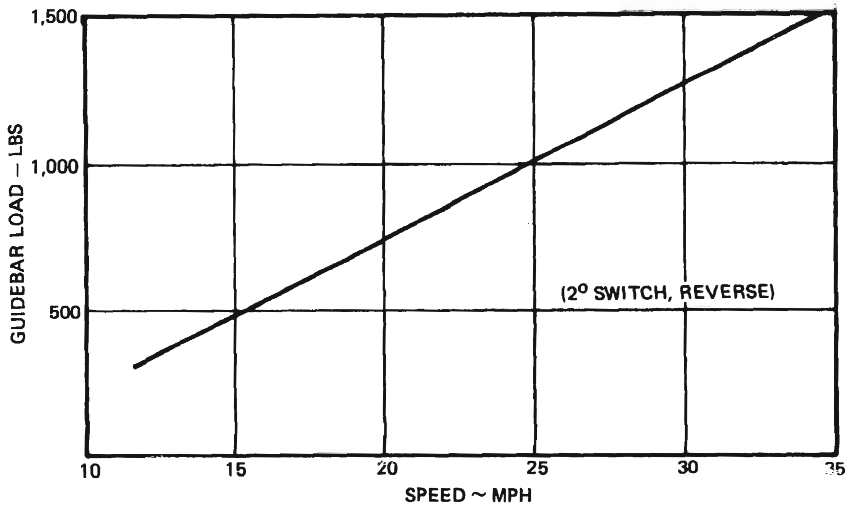


FIGURE 4–14 GUIDEBAR LOAD VS SPEED 5SB-DIV

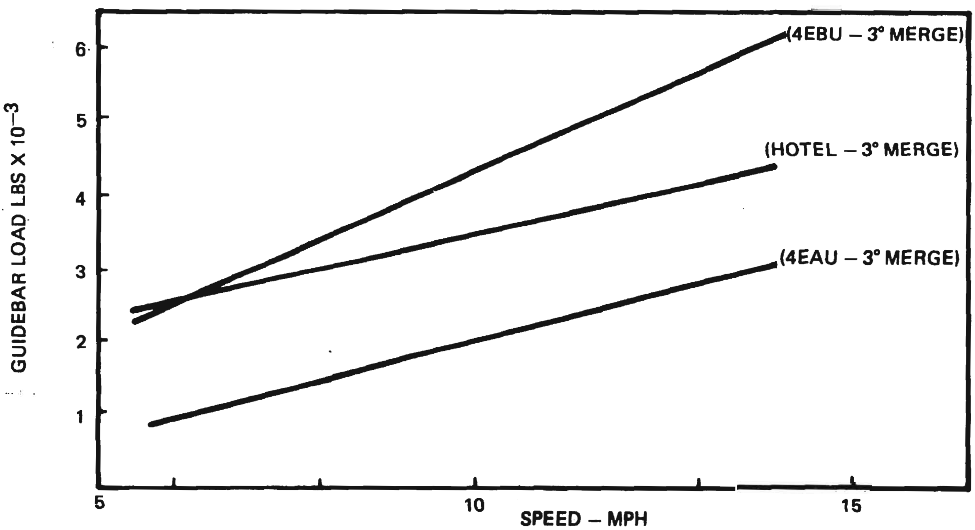


FIGURE 4–15 GUIDEBAR LOAD VS SPEED

peak load recorded at the 5SB diverge switch was 1360# for a vehicle speed of 31.3 MPH. This load which is a combination of the spring and fixed switchwheel is shown in Figure 4-12. The 4EBU diverge switch produced a peak load of 680# for a vehicle speed of 10.1 MPH, which is the maximum speed allowed for this type switch.

The three merge switches used in this evaluation were:

4EBU - Merge (data point #2)

4EAU - Merge (data point #6)

HOTEL - Merge (data point #19).

The above switches are all 3° merge switches and occur in the normal test route. Figure 4-15 shows guidebar lateral load vs vehicle speed comparison for the above switches. The 4EBU switch produces a peak guidebar load of 4340# which includes the fixed and spring loaded guidewheels effects. This load is not required for steering since no eyebolt or steering link loads are present, but is the result of the guidebar being trapped between the switch blade/switch wheel on the L/H side and the guidewheel/guide wall on the R/H side. A load of 3610# was developed on the guide wall. These loads are presented in Figure 4-16 which shows the loads traces as the vehicle moves into this merge switch. This trace is a typical "signature" for merge switches and is found on the 4EAU and hotel merge switch also. The rear guidebar reacts similar to the front guidebar with only small differences in loads. These switches, 4EAU and 4EBU, are geometrically identical but produce guidebar loads that vary greatly as opposed to the diverge switch loads which are more consistent.

Since these switches should produce loads of similar magnitudes, a variation such as this can be attributed to a combination of the following possible causes:

(1) Variation in switchblade angle,

(2) Variation in angle at which vehicle engages switches,

(3) Guideway width differences, and

(4) Point at which vehicle contacts switch rail in relation to pivot point of switch rail.

All these possible causes could be the result of tolerances occuring during construction of the guideway.

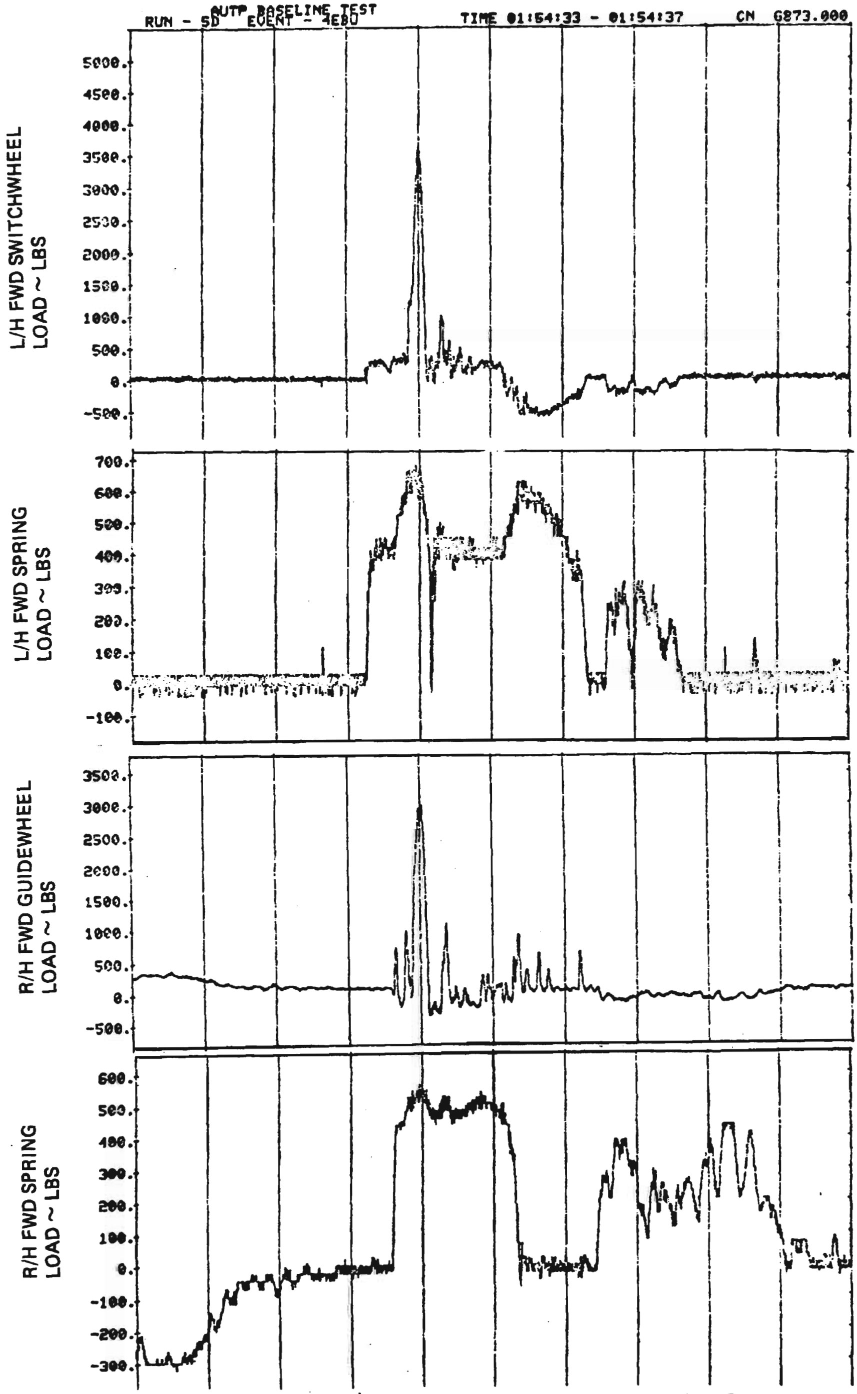
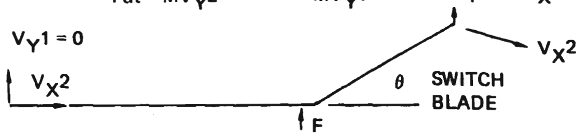


FIGURE 4–16 STEERING LOADS AT 4EBU-MERGE

The test data presented in Figures 4-14 and 4-15 have an interesting aspect in that the load vs speed buildup is linear. This relationship is explained in the following equation and sketch:

$$Fdt = MV_Y2 - MV_Y1 \qquad V_Y2 = V_X\theta$$



which equates the impulse to the vehicle momentum change. From this simplified illustration, the forces in the system can be seen to vary linearly with velocity (V) and switch angle (θ). Vought has used this principle to generate a model as discussed in APPENDIX B that considers the following additional aspects of the design:

(1) guidebar stiffness,

(2) wheel angle stiffness,

(3) guide/switchwheel stiffness, and

(4) switch angle.

Figure 4-17 presents the results that this program has calculated for a 2° switch similar to the 5SB diverge switch, which does show a linear variation of guidebar load with speed.

The effect of speed on vehicle ride quality is shown in Figure 4-18. The variation in ride index, G_{RMS}, is displayed vs speed for two events; traverse of a straight guideway section and a 2° diverge switch encounter. The G_{RMS} levels may be seen to be rapidly increasing with speed for both the vertical and lateral accelerations.

4.4.1.4 <u>Fixed/Springloaded Guidewheel Interaction</u> (Guidebar "Pounding") - A phenomenon associated with the vehicle operation in tight turns was measured during the baseline tests. The guidebar in 150' radius turn sets up an oscillation between the fixed guidewheel on the inside of the curve and the springloaded guidewheel on the outside of the curve. This is due to the springloaded guidewheel being located 14 inches from the solid guidewheels on the end of a guidebar resulting in the diagonal distance between a solid guidewheel and the springloaded guidewheel on the other end of the guidebar being 1 inch greater than the distance between them parallel to the guidebar. Due to the guidebar being non-perpendicular to the guidewalls, the guidewheels on a guidebar get squeezed together 0.7 inch more in a 150 foot radius turn than on a straight if the guidewall width is the same. The springloaded guidewheel on the outside wall of a 150 foot radius turn is usually compressed greater than .16 inch and the solid guidewheel on the inside wall is preloaded against the wall by the spring force in excess of that required to steer the tires. This means that the path followed by the guidebar in a 150 foot radius turn is determined by the inside wall which the solid guidewheel follows very closely while the springloaded guidewheel load on the outside wall is determined by the variation in guideway width. The solid guidewheel peak load is

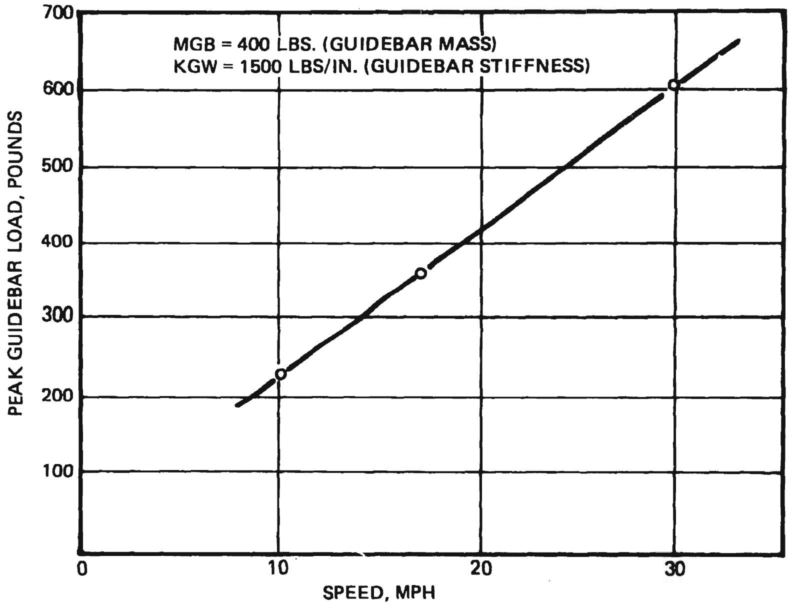


FIGURE 4–17 SIMULATION OF VEHICLE PASSING 2° DIVERGE SWITCH–IMPROVED MECHANICAL

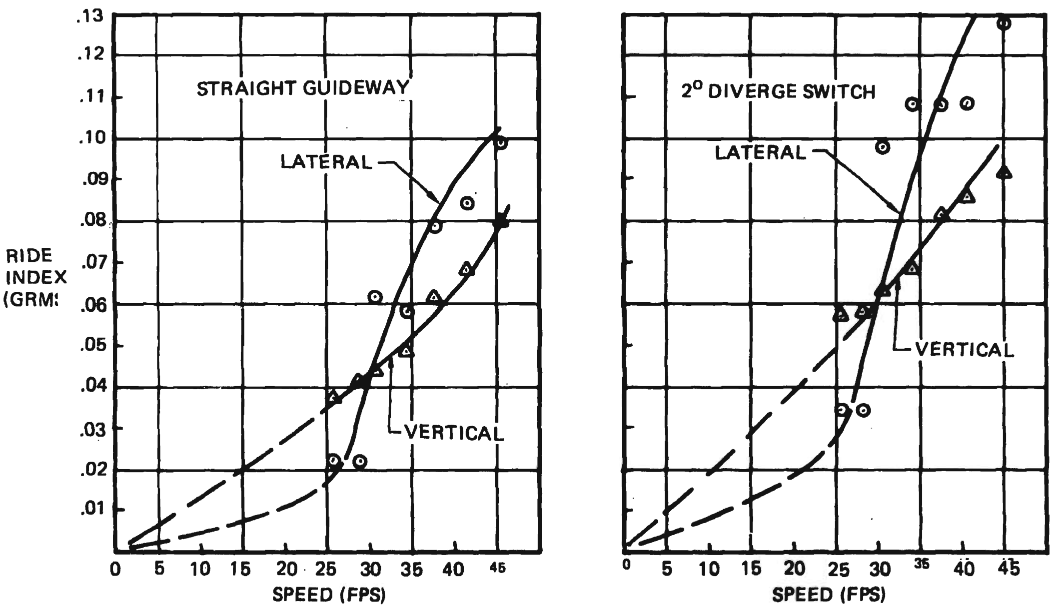


FIGURE 4–18 AUTP BASELINE VEHICLE EFFECT OF SPEED ON VEHICLE RIDE

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then determined primarily by the solid wheel stiffness and the inside wall roughness. Having a spring on the opposite end of the guidebar tends to set up a "pounding" in the 150 foot turns. This action is shown in Figure 4-19 which shows the RH front guidewheel load during a 150 foot right turn. During this five second interval, a peak load of 2320 lbs. was measured with numerous other peaks recorded as shown by the cumulative frequency of occurrence curve in Figure 4-20. This loading was transmitted to the tires also as shown by traces in Figure 4-21 of the eyebolt, steering link, and tie rod loads. This type of loading would definitely cause excessive and uneven tire wear. A left hand 150 foot turn would produce the same type loading also as noted in Figure 4-22.

Evidence of guidebar "pounding" is transmitted to the vehicle body and is also very apparent on the vehicle floor acceleration data. As seen in the loads data of Figures 4-19 and 4-21, the "pounding" phenomenon may be associated with a periodic condition at approximately 20 Hz.

4.4.1.5 Effect Of Kingpin Friction - Initial baseline tests were made using kingpin bushings which are in the standard Rockwell axle on the AIRTRANS vehicle. The bushings were then replaced with anti-friction kingpin bearings and the test repeated. Test results using anti-friction bearings show that:

(1) Steering link loads are reduced to 45% of the loads with kingpin bushings,

(2) Tie rod loads were reduced to approximately 60%,

(3) Fixed guidewheel loads and guidebar lateral accelerations show about 20% increase (This is due to the reduced damping without kingpin friction when the fixed guidewheel is bouncing.), and

(4) The guidewheel load and guidebar displacements were essentially the same on both tests. (The springloaded guidewheel load is a function of displacement which is consistent with guideway position. The reason that displacements are consistent is because the guidewheel displacements were a result of the guidewall/guidewheel geometry squeezing the guidewheels in a turn.)

The springloaded guidewheel provides 400 lbs. of force at 0.16 inch displacement and 700 lbs. force at 1.00 inch displacement. Thus, any time a springloaded guidewheel is displaced 0.16 inch or more, it is exerting a force (400 + lbs.) on the guidebar greater than that required to steer the tires on either run 5D (360 lbs. maximum) or run 101 (160 lbs maximum). (Guidebar steering loads are 40% of steering link loads.)

The overall result of installing the antifriction kingpin bearings was to reduce the required steering force at the

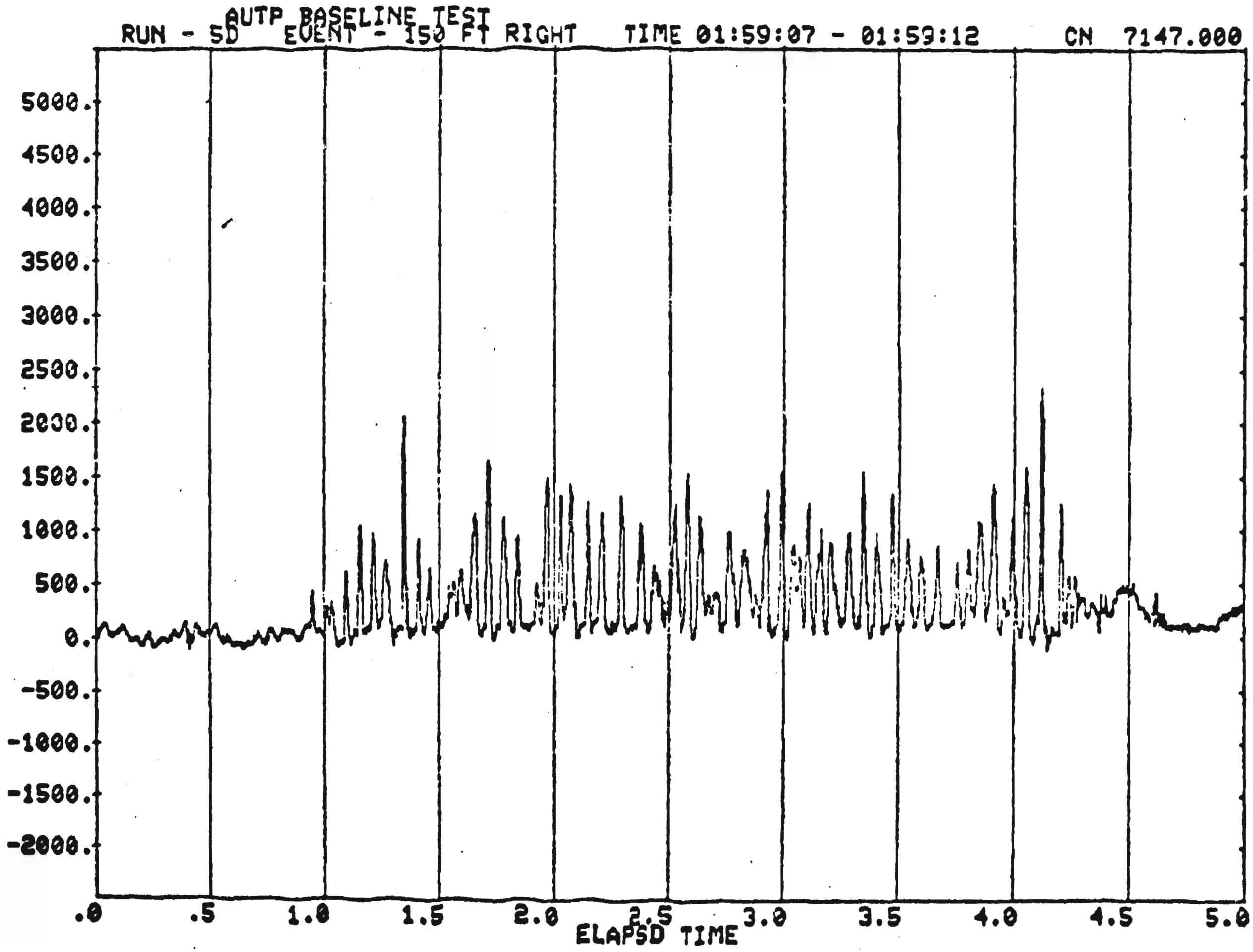

FIGURE 4—19 R/H FWD GUIDEWHEEL LOAD

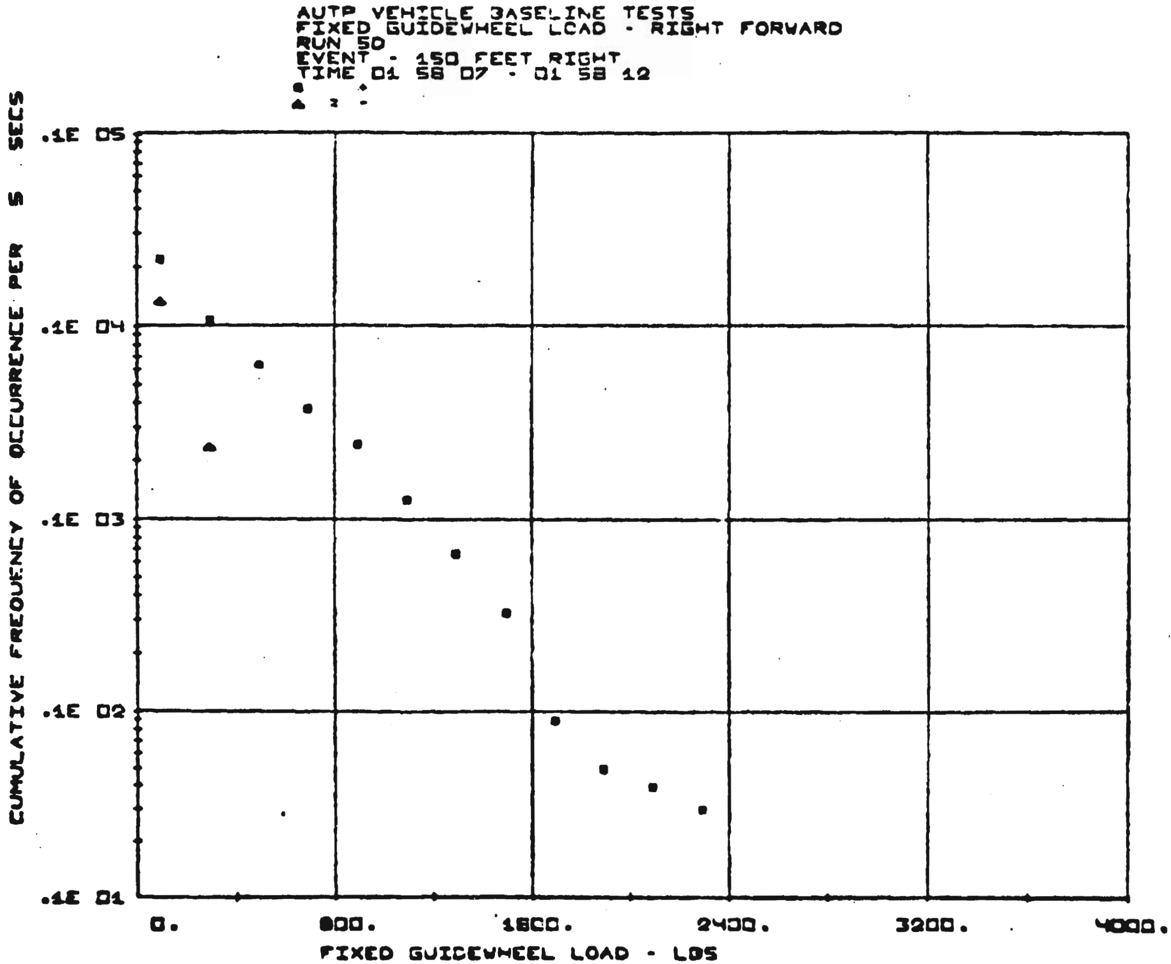

FIGURE 4–20 FREQUENCY OF OCCURRENCE CURVE

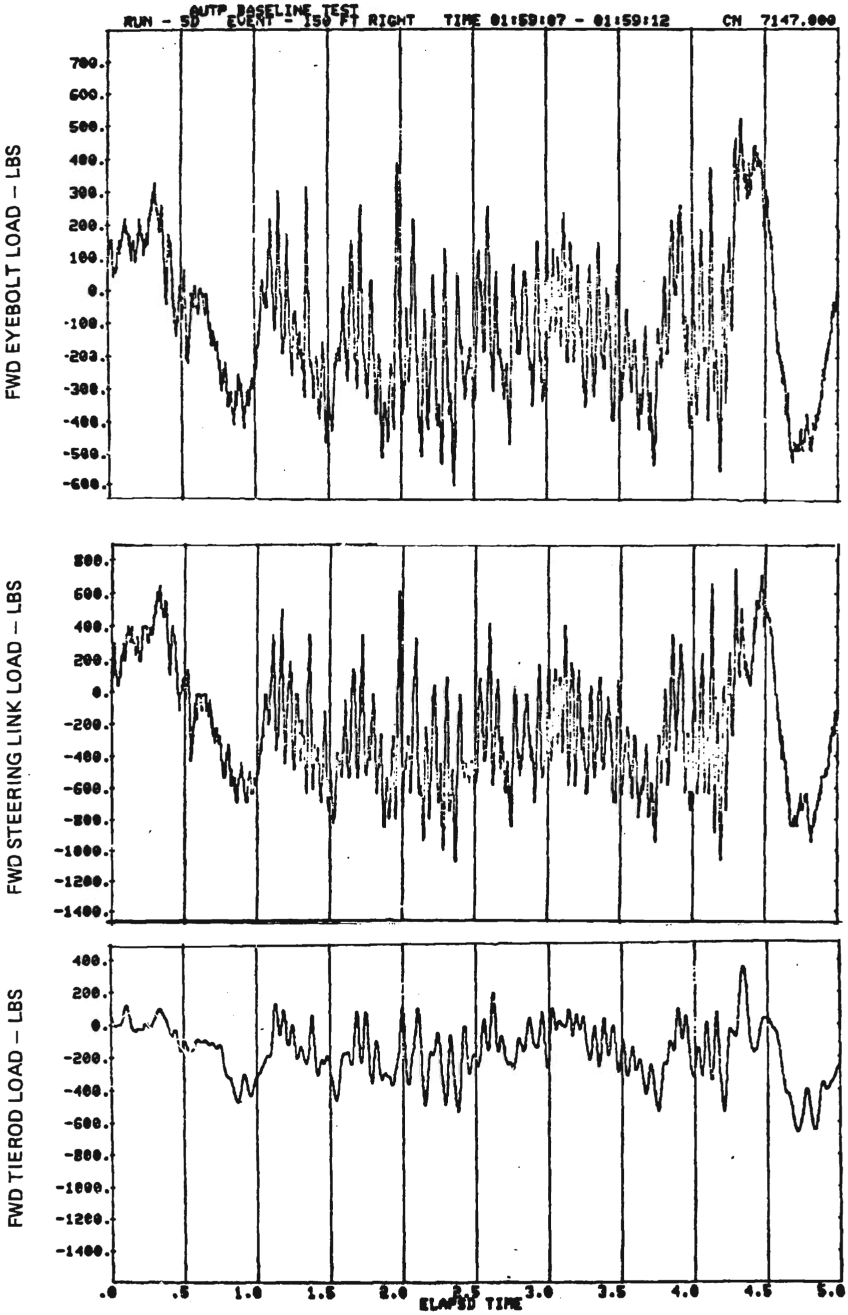

FIGURE 4–21 TYPICAL COMPONENT TIME HISTORY

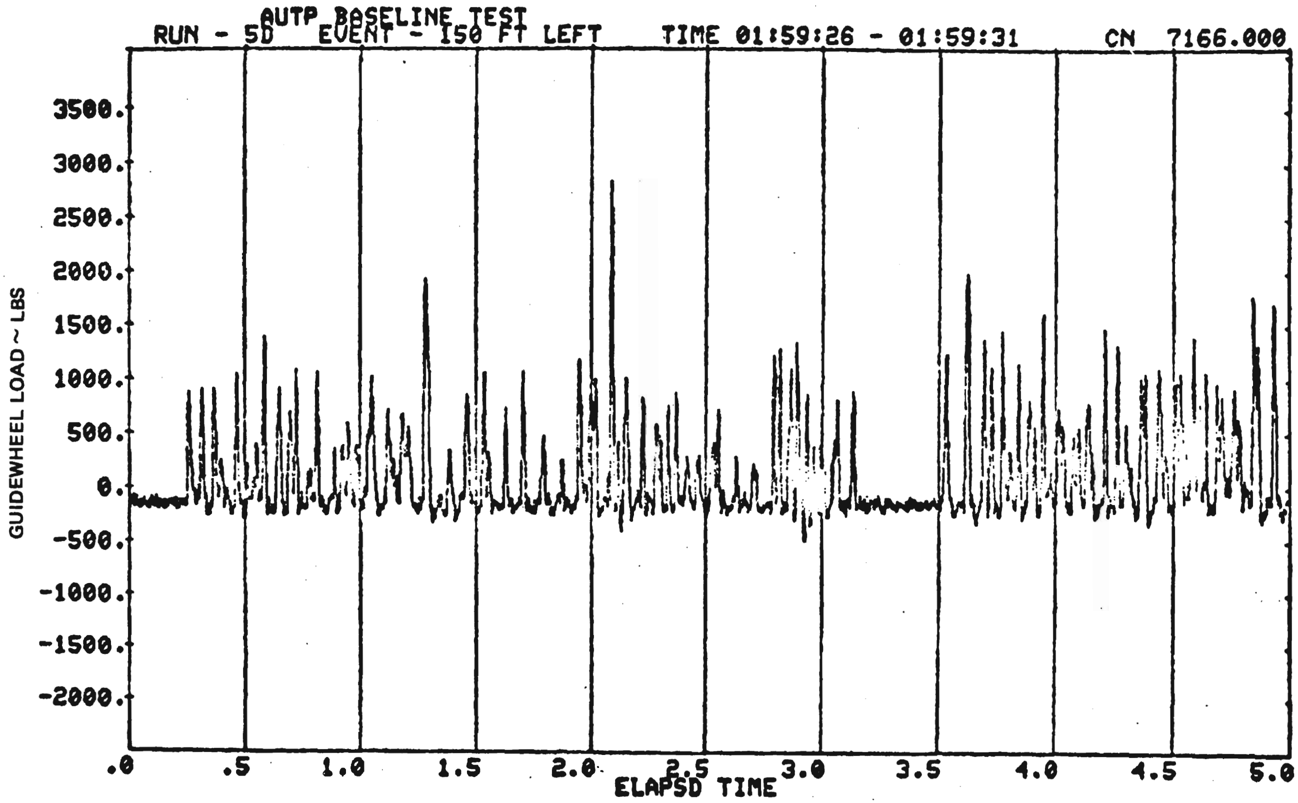

FIGURE 4–22 L/H FWD GUIDEWHEEL LOAD

guidebar from 360 pounds to 160 pounds.

The vehicle ride quality was significantly improved with the incorporation of antifriction kingpin bearings. This may be seen by comparing the G_{RMS} levels between runs 5D and 101 as presented in Table 4-3. This improvement exists for all of the different guideway events presented in Table 4-3.

4.4.2 IMPROVED MECHANICAL STEERING TESTS - Tests similar to the baseline tests were conducted on the baseline vehicle modified with the steering system improvements discussed in Section 4.3.2. The steering system components instrumented during the improved steering tests are presented in Table 4-4. These components are the same as on the baseline tests with the exception of components that were deleted. These components were calibrated as in the baseline tests to obtain a load vs microvolt relation, the wishbone links were the only component calibration retained from the baseline tests, all other were new components. Figure 4-23 presents the instrumentation in relation to the vehicle.

The test route for the improved mechanical steering test was identical to the baseline test. A description of the test runs accomplished during the improved mechanical steering tests is presented in Table 4-5. The improvements presented in Section 4.3.2 were evaluated from data acquired during the test runs. Vehicle/guideway interface, speed and springloaded wheels were investigated as to their merits for improving the vehicle's steering system.

Similar to the baseline test presentation of ride quality data, Table 4-6 presents the overall G_{RMS} levels for the different improved mechanical steering test conditions and guideway events. Annotations appear in the run column of Table 4-6 to describe the variations being performed. Table 4-5 is referred to for a more detail description of the test configurations.

4.4.2.1 Interconnect Linkage - Similar to tests that were conducted in the baseline tests series, a run was performed with the interconnect link disconnected. The objective was to evaluate the improved mechanical steering system under independent front and rear steering. (Ref Paragraph 4.4.1.2) This test was performed on the improved mechanical steering system configuration which included the reduced guidewheel spring rate.

A review of the data presented in Table 4-6 will be used in this evaluation as far as the vehicle ride is concerned. From these data, there is no significant difference in the vehicle ride associated with the interconnect link being connected or disconnected. Information is not available in Table 4-6 for the evaluation of the vehicle ride performance change due to a diverge switch encounter.

4.4.2.2 Speed Effects On Vehicle Steering System - The 5SB diverge switch (encounter #22) and the 4EBU diverge switch (encounter #1) will be used to demonstrate the effects of speed on the steering system switching loads. These switches were taken at several speeds as shown in the following table.

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TABLE 4–4 IMPROVED STEERING ~ INSTRUMENTATION LIST

COMPONENT	LOCATION	MEASUREMENT
Bending Moment ~ Upper	Lt, Rt	Calibrated S/Wheel Load
Bending Moment ~ Lower	Fwd and Rear	Calibrated G/Wheel Load
Eye Bolt	Fwd, Rear	Axial Bridge
Steering Link	Fwd, Rear	Axial Bridge
Wishbone Link	Fwd, Rear	Axial Bridge
Steering Actuator	Fwd, Rear	Axial Bridge
Guidebar Displacement	Fwd, Rear	Lateral Guidebar Displacement Relative to Axle
G/S Wheel Stroke	Lt, Rt – Fwd & Rear	Axial Stroke
Kingpin Rotation	Fwd, Rear	Kingpin Rotation Relative to Axle
Guidebar Acceleration	Fwd	Acceleration Guidebar Lateral
Guidebar Acceleration	Fwd	Acceleration Guidebar Vertical
Collector Post	Rt Fwd	Collect Vertical Acceleration
Ride Quality Accelerometers	Vehicle Floor (See Figure)	Vertical and Lateral Accelerations

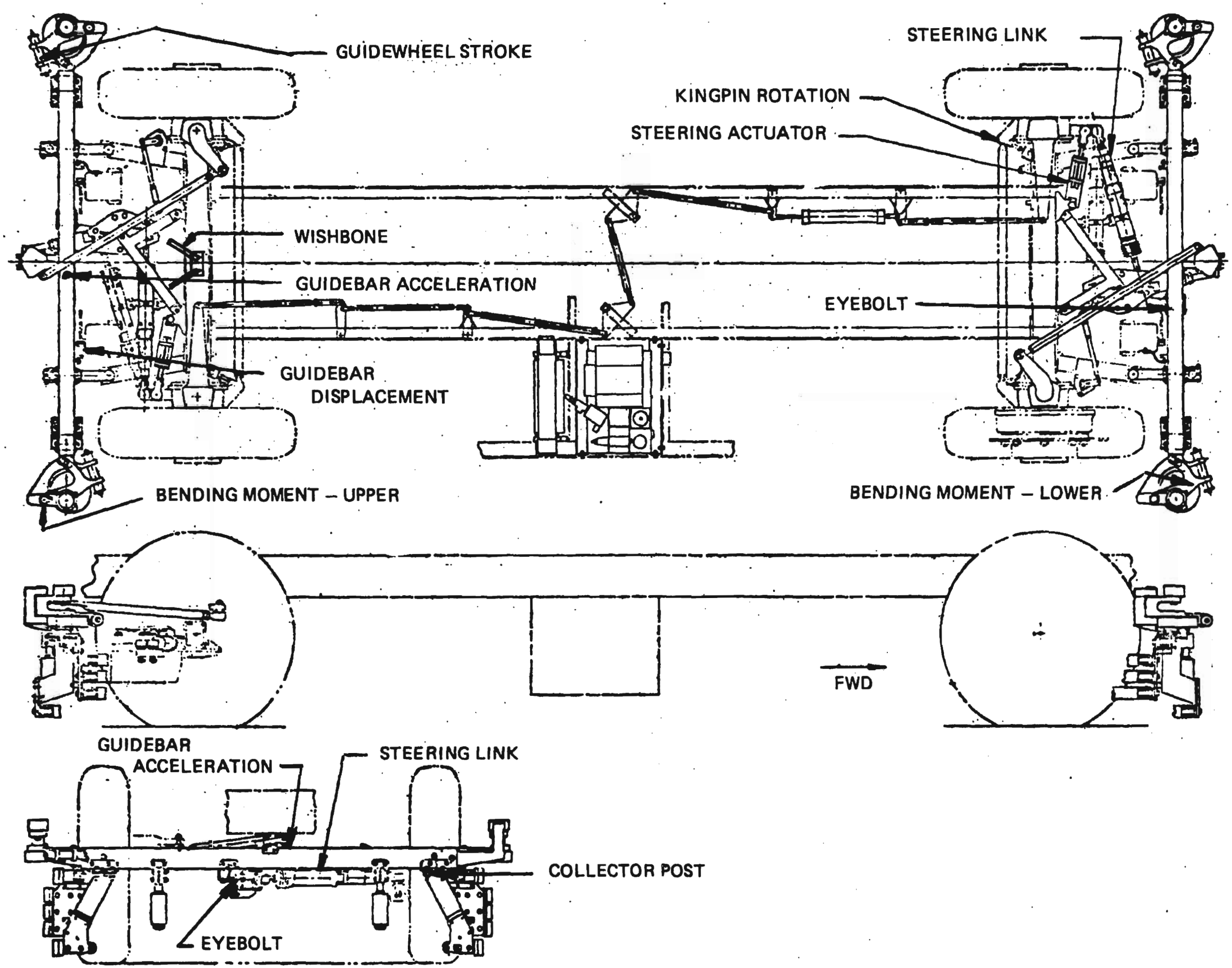

FIGURE 4–23 IMPROVED STEERING SYSTEM INSTRUMENTATION

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TABLE 4–5 IMPROVED STEERING TESTS – RUN DESCRIPTION

RUN #	TEST DATE	VEHICLE SPEED (MPH)	CONTROL MODE	TEST ROUTE	TYPE STEERING	G.W. SPRINGS	STEERING LINK PRESS (PSIG)	COMMENTS
201	11/1/77	10.2	Slow 2	2	Mech	Med	2000	
202	11/2/77	14.1	Slow 1	2	Mech	Med	2000	
203	11/2/77	17	ATC	2	Mech	Med	2000	
208	11/17/77	17	ATC	1	Mech	Med	2000	
205	11/17/77	22	HS8.5	1	Mech	Med	2000	
206	11/18/77	26	HS9.3	1	Mech	Med	2000	
207	11/18/77	30	HS9.63	1	Mech	Med	2000	
220B	11/19/77	10.2	Slow 2	1	Contactless	Med	0	Integrator removed
220X	11/19/77	4.0	*LSSO	1	Contactless	Med	0	Integrator removed
207B	11/19/77	30	HS9.63	1	Mech	Med	2000	
220XB	11/21/77	4.0	LSSO	1	Contactless	Med	0	Integrator removed
220C	11/21/77	10.2	Slow 2	1	Contactless	Med	0	Integrator removed
220.1	11/21/77	14.1	Slow 1	1	Contactless	Med	0	Integrator removed
220.2	11/21/77	17	ATC	1	Contactless	Med	0	Integrator removed
207C	11/21/77	30	HS9.63	1	Mech	Med	2000	
207D	11/21/77	30	HS9.63	1	Mech	Med	2000	
215A	11/22/77	14	Slow 1	2	Mech	Soft	2000	
215B	11/22/77	17	ATC	2	Mech	Soft	2000	
215C	11/22/77	14	Slow 1	2	Mech	Soft	600	
215D	11/22/77	17	ATC	2	Mech	Soft	400	
244	11/22/77	17	ATC	2	Mech	Soft	1400	Interconnect disconnected
213	11/22/77	22	HS8.50	1	Mech	Soft	1400	Interconnect restored
220XC	11/23/77	4.0	LSSO	1	Contactless	Soft	0	
221A	11/23/77	17	ATC	1	Contactless	Soft	0	
210A	11/23/77	26	HS9.63	1	Mech	Soft	2000	
211A	11/23/77	30	HS9.63	1	Mech	Soft	2000	
211B	11/23/77	30	HS9.63	1	Mech	Soft	2000	
211C	11/23/77	30	HS9.63	1	Mech	Soft	2000	
245	12/2/77	17	ATC	2	Pwr Boost	Soft		Garrison hydraulic
246	12/2/77	22	HS8.50	1	Pwr Boost	Soft		valves installed
247	12/2/77	26	HS9.30	1	Pwr Boost	Soft		in steering link
248	12/2/77	30	HS9.63	1	Pwr Boost	Soft		
220XD	12/6/77	4.0	LSSO	1	Contactless	Soft	0	
221B	12/6/77	17	ATC	1	Contactless	Soft	0	
220D	12/6/77	10.2	Slow 2	1	Contactless	Soft	0	
211D	12/6/77	30	HS9.63	1	Mech	Soft	2000	
223.1	12/7/77	8	MSSO	1	Contactless	Soft	0	5th Wheel Extended
223A	12/7/77	10	Slow 2	1	Contactless	Soft	0	Manual Switching
221	12/7/77	17	ATC	1	Contactless	Soft	0	@ 5WSB
222A	12/7/77	22	HS8.50	1	Contactless	Soft	0	
227	12/7/77	26	HS9.30	1	Contactless	Soft	0	
232.1A	12/9/77	10/4	Slow 2/LSSO	1	Contactless	Soft	Tone Switching at 5 WSB	
226	12/9/77	22	HS8.50	1	Contactless	Soft	No switching	
221C	12/10/77	17	ATC	1	Contactless	Soft	No switching	
222C	12/10/77	22	HS8.50	1	Contactless	Soft	No switching	
227B	12/10/77	26	HS9.30	1	Contactless	Soft	No switching	
215E	12/10/77	17	ATC	2	Mech	Soft	2000	Dampers removed

* Low Speed Section Override.

TABLE 4–6 AUTP IMPROVED MECHANICAL STEERING TESTS RIDE QUALITY ANALYSIS SUMMARY, G_{RMS}

RUN NO.	DATA IDENTIFICATION (Speed, fps; Accel., G_{RMS})	MARKER NO./EVENT: 1 4EBU MERGE/REV	6-7 4ENP16 150' RAD TURN	8-8 3ESL 800' RAD TURN	15 3ENB DIVERGE/ REV	15-16 3NB 150' RAD TURN	16-17 3NB 150' RAD TURN	20-21 4WCL STRAIGHT	21+ 4WSL "S1"	21+ 4WSL "S2"	21-22 4WSL-5WCL STRAIGHT	22 5SB DIVERGE/ NORMAL
203 (Normal ATC)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.	14.1 .0217 .0249 .0218 .0171			25.7 .0451 .0423 .0371 .0325	25.1 .0561 .0476 .0498 .0384	24.7 .0427 .0374 .0387 .0285	25.6 .0477 .0512 .0381 .0380		25.5 .0424 .0402 .0352 .0273	25.8 .0328 .0354 .0262 .0256	25.0 .0459 .0416 .0339 .0336
205 (22 MPH)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.								32.8 .0870 .0768 .0763 .0585	32.4 .0676 .0556 .0595 .0408	32.8 .0486 .0503 .0377 .0332	DIVERGE/ REVERSE 32.4 .0852 .0851 .0759 .0482
206 (26 MPH)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.								39.3 .0804 .0897 .0870 .0700	38.1 .0818 .0713 .0700 .0482	39.3 .0503 .0627 .0419 .0429	37.6 .1100 .0784 .1039 .0662
207A (30 MPH)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.								42.8 .1048 .0960 .0932 .0822	45.8 .0848 .0771 .0846 .0634	44.4 .0715 .0780 .0612 .0622	41.3 .1337 .0791 .1421 .0706
215B (Reduced Guidewheel Spring Rate Normal ATC)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.	14.2 .0265 .0202 .0272 .0199	22.7 .0487 .0343 .0459 .0308	25.5 .0332 .0284 .0269 .0229	25.8 .0496 .0400 .0419 .0340	25.2 .0585 .0451 .0502 .0404	24.3 .0432 .0362 .0403 .0301	25.7 .0510 .0499 .0379 .0394	25.9 .0628 .0525 .0598 .0480	25.5 .0487 .0391 .0421 .0298	25.8 .0301 .0346 .0273 .0268	
213 (22 MPH)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.								26.9 .0671 .0560 .0620 .0512	32.4 .0636 .0503 .0563 .0372	32.7 .0371 .0409 .0329 .0306	DIVERGE/ NORMAL 27.3 .0521 .0510 .0422 .0387
211D (30 MPH)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.								25.4 .0624 .0582 .0580 .0475	.44.3 .0858 .0720 .0833 .0580	44.4 .0607 .0687 .0486 .0487	
215C (Reduced Guidewheel Spring rate and Reduced Steering Line Pressure, 600 psi)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.			21.2 .0246 .0240 .0209 .0197			20.3 .0357 .0348 .0303 .0260	21.2 .0378 .0432 .0332 .0375		21.0 .0345 .0285 .0349 .0258		
215D (Reduced Guidewheel Spring Rate and Reduced Steering Link Pressure 400 psi)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.	14.2 .0264 .0201 .0273 .0157		25.5 .0330 .0304 .0285 .0243			24.2 .0478 .0399 .0399 .0339					
244 (Reduced Guidewheel Spring Rate Interconnect Link Disconnected)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.	14.2 .0216 .0193 .0192 .0169		26.7 .0318 .0288 .0261 .0236			24.4 .0430 .0345 .0394 .0314			25.6 .0480 .0411 .0386 .0300		DIVERGE/ REV. 25.5 .0631 .0462 .0644 .0382
215E (Reduced Guidewheel Spring Rate, Steering Damper Free)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.	14.3 .0232 .0234 .0244 .0250		25.6 .0293 .0304 .0236 [illegible]	25.8 .0549 .0448 .0521 .0398		25.1 .0444 .0402 .0449 .0344			25.7 .0482 .0448 .0448 .0330	25.8 .0273 .0318 .0259 .0297	25.3 .0624 .0518 .0636 .0412

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5SB - DIV			4EBU - DIV	
RUN NO.	SPEED	MPH	RUN #	SPEED MPH
208D		17	201	6
205		22	203	10.5
206		26		
207A		30		
207C		30		

Figure 4-24 presents a plot of the switchwheel loads buildup as the vehicle speed is increased. This plot shows a linear load buildup with speed for the improved steering system as did the baseline tests. The 4EBU-Diverge switch exhibits higher loads for the same speed which is explained by the 4EBU switch being a 3° diverge and the 5SB switch being a 2° diverge. The load/degree of blade angle of these two switches are very similar as shown by examining the switch loads at 10.5 MPH. Both encounters produce a 200#/degree relation.

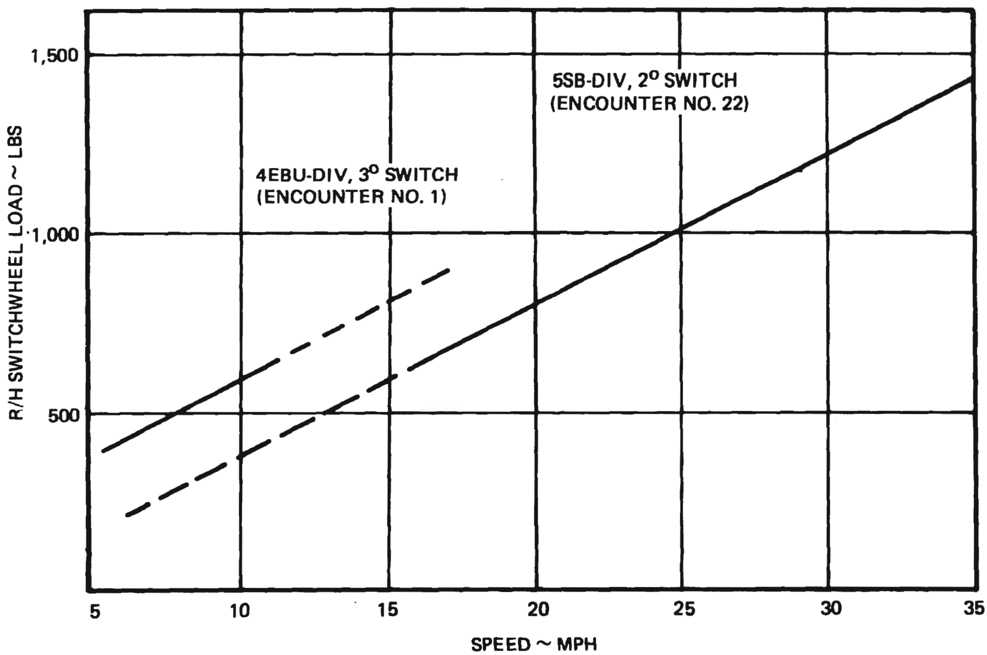


FIGURE 4–24 R/H SWITCHWHEEL LOAD VS SPEED

The speed effects on vehicle ride quality for the improved mechanical steering is illustrated in Figure 4-25. Using the G_{RMS} level as a ride index, the data in Figure 4-25 shows the ride to progressively worsen with increasing speed.

4.4.2.3 Single Guidewheel Interaction - The single guidewheel design exhibits excellent tracking of the guidewall as the vehicle operates in the 150' turns. Figure 4-26 presents guidewheel/guidewall loads on the front L/H and R/H sides of the vehicle as the vehicle operates in a 150' left turn. These data were obtained during Run #203 on an ATC (17 mph) run with medium stiffness springs at the guidewheel. These plots indicate the vehicle tracking the R/H. The load variation is attributed to the guidewall roughness only with a complete absence of the "pounding" phenomonem. The "soft" spring loaded guidewheel (as compared to the AIRTRANS fixed guidewheel) doesn't generate the magnitude of load the fixed guidewheel did; therefore, the damper controls the guidebar movement. Since lateral inertia loads are partially reacted by the guidewheels, definition of these loads are required to design the steering system. Figure 4-27 presents exceedance data for the R/H and L/H FWD. guidewheel. This curve the number of times a certain load occurs in this 150' right turn which furnishes very useful fatigue data for the design of steering system components.

The single guidewheel modification has resulted in a significant improvement in vehicle ride quality. This is particularly the case in the 150' radius turns.

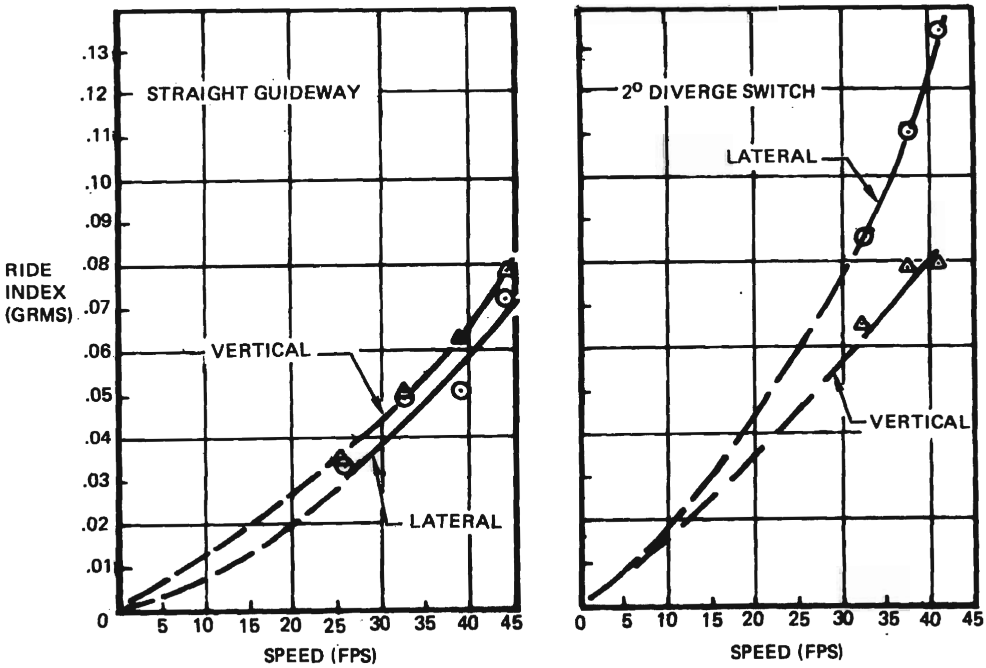
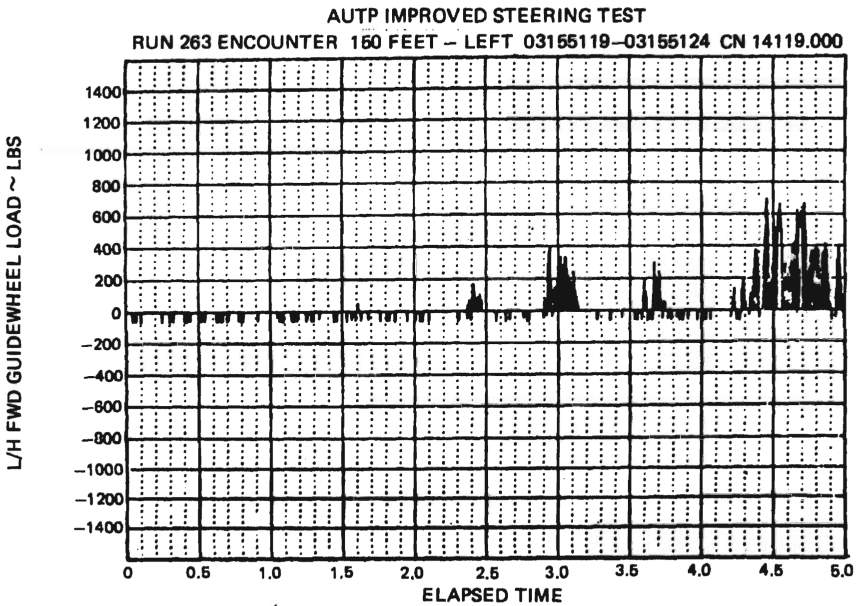


FIGURE 4–25 AUTP MODIFIED TEST VEHICLE EFFECT OF SPEED ON VEHICLE RIDE FOR IMPROVED MECHANICAL STEERING



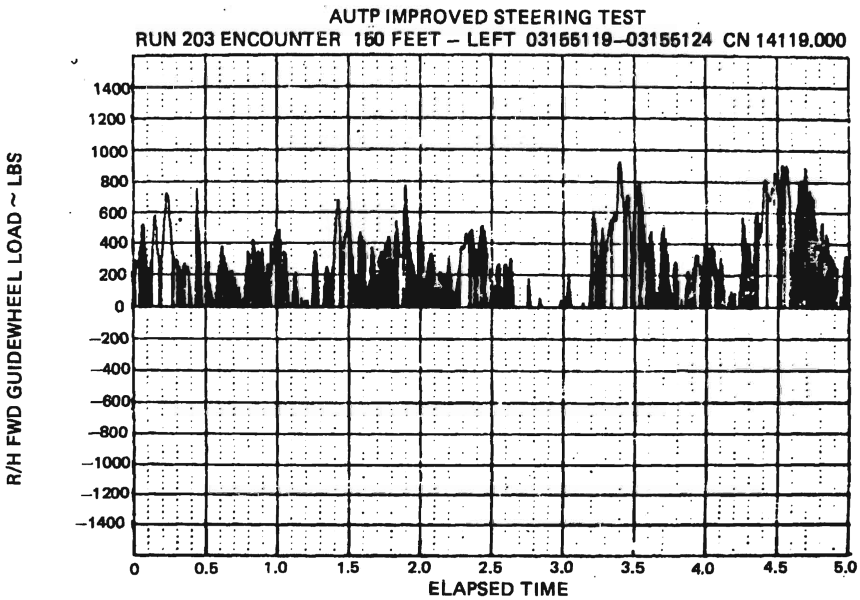
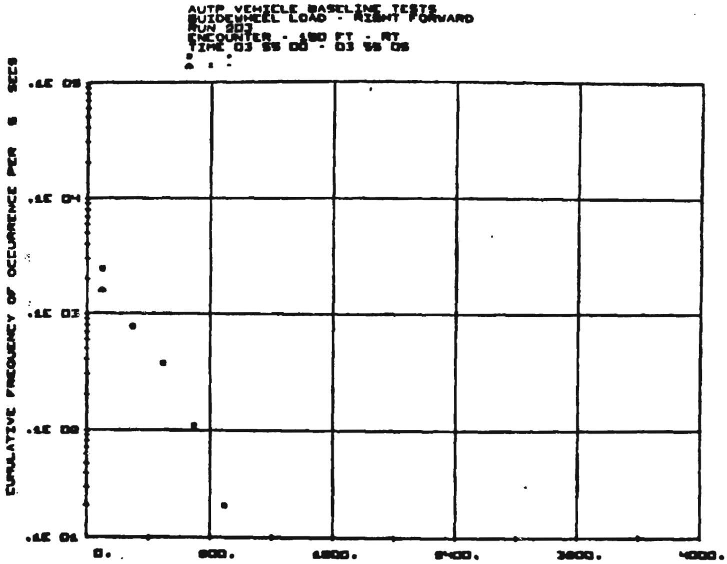
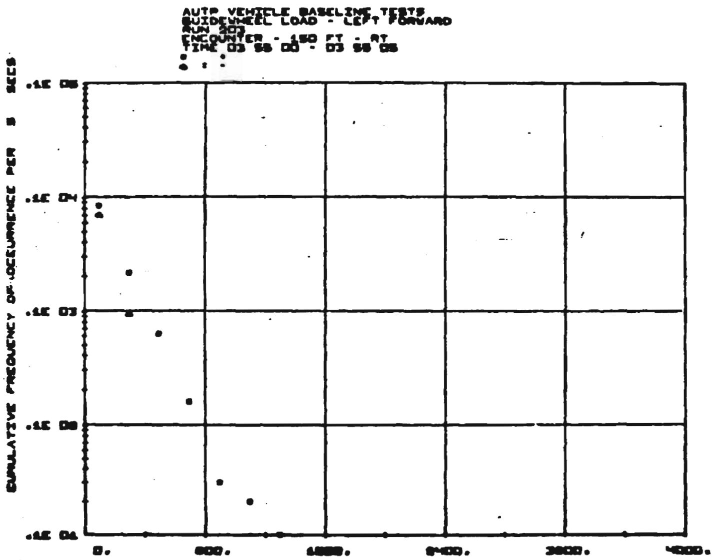


FIGURE 4–26 L/H AND R/H FWD GUIDEWHEEL LOAD TIME HISTORY IN 150′ LEFT TURN



R/H FWD GUIDEWHEEL LOAD ~ LBS



L/H FWD GUIDEWHEEL LOAD ~ LBS

FIGURE 4–27 L/H, R/H FWD GUIDEWHEEL LOAD EXCEEDANCE DATA FOR 150' RIGHT TURN

4.4.2.4 Spring Rate Evaluation - Two hardnesses of rubber springs were evaluated for the guidewheel/switchwheel spring. Run #203 through the regular route had a guidewheel spring rate of 3076 16/in. Run #215B through the regular route had a spring rate of 1670 lb/in.

From the steering loads standpoint, the 4EAU - Diverge (encounter #3) switch will be used as an example. Figures 4-28 and 4-29 present time history plots of the L/H fwd switchwheel load with the medium and soft springs respectively. A load of 560 lbs. for the medium spring and 510 lbs. for the soft spring gives a switchwheel load difference of only 10% for an approximate 100% decrease in spring rate, indicated that the required load to turn the vehicle is relatively constant for a given switch. Guideway geometry has the greatest effect on loads from a spring rate change. Figure 4-30 shows the L/H fwd guidewheel load prior to encounter 3, Run 203 (medium spring), and Figure 4-31 shows the L/H fwd guidewheel load prior to encounter 3, Run 215B (soft spring). At this point, the medium spring develops a 1450# guidewheel load, and the soft spring develops an 820# guidewheel load. From the loads viewpoint, a softer spring is more desirable.

The data analysis performed to determine the effect on ride quality due to the guidewheel spring rate change shows no distinctive differences. This may be seen in Table 4-6 through a comparison of G_{RMS} levels between Runs 203 and 215B.

4.4.2.5 Additional Spring In Steering Link - The steering link cylinder was normally pressurized to 2000 psi for the improved mechanical steering tests series. At this pressure the steering link is effectively rigid since no steering loads are experienced that will overcome the effective pre-load represented by the 2000 psi cylinder pressure. However, to investigate the effect of adding another spring in series with the guidewheel spring, the cylinder pressure was reduced to 600 psi, and then 400 psi in Runs 215C and 215D, respectively. The objective was to permit additional spring stroking in the steering system before delivering guidebar displacement to the wheel as a steering angle. These pressures were selected to provide a breakout load for the cylinder that closely matches the full stroke load for the guidewheel springs. After the breakout load is reached in the steering link, the cylinder then behaves as an air spring.

Reviewing the data presented in Table 4-6, there appears to be a trend toward increasing the vehicle acceleration levels on reducing the pressure in the steering link. The data for the intermediate pressure, 600 psi, were taken at a modified speed condition, hence these data are not comparable to the 2000 psi and 400 psi conditions. A comparison of 1/3 octave band data between Runs 215B and 215D shows a very similar frequency signature with only general overall level differences. Therefore, from a ride quality perspective, it was concluded that the additional spring in the steering link was not beneficial for the

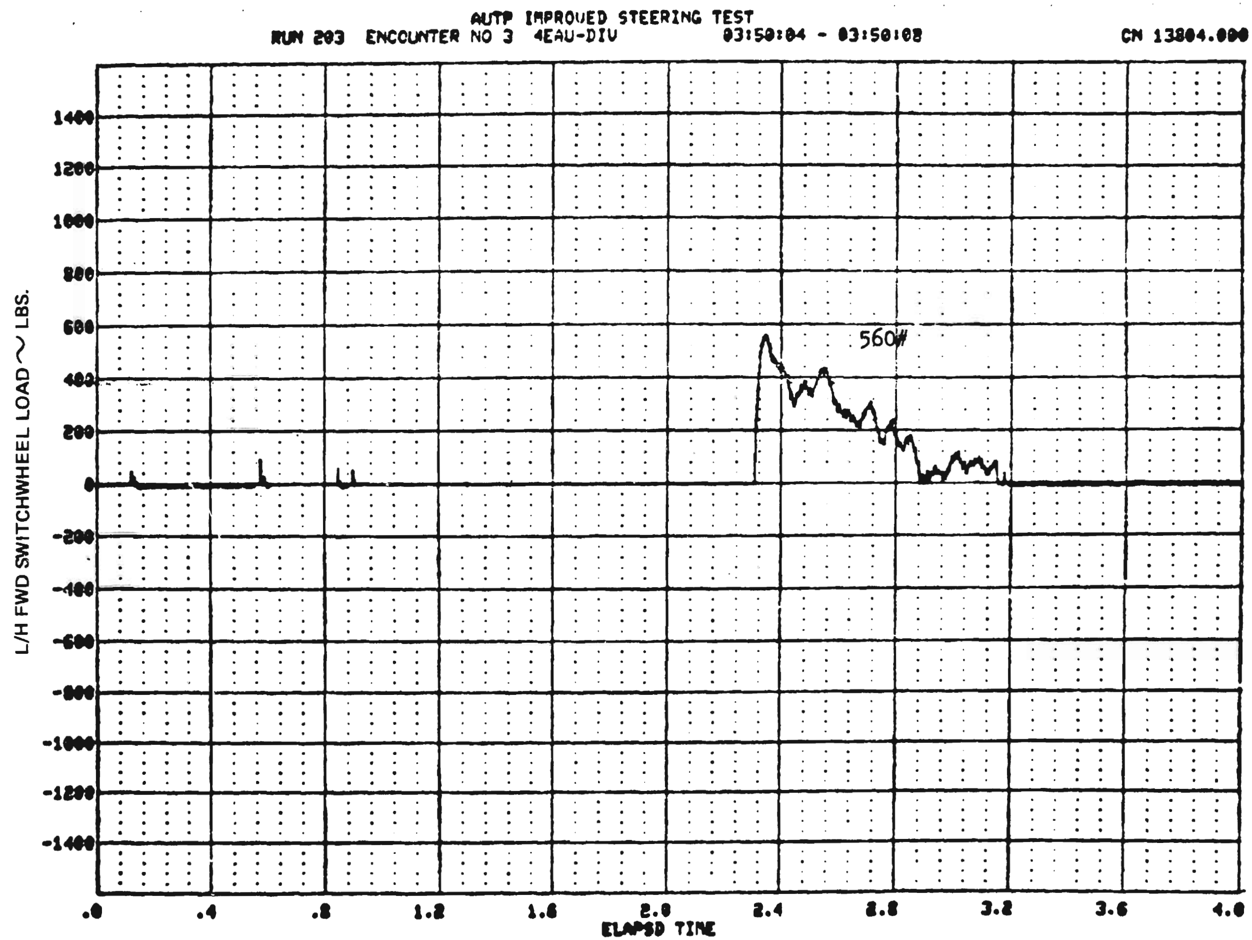


FIGURE 4–28 L/H FWD SWITCHWHEEL (MEDIUM SPRING)

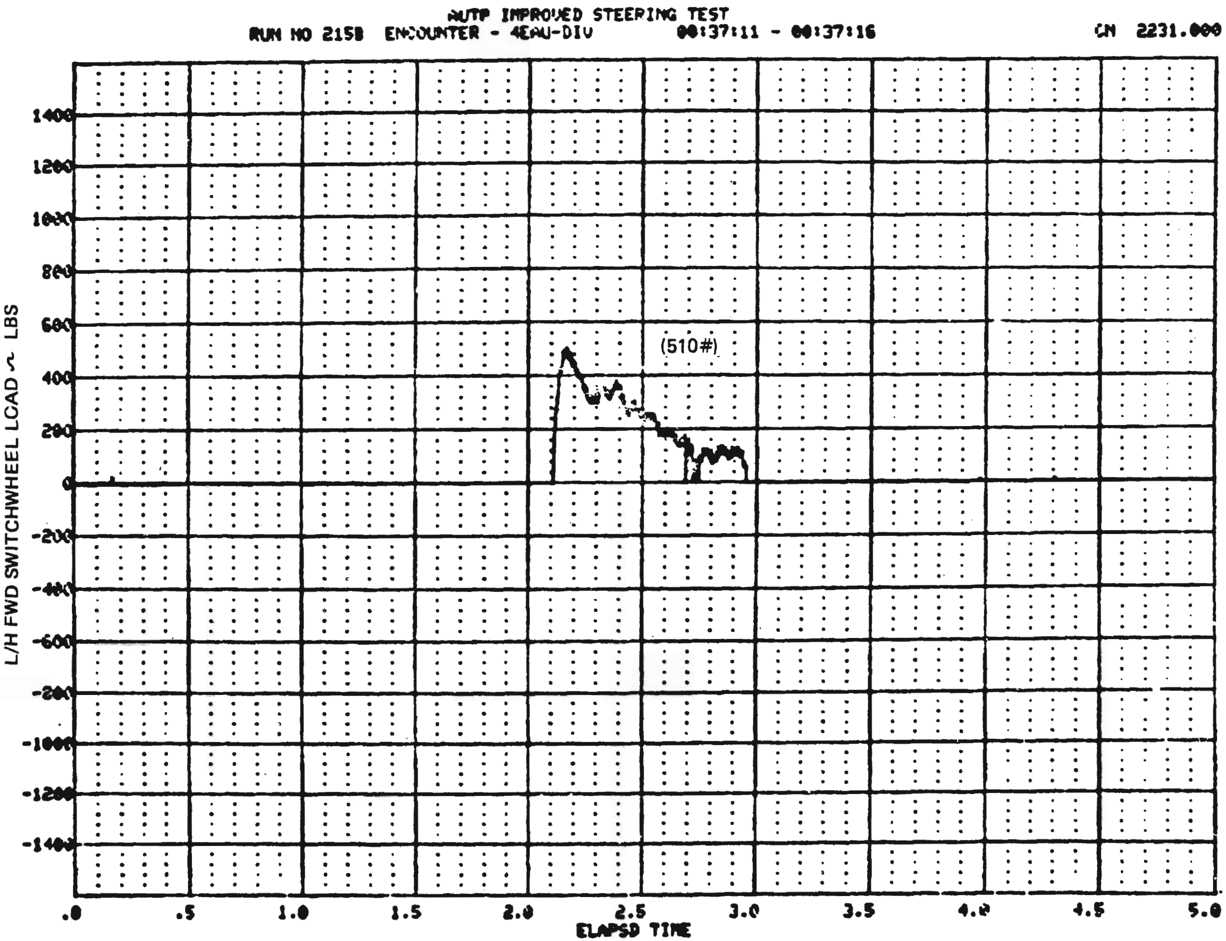


FIGURE 4–29 L/H FWD SWITCHWHEEL (SOFT SPRING)

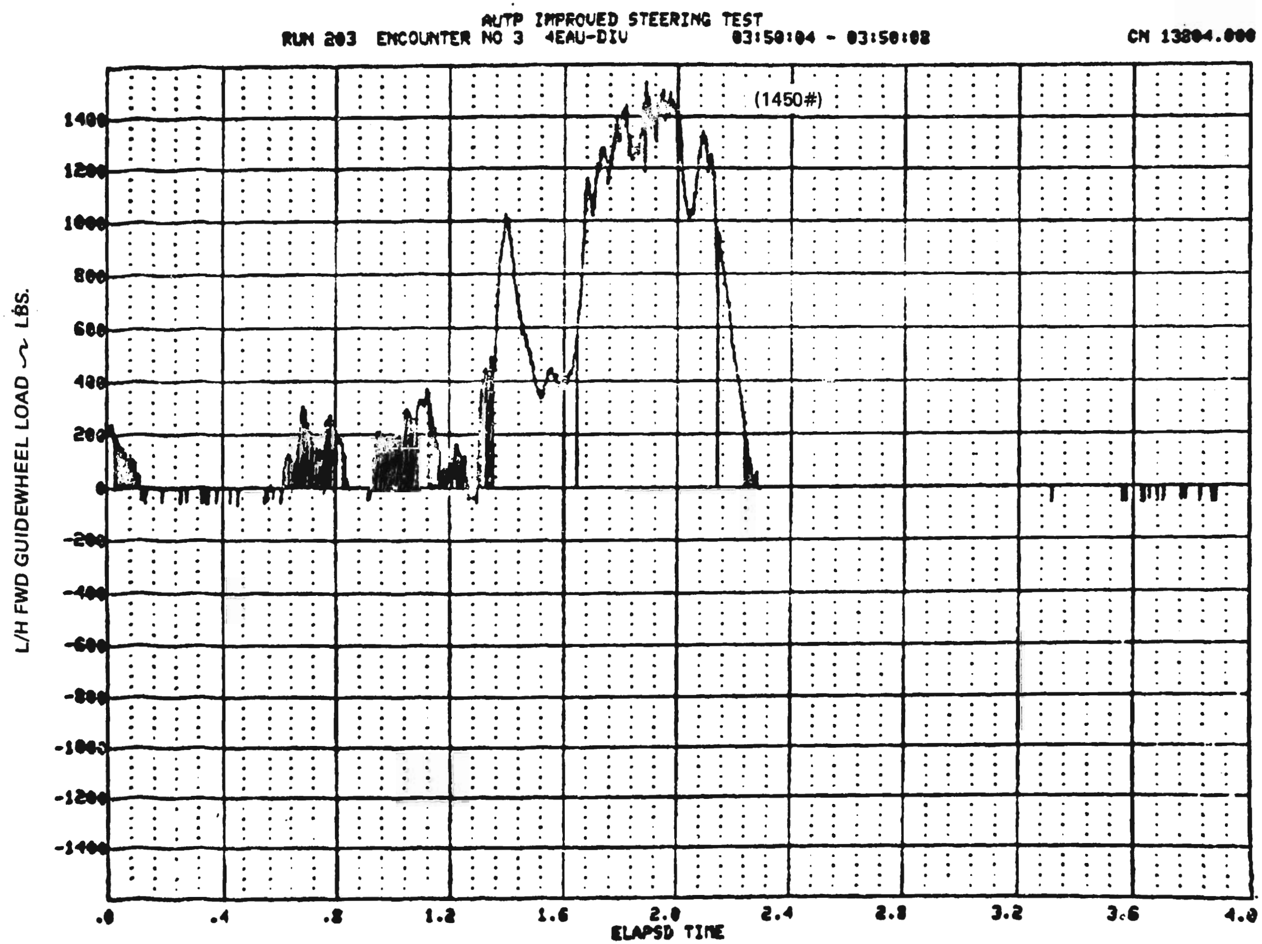


FIGURE 4–30 L/H FWD GUIDEWHEEL (MEDIUM SPRING)

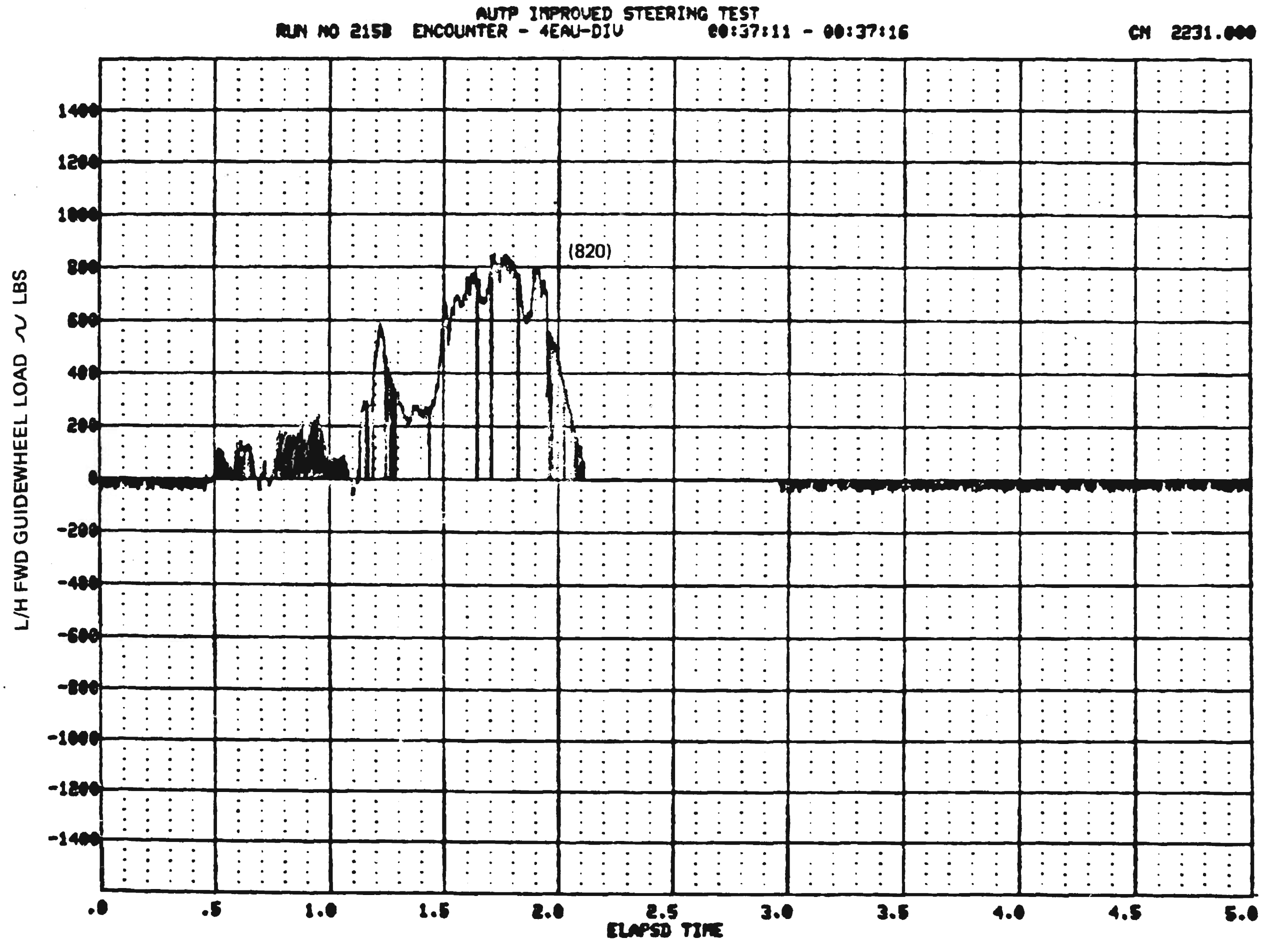


FIGURE 4–31 L/H FWD GUIDEWHEEL (SOFT SPRING)

conditions investigated.

4.4.2.6 Damper Disconnected - The steering damper was disconnected to demonstrate the effect of damping on the vehicle performance. Figure 4-32 presents a time history of the front guidebar displacements in the approach and during the encounter with the 3ENB diverge switch in the reverse position. These data are presented for both the run 215B and 215E; i.e., with and without the steering damper. A comparison of these data show the guidebar motion to be better controlled with the damper. Even further control and smoothness in the guidebar displacement is evident on reviewing comparable data from run 203 where the damper was further assisted by the stiffer guidewheel springs. The vehicle ride is improved with the damper active. The improvement in the vehicle ride is realized primarily in reduced amplitudes in the vehicle 1.7 to 2.0 Hz response. These frequencies correspond to vehicle body pitch and roll. The records also show a reduction in the oscillatory behavior associated with the active damper.

4.4.3 POWER BOOST SYSTEM - The power boost system was tested using the instrumentation that was used during the improved mechanical and contactless tests. The test route for the power boosted system was the same as used during the improved steering tests. Run #245 (ATC) was made in the regular route while runs 246, 247 and 248 were made at 22, 26 and 30 MPH respectively in the high speed test area.

4.4.3.1 Performance - The power boost steering system ride quality performance is summarized in Table 4-7. This summary is presented in a format identical to the summaries of the other steering systems using G_{RMS} as the ride indicator. The ride quality performance of the power boost steering was somewhat reduced by the occurrence of coupling between the vehicle body dynamics and the characteristics of the steering actuator. The tests were continued with the original power boost steering design since decoupling may be accomplished for subsequent testing through a simple gain change.

4.4.3.2 Speed - The "S" turn in the high speed test area was used as based for comparison of speed effects on the steering system. The steering actuator loads were used for this comparison since the guidebar, eyebolt and steering link loads are not a part of the steering in the power boost arrangement because of the isolating effect of the boost valve in the steering link. The guidebar loads are not used to steer the vehicle but guidebar movement is used to give inputs to the boost actuator servo. Figures 4-33 and 4-34 present time history curve for the forward steering actuator load at speeds of 17, 22, 26 and 30 MPH as the vehicle enters the "S" turn.

These curves show the load varies primarily due to guidewall roughness and instrumentation noise but a mean load for each speed can be seen. The mean actuator load indicates a slight increase in load as the speed increases and the increase was

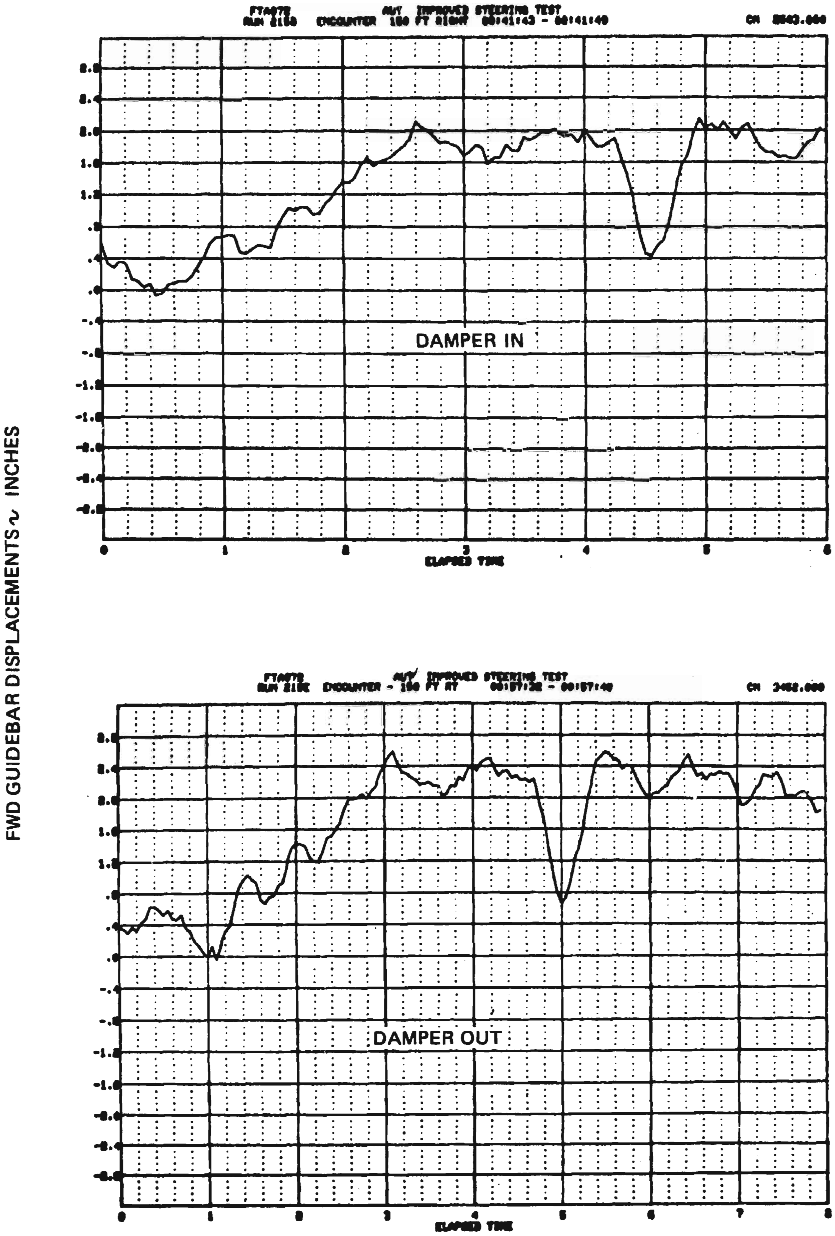


FIGURE 4–32 GUIDEBAR DISPLACEMENTS COMPARISON WITH AND WITHOUT DAMPER

TABLE 4–7 AUTP POWER BOOST STEERING TESTS RIDE QUALITY ANALYSIS SUMMARY, G_{RMS}

		MARKER NO./EVENT										
RUN NO.	DATA IDENTIFICATION (Speed, fps; Accel., G_{RMS})	1. 4EBU MERGE/ REV	6-7 4ENP16 150' RAD TURN	8-9 3ESL 800' RAD TURN	15 3ENB DIVERGE/ REV	15-16 3NB 150' RAD TURN	16-17 3NB 150' RAD TURN	20-21 4WCL STRAIGHT	21+ 4WSL "S1"	21+ 4WSL- 5WCL "S2"	21-22 4WSL- 5WCL STRAIGHT	5SB DIVERGE REVERSE
245 (Reduced Guidewheel Spring Rate Normal ATC)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.	14.3 .0233 .0227 .0214 .0163	22.8 .0519 .0377 .0514 .0311	25.7 .0351 .0333 .0268 .0242	25.9 .0576 .0446 .0541 .0328	25.3 .0614 .0512 .0644 .0426	25.1 .0508 .0483 .0480 .0321	25.8 .0558 .0596 .0383 .0397	25.5 .0693 .0619 .0636 .0492	25.5 .0511 .0436 .0413 .0291	25.9 .0306 .0335 .0267 .0270	25.6 .0681 .0540 .0589 .0371
246 (22 MPH)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.								27.1 .0736 .0671 .0683 .0521	32.1 .0647 .0479 .0682 .0368	32.4 .0403 .0456 .0313 .0284	26.8 .0633 .0469 .0559 .0349
247 (26 MPH)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.								27.4 .0824 .0747 .0698 .0549	38.6 .0786 .0646 .0756 .0490	38.6 .0544 .0587 .0451 .0408	
248 (30 MPH)	Average Speed Lateral, Front Accel. Vertical, Front Accel. Lateral, Rear Accel. Vertical, Rear Accel.									44.1 .0924 .0728 .0874 .0676	43.8 .0767 .0710 .0807 .0543	

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STEERING ACTUATOR LOAD ~ LBS

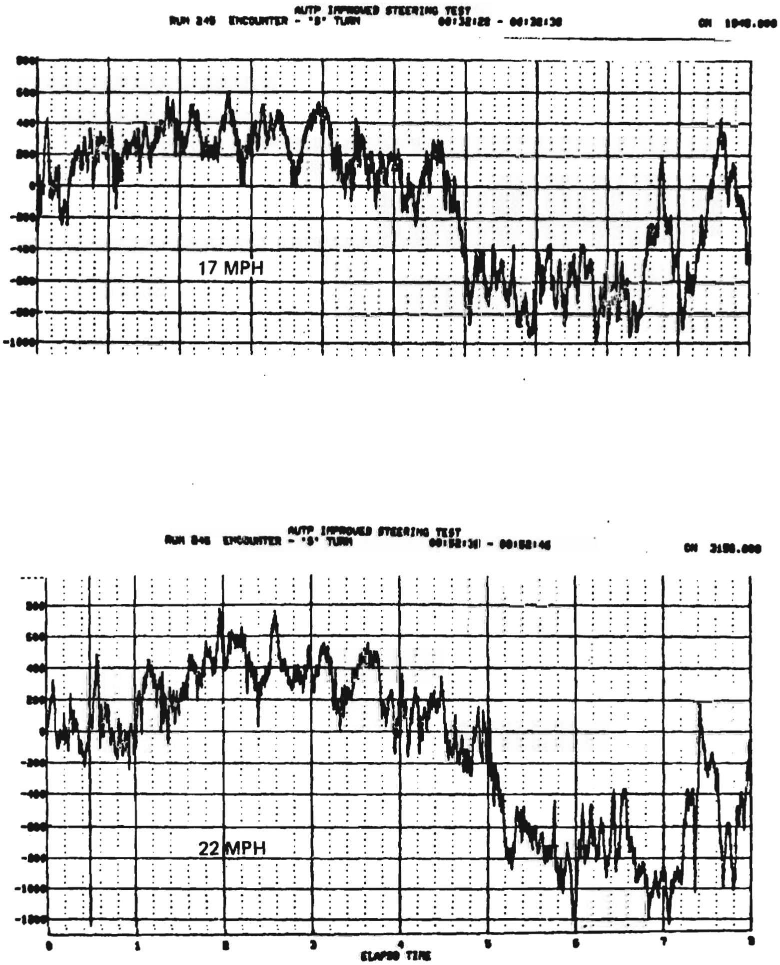


FIGURE 4–33 STEERING ACTUATOR LOAD, 17 AND 22 MPH

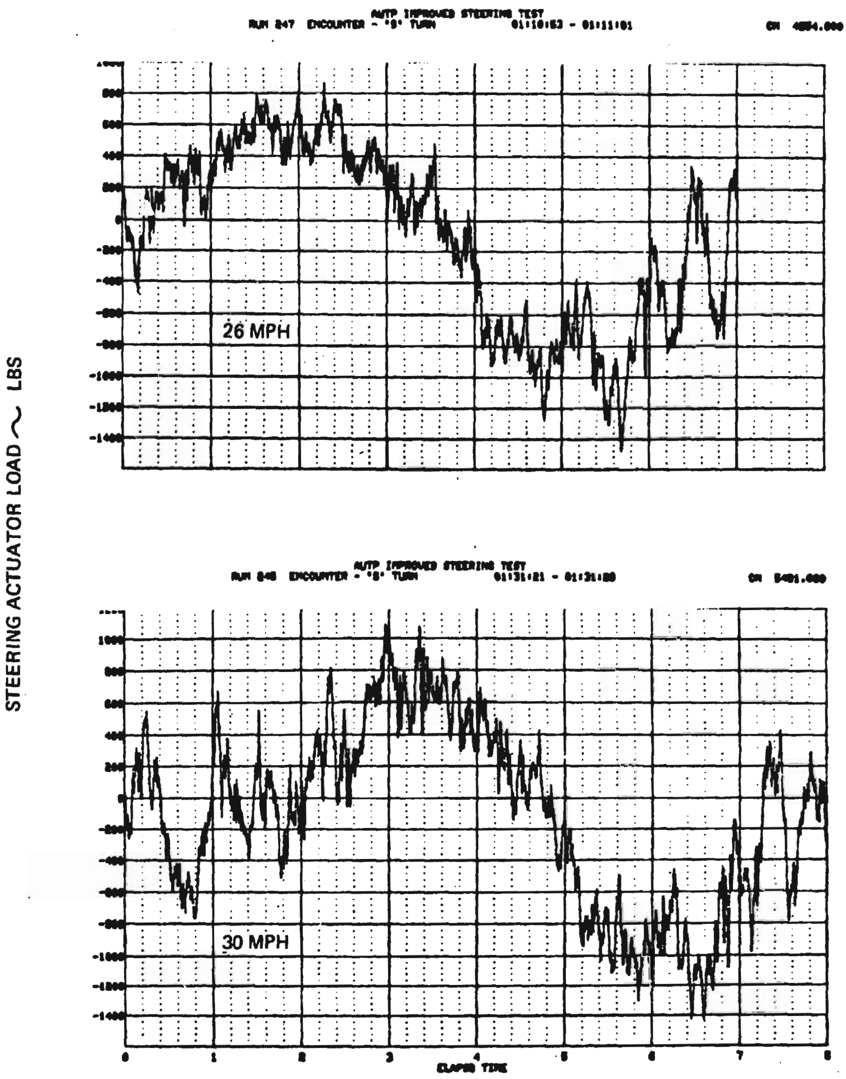


FIGURE 4–34 STEERING ACTUATOR LOAD, 26 AND 30 MPH

interpreted to be linear.

Figure 4-35 shows the increase in vehicle floor accelerations with increased speeds in a straight section of guideway. These curves show a progressive deterioration in the vehicle ride with speed.

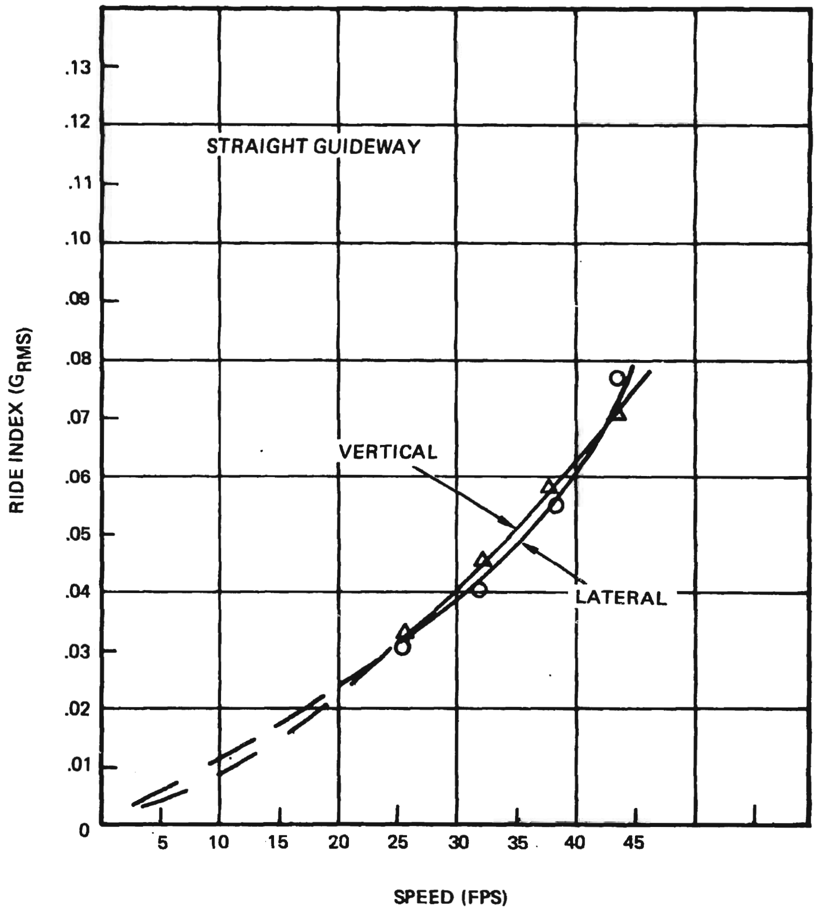


FIGURE 4–35 AUTP POWER BOOST STEERING EFFECT OF SPEED ON VEHICLE RIDE

4.4.4 CONTACTLESS STEERING SYSTEM - Bench tests and vehicle integration tests were performed on the system prior to testing in the guideway. On the guideway the system was tested with the same instrumentation being recorded as during the improved mechanical tests. The test section for the contactless system was restricted to the high speed section of the guideway where approximately 5000' of metal strip was installed. Straights, "S" turns and switches were represented in this section of the guideway. The test runs used to evaluate the contactless steering system were Runs #221, 221B, 222A and 227A. These runs were made at 17, 22 and 27 MPH.

While the vehicle was preceding to and returning from the guidestrip area, the vehicle was under the control of the mechanical steering system. The mechanical steering system also served as a backup to the contactless steering system.

The test objectives were to verify the proper operation of the system throughout the opeating range. The contactless steering system was tested at speeds up to 27 miles per hour in the straight sections and through the "S" turns. The response of the vehicle/steering system closely matched the response obtained from the simulations. A comparison of the simulated and measured response of the vehicle/contactless steering system is illustrated in Figures 4-36 and 4-37.

Tests were conducted in which the vehicle passed through the switch. The vehicle passed through the switch at speeds of 10 miles per hour in which the switching was activated by manual command. Electronic switching, initiated by the tone generator, was demonstrated at a vehicle speed of 3 miles per hour.

4.4.4.1 Bench Tests - The purpose of the bench tests was to simulate as closely as possible the dynamics of the closed loop contactless steering system. The hardware linkages were simulated by a spring and a mass attached to the output of the actuator. A schematic of the test set-up is shown in Figure 4-38.

The closed loop dynamics were determined by performing a frequency response test on the system as follows. An electrohydraulic servo was used to move a section of guidestrip in sinusoidal motion at varying frequencies. The path follower sensor was mounted above the guidestrip. The output motion of the actuator was measured by means of the feedback linear variable differential transformer (LVDT). The amplitude ratio and phase angle between the input and output was automatically processed and recorded. The result is shown in Figure 4-39. Based on the simulation discussed in APPENDIX B, the servo was required to have a phase angle of 45 degrees at a frequency of 3 Hz or better. This phase angle actually occurs at a frequency of 4 Hz. The resonance that occurs at 7.8 Hz is due to the simulated spring and mass of the tires. There is no performance requirement for the value of this resonance except that it be well above the break frequency, 4 Hz, of the servo. Based on these results, the path follower servo was accepted without any changes.

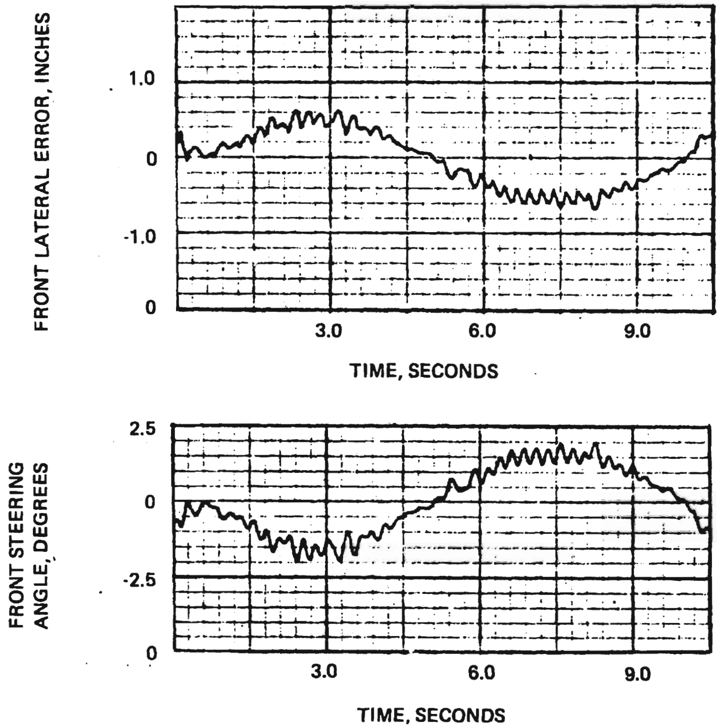


FIGURE 4–36 COMPUTED RESPONSE OF VEHICLE IN "S" TURN V = 17 MPH

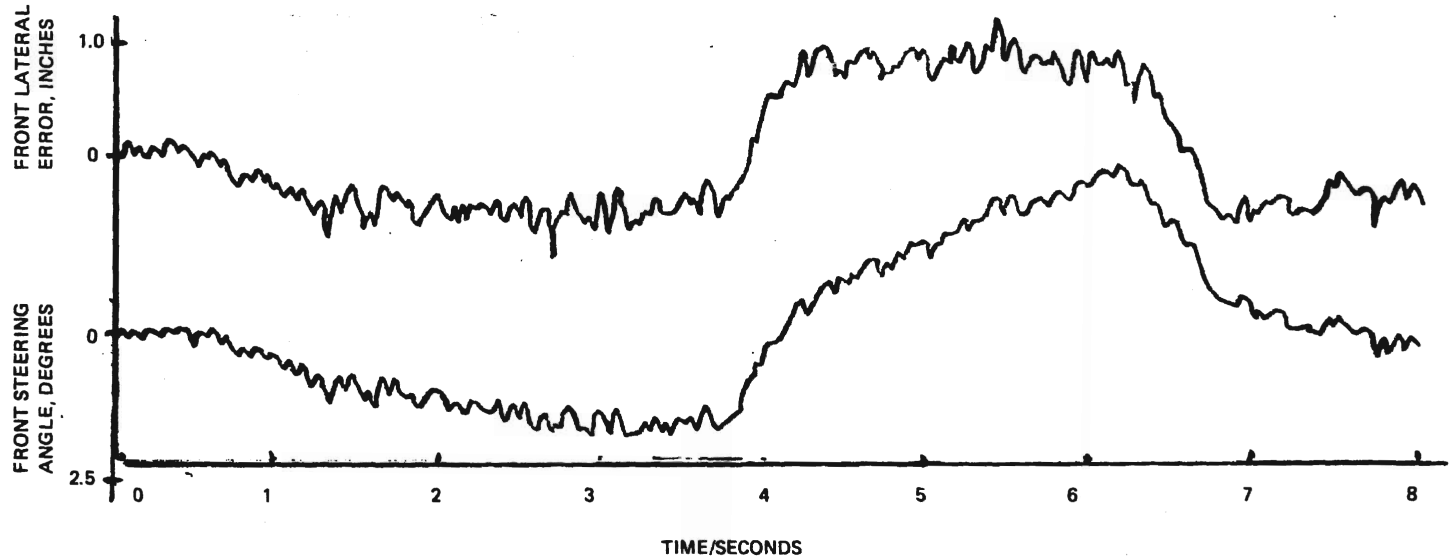


FIGURE 4–37 MEASURED RESPONSE OF VEHICLE IN "S" TURN

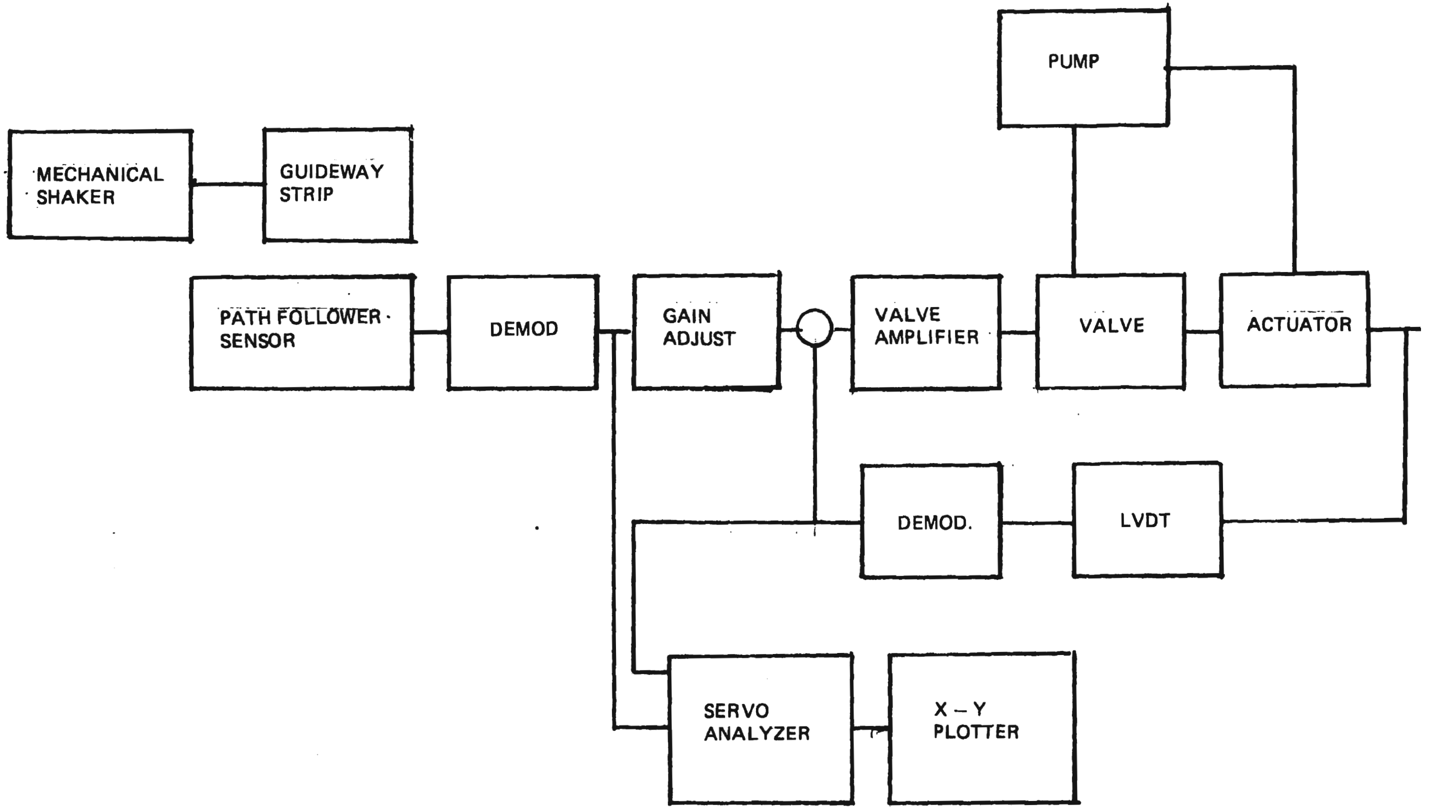


FIGURE 4–38 SCHEMATIC OF BENCH TEST

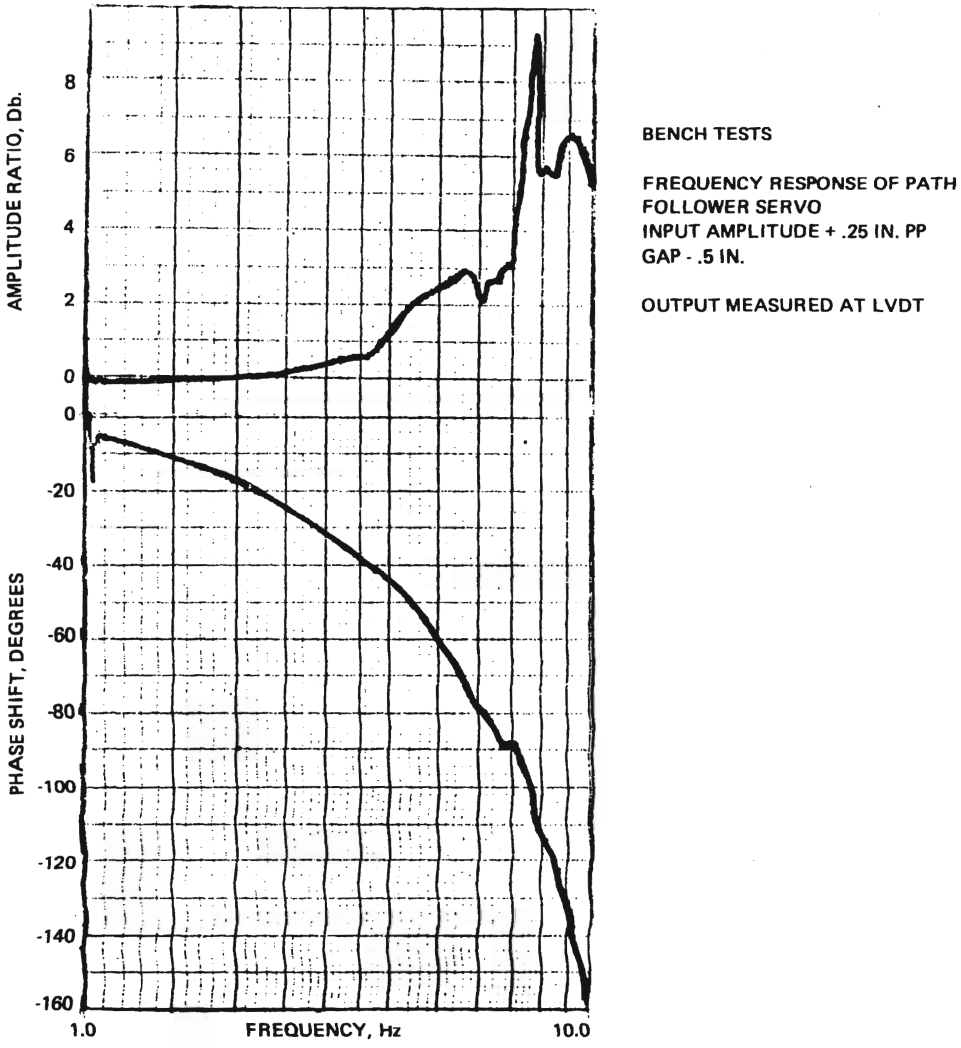


FIGURE 4–39 PHASE SHIFT AND AMPLITUDE RATIO VS FREQUENCY

The bypass is required to disengage the actuator in the event of a failure. The bypass operation is required to occur in 20 milliseconds or less. This was verified by measuring the dynamic response of the pressure in the actuator due to the removal of current in the solenoid bypass valve.

4.4.4.2 Vehicle Integration Tests - The purpose of these tests was to verify the dynamic performance, the switching logic and the failure modes of the AIRTRANS contactless steering system. The vehicle was placed on jacks to allow the wheels to rotate freely, except as noted. Similar tests were performed on the front and rear steering system.

A section of guidestrip was attached to an electro hydraulic shaker and placed under the forward right hand sensor at a gap of 0.75 inches. A stationary guidestrip was placed under the right rear sensor. A frequency response test was performed. The amplitude ratio and phase angle of the front steering system is shown in Figure 4-40. A phase shift of 45 degrees occurs at 6 Hz. The amplitude ratio at resonance is 2 Db. This is to be compared with 5 Db that was measured on the bench tests. A similar frequency response was performed on the rear steering system. A phase shift of 45 degrees occurred at a frequency of 3.5 Hz, which is acceptable.

The guidestrip detection circuit logic described in 4.4.3 was checked out by simulating normal and abnormal conditions in the following manner. A section of guidestrip was placed under each sensor. A 10 Khz tone generator was applied to the strips to simulate the following conditions:

The guidestrips were manually placed in the following configurations:

CONDITION	NORMAL	ABNORMAL	RESULT
Tone generator applied to:			
(1) None of the strips		X	FI (Failure Indication)
(2) All four strips		X	FI
(3) Right front	X		No change
(4) Right rear	X		No change
(5) Right front and right rear	X		Switch to left sensors.

Since all results were correct, the path follower servo was accepted without any changes.

4.4.4.3 Performance - The ride quality performance evaluation of the contactless steering system is limited by the restricted test

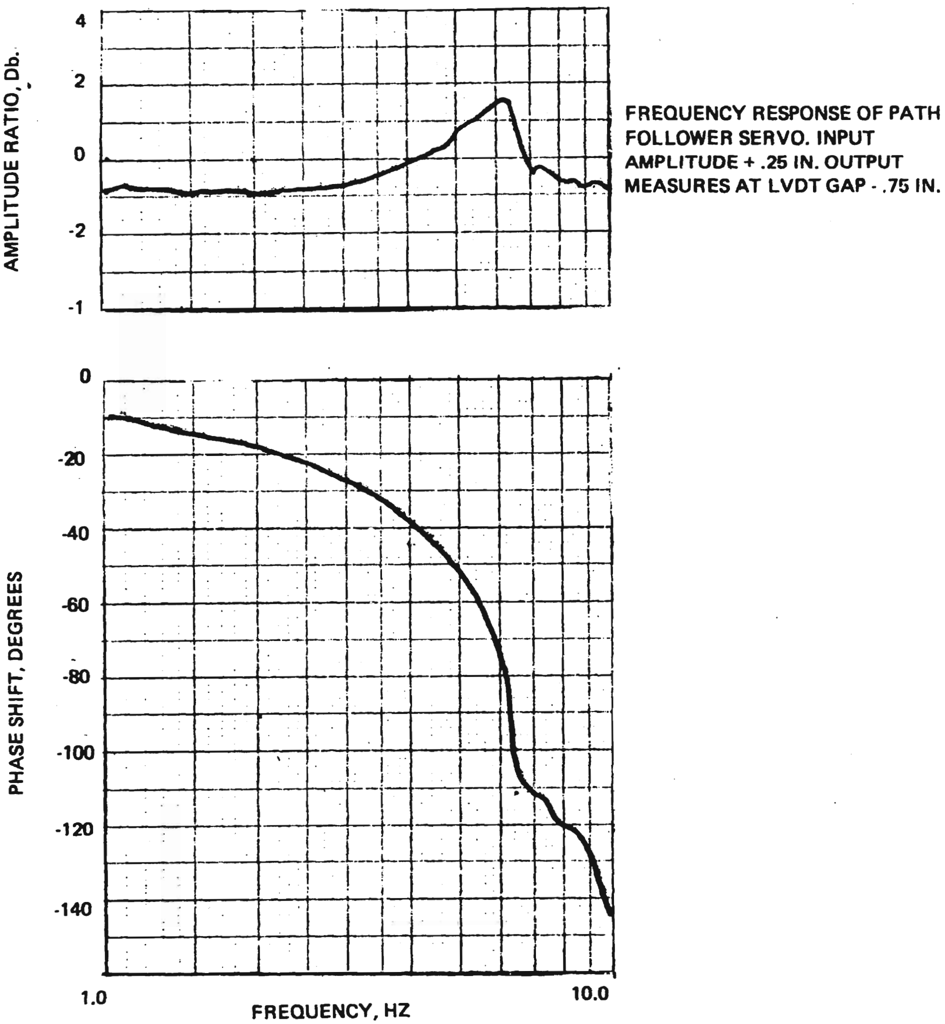


FIGURE 4—40 PHASE SHIFT AND AMPLITUDE RATIO VS FREQUENCY

site and the small variety of guideway events available. Table 4-8 presents the summary of G_{RMS} levels for events common to those presented in the Improved Mechanical Steering Tests.

4.4.4.4 Speed - The 22 MPH run (#222A) was considered the best contactless run. For this run, data were reduced in a straight and "S" section of the guideway. Figure 4-41 shows a comparison of guidewheel loads in a straight section of the guideway for speeds of 17, 22 and 27 MPH. From this comparison, it is evident that speed does not increase the magnitude of the guideway/guidewheel loads. In fact this plot indicates a slight reduction in load during the 27 MPH run. As shown in Table 4-8, only two speed conditions were suitable for ride quality data analysis. This is inadequate to fully establish the ride quality trend with speed.

4.4.5 COMPARISON OF STEERING SYSTEMS

4.4.5.1 Effects Of Speed - The test results at the 5SB-diverge switch were used to compare the baseline and improved mechanical and power boosted steering systems. The righthand switchwheel load variation with speed is presented in Figure 4-42. The contactless system is not applicable in this comparison.

The baseline and improved steering compare very favorably both exhibiting linear variations with speed and very similar peak switchwheel loads, especially at the higher speeds. At the lower speeds there is a slight variation which is explained by a difference of the baseline and improved mechanical systems switchwheel spring rates.

4.4.5.2 Effects Of Fixed Guide/Switchwheel Deletion - One of the most noticeable aspects in riding an AIRTRANS vehicle is the guidebar "pounding" in a tight (150' radius) curve. This phenomenon is dicussed in Section 4.4.1.4. The improved mechanical steering design eliminated this "pounding" as discussed in Section 4.4.2.3. From a loads standpoint, the single guide/switchwheel configuration reduced the vehicle/guidewall loads greatly. This comparison is shown in Figure 4-43. The baseline tests (Run 5D) show the righthand guidewheel pounding on the inside wall of a righthand 150' radius turn while the lefthand spring loaded wheel follows along the lefthand wall. This is contrasted to the improved mechanical steering results (Run 203) that shows the lefthand guidewheel tracking the lefthand wall as the righthand guidewheel contacts the wall only at the high places. The baseline tests produced peak fixed guidewheel loads of 2357 lbs., compared to the single guidewheel load of 1210 lbs. produced by the improved mechanical system. Not only was the peak load reduced but the number of occurrences was reduced as shown by the frequency of occurrence curves presented on Figures 4-44 and 4-45. These data are very useful for the fatigue design requirements of components. These types of data are available for the components instrumented in both baseline and improved mechanical tests.

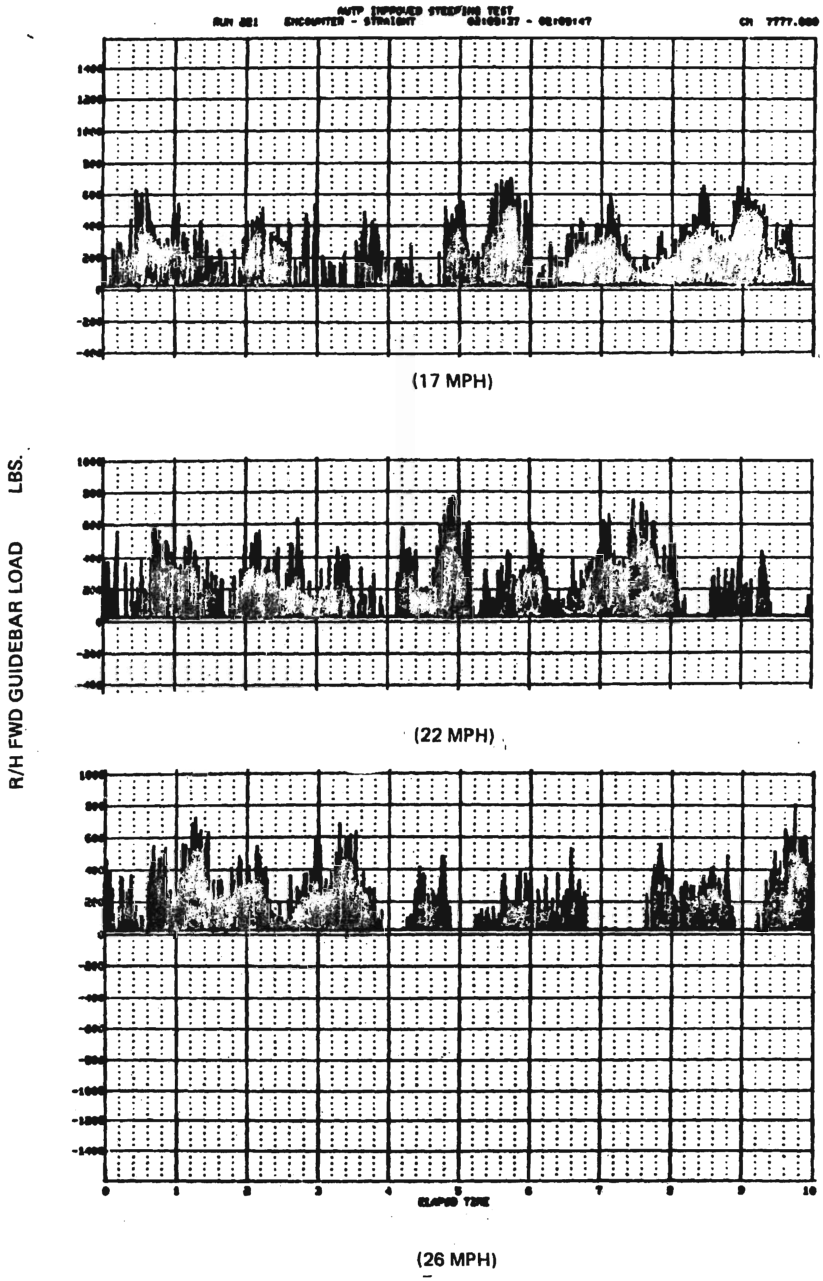


FIGURE 4–41 GUIDEWHEEL LOAD VS SPEED COMPARISON - CONTACTLESS

TABLE 4-3 AUTP CONTACTLESS STEERING SYSTEM TESTS RIDE QUALITY ANALYSIS SUMMARY

G_{RMS}

RUN NO.	DATA IDENTIFICATION (Speed, fps; Accel, G_{RMS})	MARKER NO./EVENT 21+ 4WSL "S2"	21-22 4WSL-5WCL STRAIGHT
221	Average Speed		25.8
	Lateral, Front Accel.		.0372
	Vertical, Front Accel.		.0397
	Lateral, Rear Accel.		.0362
	Vertical, Rear Accel.		.0311
222A	Average Speed	32.1	32.4
	Lateral, Front Accel.	.0792	.0399
	Vertical, Front Accel.	.0696	.0452
	Lateral, Rear Accel.	.0597	.0377
	Vertical, Rear Accel.	.0419	.0354

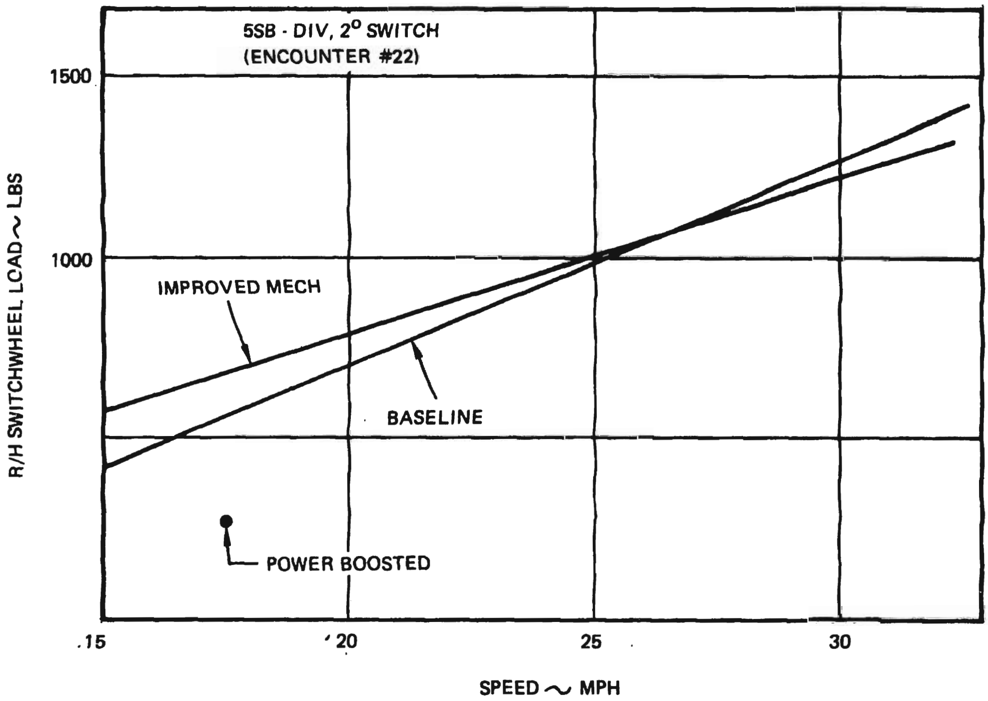


FIGURE 4–42 STEERING SYSTEM COMPARISON FOR SWITCHWHEEL LOAD

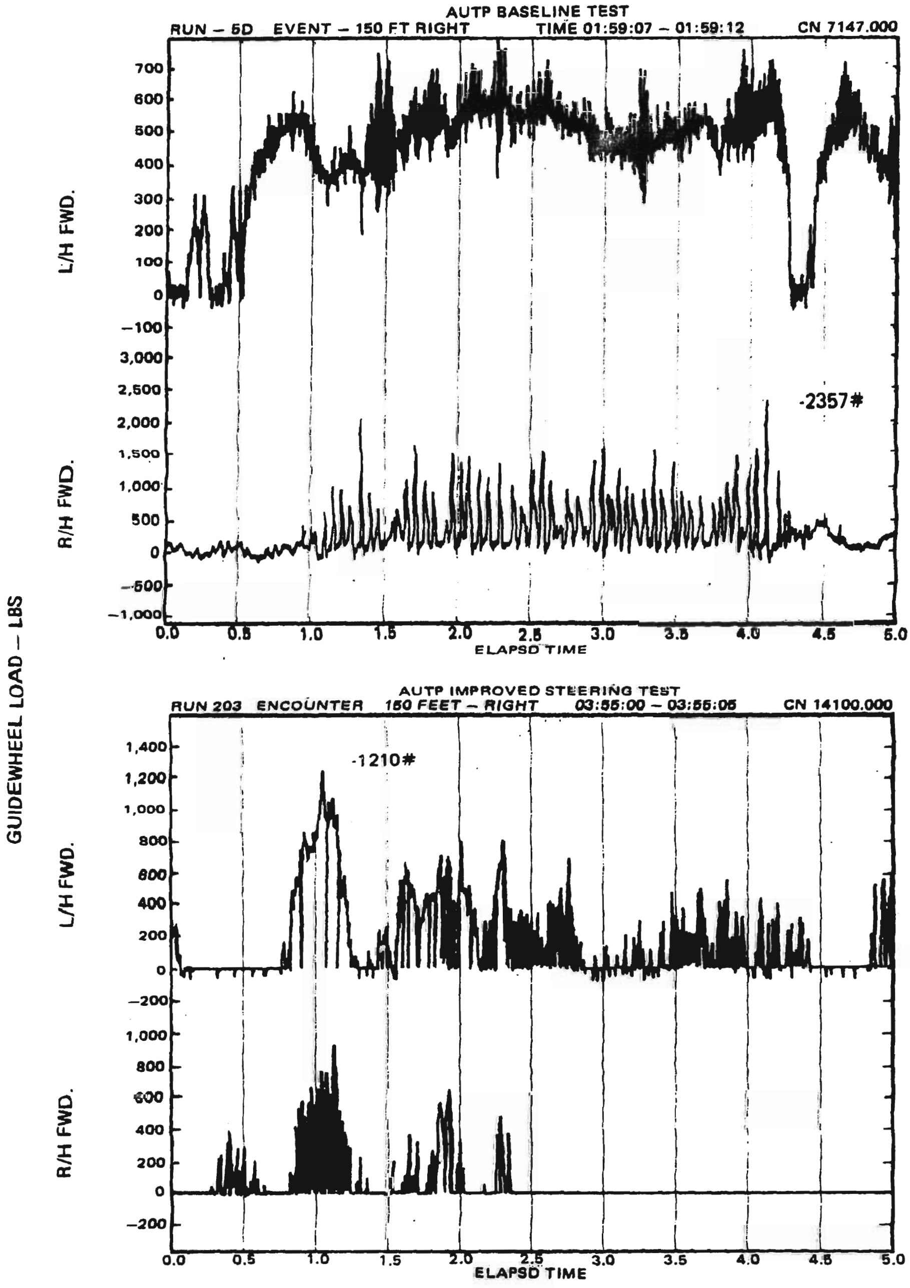
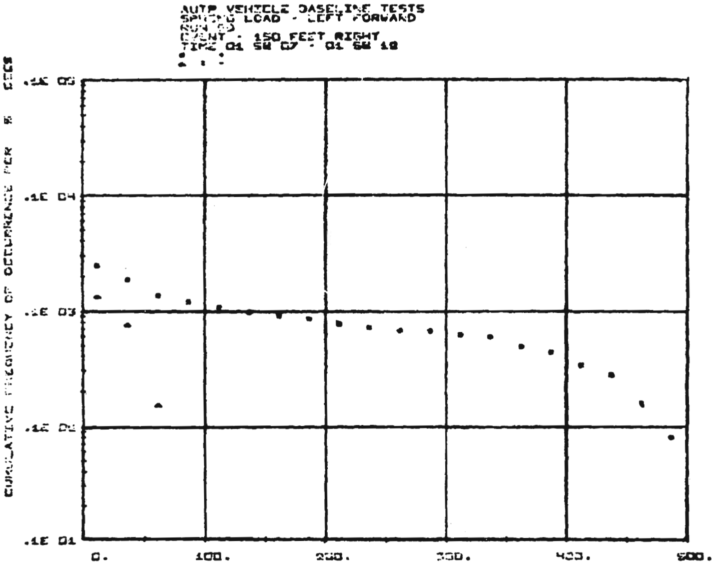
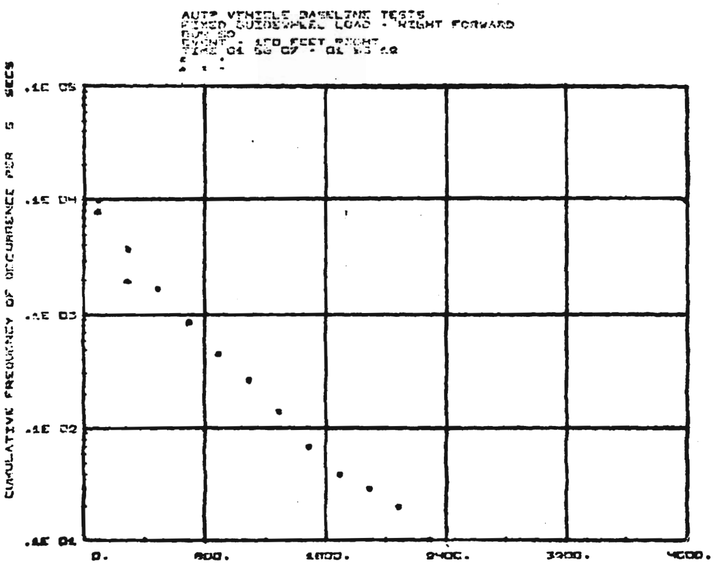


FIGURE 4–43 GUIDEWHEEL LOAD COMPARISON – 150′ RT TURN

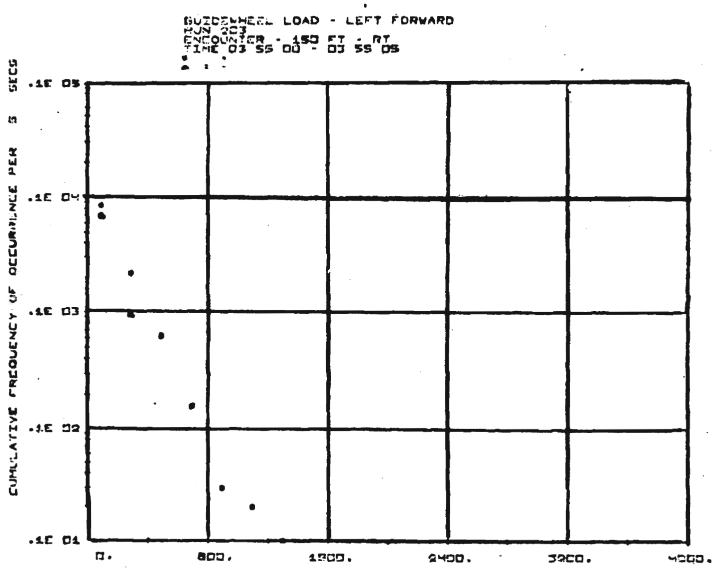


L/H FIXED GUIDEWHEEL LOAD ~ LBS.

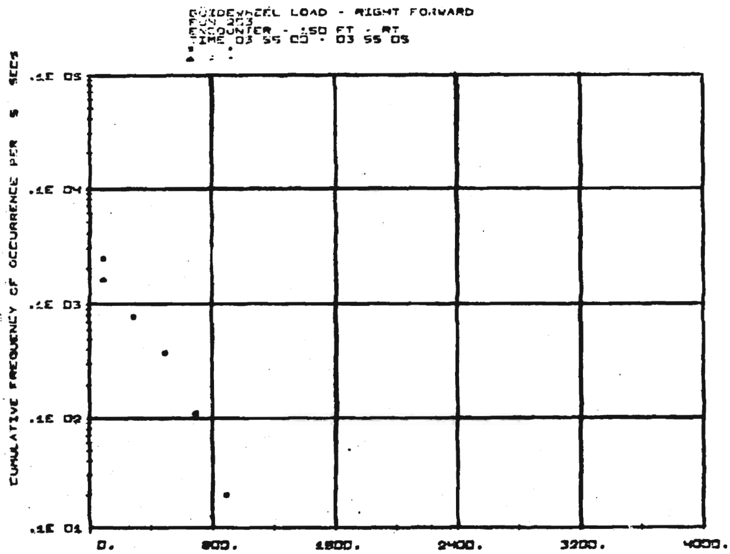


R/H FWD SPRING-GUIDEWHEEL LOAD ~ LBS.

FIGURE 4–44 GUIDEWHEEL EXCEEDANCE LOADS BASELINE TEST (AIRTRANS)



L/H FWD GUIDEWHEEL LOAD ~ LBS.



R/H FWD GUIDEWHEEL LOAD ~ LBS.

FIGURE 4–45 GUIDEWHEEL EXCEEDANCE LOADS IMPROVED MECHANICAL TESTS

4.4.5.3 Ride Quality Comparisons - A ride quality comparison among the four steering systems, baseline, improved mechanical, power boost and contactless, reveals some important differences. One change, anti-friction kingpin bearings was tested separately in the baseline tests. This test demonstrated a significant and general improvement in both lateral and vertical ride quality as detailed in paragraph 4.4.1.5. The improved mechanical system, which includes the king pin bearing change, showed a marked improvement over baseline at all speeds and conditions. Tests of contactless and power boost were generally on a par with the improved mechanical test with regard to ride quality. Both power systems incorporate the improved mechanical system.

The front and rear steering interconnect linkage, while improving the baseline ride a small amount, showed insignificant differences when disconnected during improved mechanical system tests.

The steering damper was demonstrated to be a worthwhile component, providing better ride and smaller guidebar excursions when incorporated.

Ride quality was shown to deteriorate with speed for all configurations. This deterioration was more pronounced for the baseline. Since the turns and switches where the tests were made were specifically designed for a 25 FPS (17 MPH) system, it is not surprising that ride quality exceeded guidelines at speeds above 30 FPS (20 MPH).

For a relative comparison between systems see Figure 4-46. Here a consistent improvement can be seen in every instance for the improved mechanical, the contactless and the power boost over the baseline. The improved mechanical system met UMTA ride quality guidelines (Reference 11).

4.5 CONCLUSIONS

The improved mechanical, power boost, and contactless steering systems are all viable steering concepts. Each shows improvement over the baseline AIRTRANS steering system and should be considered depending on the particular AGT system application.

Additional development of the power boost and contactless systems appear warranted by the potential improvements from these systems particularly at higher speeds. The improved mechanical system is suitable for production as designed, fabricated, and tested for speeds up to 30 MPH.

4.5.1 BASELINE - Besides establishing a basis for comparison of the other systems, the baseline tests of the AIRTRANS steering system verified several important conclusions.

(1) The measured wheel turn angles in a 150 foot radius turn closely matched the predicted angles indicating

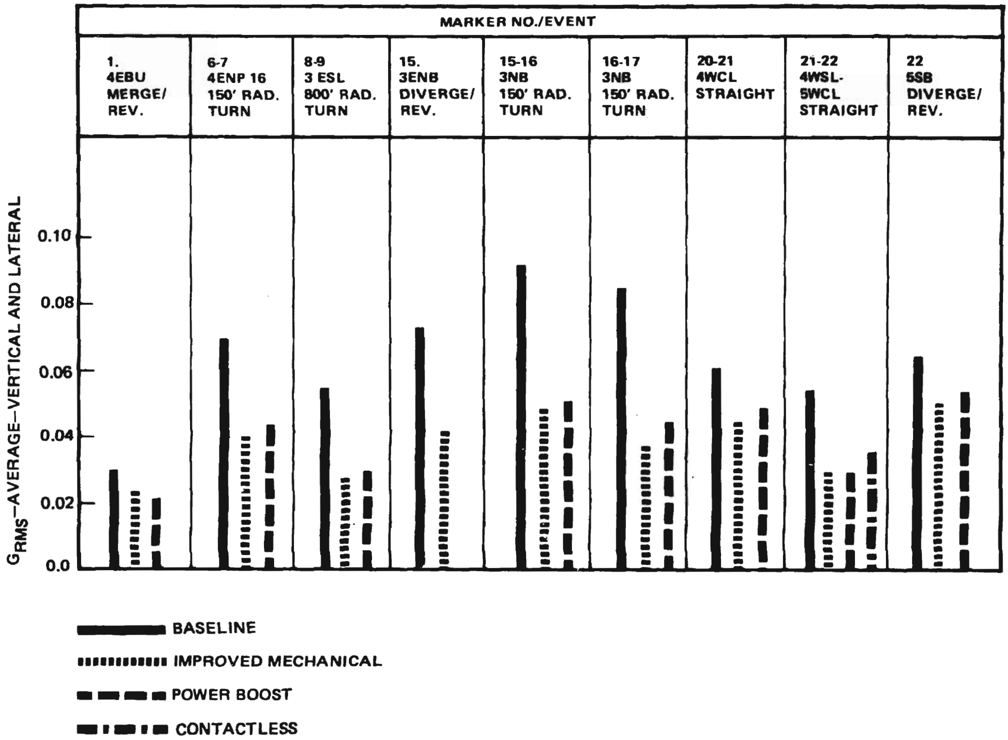


FIGURE 4–46 RIDE QUALITY COMPARISON BETWEEN SYSTEMS

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the vehicle tracking assumptions are realistic.

(2) The interconnect linkage (front to rear) does improve the steering tracking and ride of the vehicle as opposed to completely independent front and rear steering or front only steering with rear castoring up to the rear guidebar stops.

(3) A dynamic pounding of the guidebar occurs in a 150 foot radius turn between the fixed guidewheel on the inner side and the spring loaded guidewheel on the outer side of the vehicle.

(4) The installation of anti-friction (needle) kingpin bearings in place of the AIRTRANS journal type kingpin bearing reduced the steering link and tie rod loads by 45% and 60% respectively.

4.5.2 IMPROVED MECHANICAL - Tests of the improved mechanical steering system established the following characteristics.

(1) Providing only spring loaded guide/switch wheels at each corner of the vehicle (inplace of fixed and spring loaded guide/switch wheels) completely eliminates the pounding observed in the baseline tests of the basic AIRTRANS steering system. The guidebar loads were significantly reduced in magnitude and number of occurrences and the ride quality was pronouncedly improved.

(2) Reduction in guidebar weight, low friction steering damping and increased guidewheel size contribute to the loads reduction and the improved ride quality.

(3) The use of the softer guidewheel spring rate of 3140 lbs/inch provides lower loads over the stiffer springs.

(4) The steering damper does control the guidebar motion better than with no damping. Loads, however, do not appear to be a criteria for the damper.

(5) The use of an additional spring in the steering link does not improve the vehicle ride.

(6) The improved mechanical steering system as developed and demonstrated is suitable for immediate applicaton on AGT systems.

4.5.3 POWER BOOST STEERING - The tests of the power boosted steering system verified the following conclusion.

(1) The power boost system is a workable option.

(2) The power boosted system will decrease the guidebar, eyebolt and steering link loads at encounters such as switches compared to the improved mechanical system.

4.5.4 CONTACTLESS STEERING - From the tests of the contactless steering system the following conclusions are evident.

(1) The feasibility of the full servo steering system was demonstrated. The system performed according to predictions determined by simulations and component tests.

(2) The concept of a passive strip was proven to be a viable one. Steel switch pit covers or steel reinforcing rods embedded in the guideway are not a problem. The thermal expansion joints should be designed so that any noise spikes are generated at a frequency that is removed from vehicle/steering system resonant frequency. The sensor design should be modified to accommodate a gap of two inches or greater.

(3) The hydraulic system performed reliably and according to specification. No leaks were experienced at any time during the program.

(4) The fail-safe dual system approach is a viable method of achieving safety in a contactless steering system. The transition from contactless to mechanical steering proved to be smooth.

(5) Before a contactless steering system can be employed in a production system, the interface between the brakes, the steering system, the guideway strips, and the failure logic must be established.

5.0 CONTROL AND COMMUNICATIONS

The major AUTP effort for the control and communications system was directed towards improving the overall system effectiveness. In order to accomplish this objective, program goals were established to reduce operational costs by improving maintainability, simplifying designs and modernizing equipment. The vehicle portion of the AIRTRANS control system is a high cost maintenance item both in material and skilled manpower. Review of the costs associated with maintaining the AIRTRANS vehicle control electronics had previously resulted in a program to consolidate the nonvital vehicle logic and controls into a single package. The objectives were to explore the feasibility of using a microprocessor to accomplish the many logic manipulations distributed in several AIRTRANS hardware units. The state-of-the-art was such that the speed and flexibility of the microprocessors had increased to the point where such an approach offered several potential advantages in turns of simplification, improved reliability, increased flexibility, reduced size, weight, and power consumption. Increased maintainability was a possibility because of the flexiblity of the microprocessor providing diagnostic data collection and analysis. Based on these considerations the AUTP tasks were selected to further develop the designs, implement a second generation set of hardware and demonstrate, where possible, specific features contributing to the general goals enumerated above. The specific Control and Communications efforts are described in detail in the following paragraphs of this section of the report. In order to provide the reader with a better understanding of the program tasks, a brief functional description of the AIRTRANS control system is given below, followed by the detailed program tasks and the results and conclusions.

5.1 FUNCTIONAL DESCRIPTION

The AIRTRANS control system consists of three subsystems which are used to control the movement of vehicles in the system. They are called:

(1) Automatic Vehicle Protection (AVP),

(2) Automatic Vehicle Operation (AVO) and

(3) Supervisory Data System (SDS).

These subsystems are combined into an integrated whole which is called the Automatic Vehicle Control (AVC) System. (Note: In this section, "vehicle" is used to denote a single or multi-unit operating consist.)

Figure 5-1 is an illustration which details the major functions of a typical AVC system. The safety hardware includes the basic block system described in Figure 5-2, and the wayside

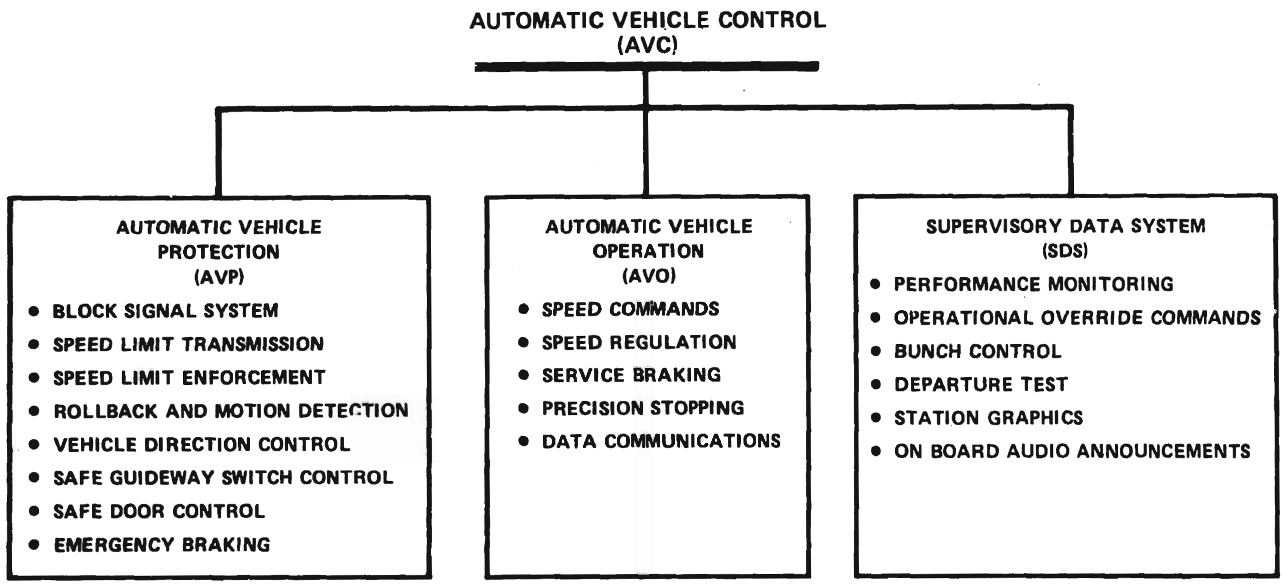

FIGURE 5–1 FUNCTION OF AUTOMATIC VEHICLE CONTROL SYSTEM

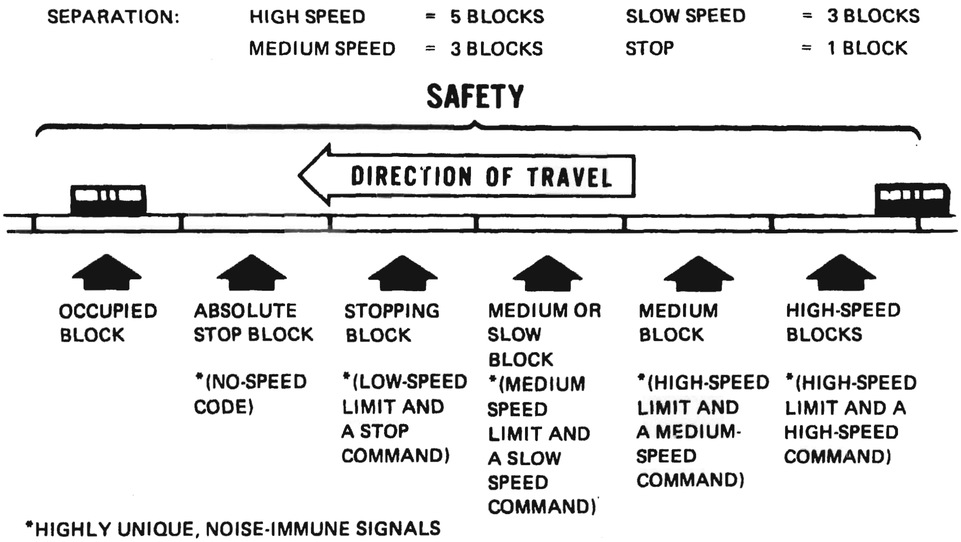

FIGURE 5—2 AUTOMATIC VEHICLE SPACING BASED ON BLOCK OCCUPANCY

elements for vehicle detection, vehicle control signal generation, switch interlocking and control, and station platform door control.

5.1.1 LOCATION OF AVC COMPONENTS - Some of the AVC equipment is located on the vehicles, and other components are located along the wayside. Vehicle-borne equipment and wayside equipment are connected via a communication link consisting of signal rails mounted on the guideway walls and signal collectors mounted on the vehicle.

5.1.2 VEHICLE EQUIPMENT - Equipment on the vehicle executes commands transmitted from wayside, performs safety checks, monitors performance of vehicle subsystems and sends data reports to the wayside receiving equipment as illustrated in Figure 5-3. It should be noted that for the AUTP non-vital control functions are primarily accomplished by the "Vehicle Control Equipment" (VCE). As shown on the figure, the AUTP "VCE" encompasses both the AIRTRANS CLA functions and the speed regulation and stopping functions performed in AIRTRANS by the AVO.

5.1.3 WAYSIDE EQUIPMENT - Equipment at wayside locations prepares commands for the vehicle, controls vehicle routing and station operations, and processes vehicle status data as illustrated in Figure 5-4. This equipment would be physically located in the Central Control Facility, in small wayside buildings and/or in the stations throughout the system.

5.1.4 CENTRAL CONTROL FACILITY - The Central Control Facility provides a central location for line supervision of the system and control of the voice and video communication systems. A guideway schematic display provides the system controller with the location of all vehicles, and data on those that are reporting malfunctions or have had supervisory overrides. Certain command features can be provided such as route designation, extend station dwell, station bypass, etc. The commands cannot override the safety provisions of the system. Switch position, command direction of travel and any switch malfunction are shown. The status of each sectionalized zone of the electric power system is indicated. Any station malfunction sensed by the line supervisory system causes that station indicator on the schematic to light up.

5.1.5 COMMUNICATION SYSTEM - The vehicles, stations, and other components of the system are interconnected by a communication system as shown in Figure 5-5. This system performs the function of relaying information and commands from one point to another. The command part of this system is an integral part of the AVC system described previously. The voice and video parts of the system are described below.

Radio and public address communications systems link the central controller with stations, passengers and maintenance workers. It permits public address announcements on a selective

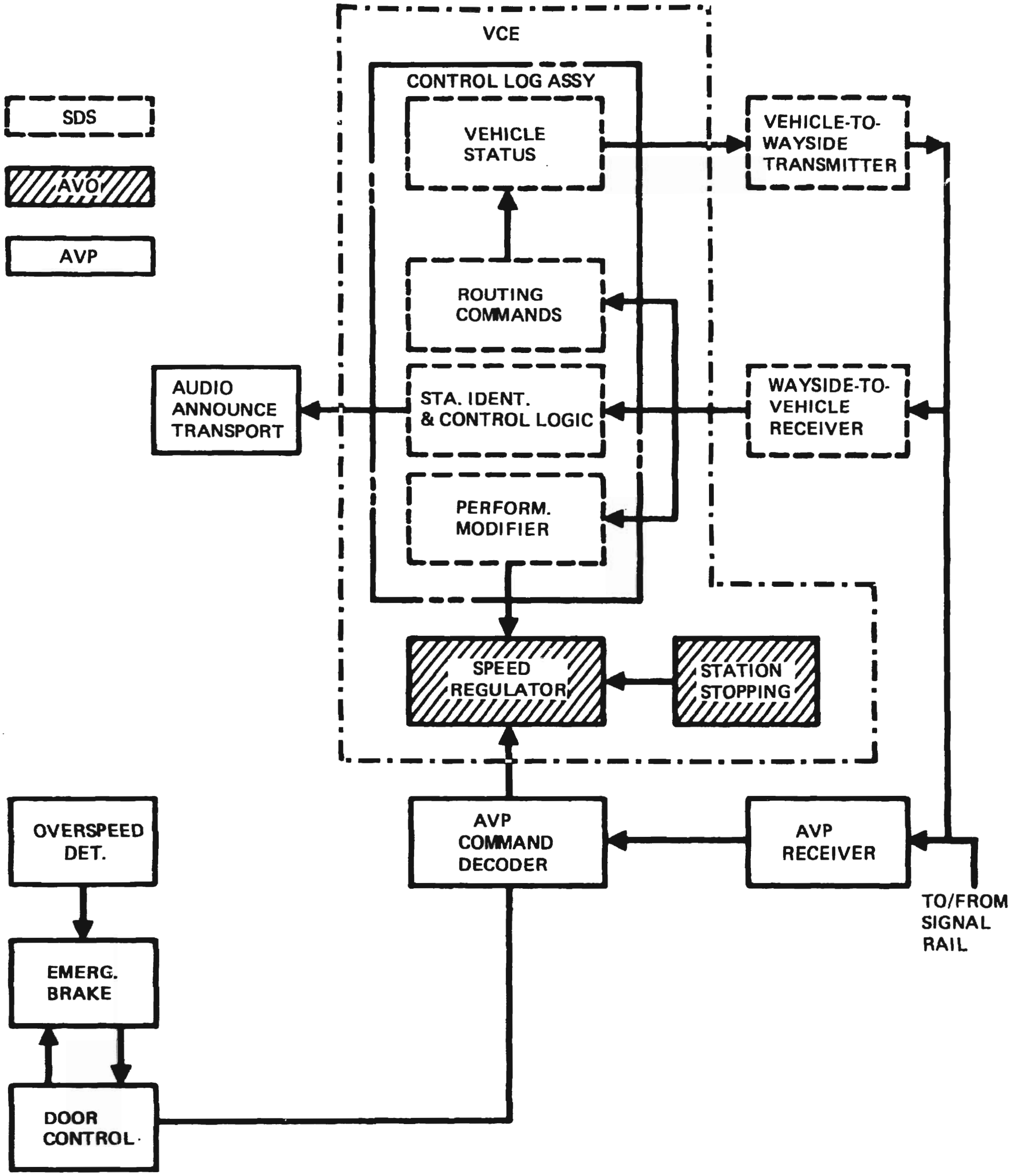

FIGURE 5–3 VEHICLE BORNE AUTOMATIC VEHICLE CONTROL EQUIPMENT

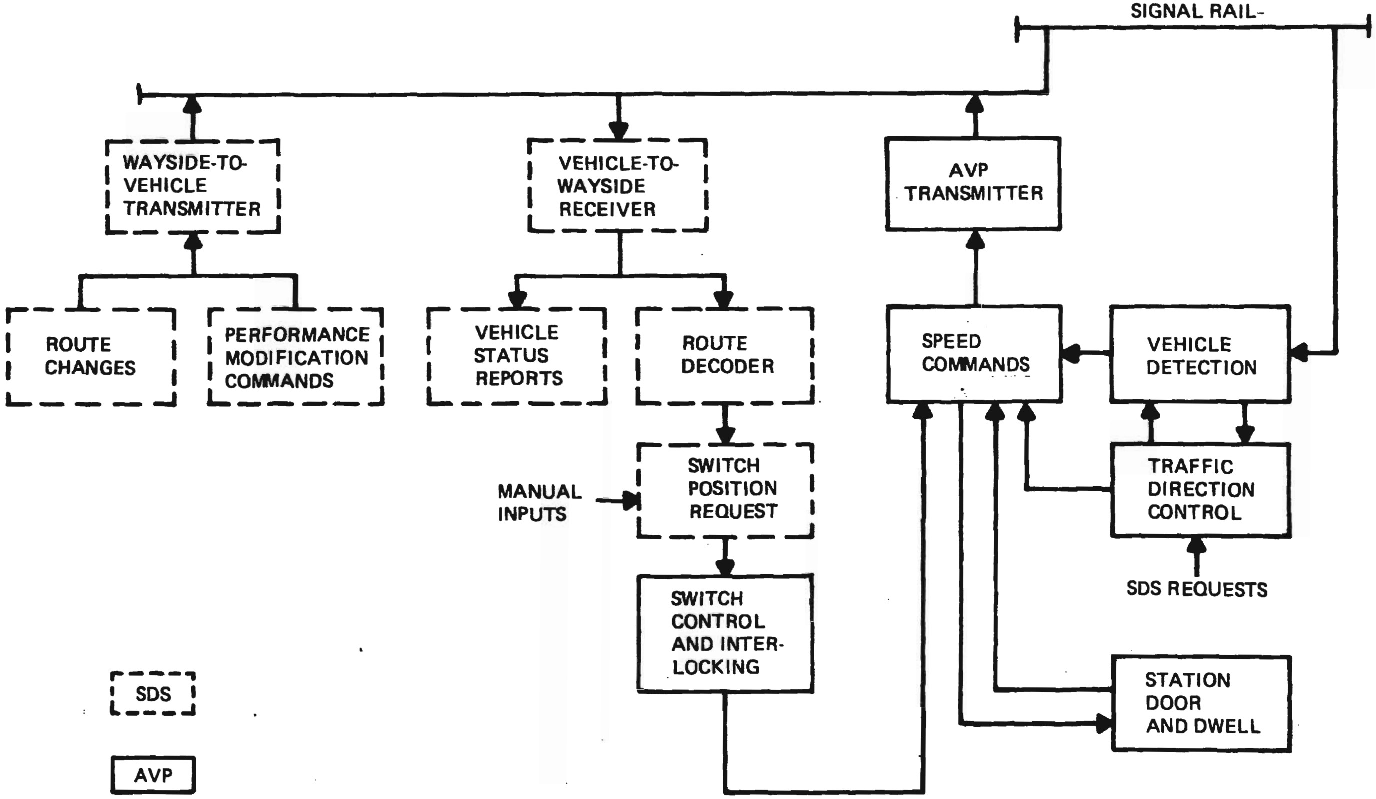

FIGURE 5–4 WAYSIDE AUTOMATIC VEHICLE CONTROL EQUIPMENT

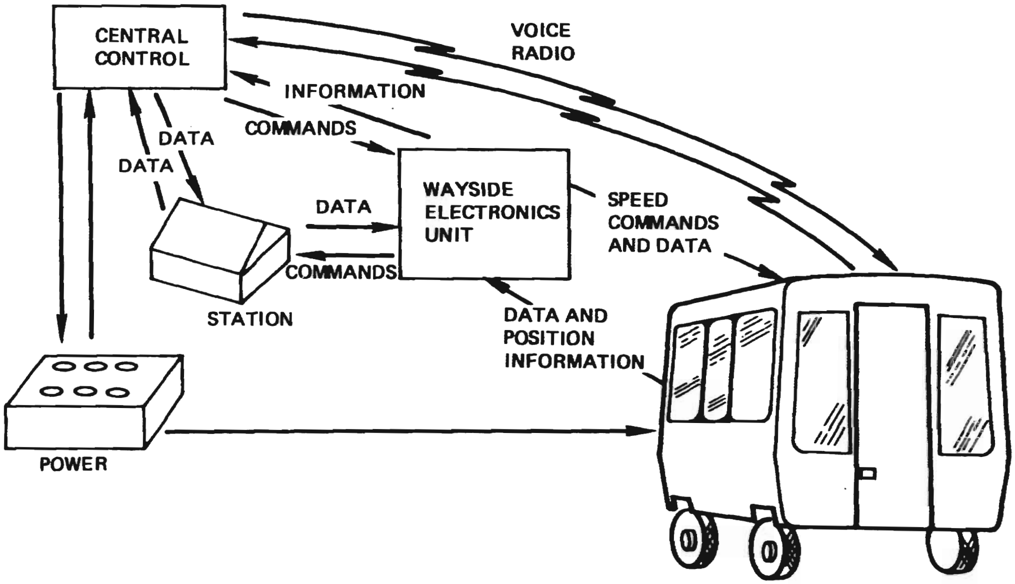

FIGURE 5–5 COMMUNICATIONS SCHEMATIC

or general basis to passengers in the stations and on the vehicles. Simultaneous private conversations may be carried on with maintenance personnel located in the stations or on the vehicles. A private automatic branch exchange telephone system permits direct dialing between extensions of the system. The maintenance radio system also provides communication capability between the system controller, maintenance building, guideway and non-guideway maintenance vehicles, and maintenance workers on foot.

The video communications system includes television cameras at each employee and passenger station which transmit to TV monitors at the Central Control Facility, providing surveillance of passenger boarding areas.

5.1.6 MANUAL VEHICLE CONTROL SYSTEM - The Manual Vehicle Control (MVC) system provides a means of bypassing the AVC system so that vehicles may be operated manually for positioning in maintenance guideways or on the mainline guideway subsequent to failures of onboard automatic control system functions. Manual control is obtained through the connection of a portable manual control box.

The MVC incorporates the switches, lights and variable resistors required to formulate or control the DC voltages needed to operate the vehicle under manual control. Specifically, the MVC supplies control functions of:

(1) Reset emergency or service brakes,

(2) Hold off service brakes,

(3) Apply emergency or service brakes,

(4) Apply enable control voltage to the motor controller,

(5) Apply a specific command to the motor controller, and/or

(6) Apply open/close commands to the vehicle doors.

5.2 SCOPE OF CONTROL SYSTEM AUTP

The specific Control and Communications efforts are described in detail in the following paragraphs of this section of the report and a summary listing of the major tasks for the Phase I AUTP are as follows:

(1) Vehicle Control Electronics (VCE) - Accomplish the hardware and software tasks to design, implement, test and demonstrate a multi-mode VCE unit to replace the AIRTRANS Vehicle Control Logic Assembly (CLA) and Automatic Vehicle Operations (AVO) unit, complete with Wayside Signal Analyzer reporting logic and multi-mode vehicle operation. The unit must be compatible with

Automatic Test Equipment. Multi-mode operation and test controls are provided by software and a Test and Control Panel which allows the test vehicle to be operated as a Utility, Employee or Passenger vehicle to aid in testing added functions are included on the panel such as a speedometer, a display of running route code, etc.

(2) Wayside Signal Analyzer (WSA) - Provide a wayside signal analyzer unit capable of measuring the various speed and communications frequencies present in the AIRTRANS guideway. Interface the data output to the VCE and provide on board display and test points. Make additions to the VCE software design requirements to provide WSA logic, and design and implement Central Control software for hard copy output of the WSA data.

(3) Vehicle Radio - Provide an improved vehicle radio for the AIRTRANS network and demonstrate remoted data exchange via the R.F. link.

(4) Vehicle Safety Equipment - Obtain a safety analysis of the Vought designed automatic vehicle safety electronics (VSE) for the AIRTRANS vehicle.

(5) Test and Demonstration - Perform all laboratory and guideway tests to verify the Command and Control hardware and software changes and improvements.

5.3 VEHICLE CONTROL ELECTRONICS (VCE)

A second generation prototype version of the Vehicle Control Electronics unit was designed, fabricated and exercised in the AUTP test vehicle. This unit incorporated features of the "baseline" VCE fabricated by Vought in 1976. The VCE contains the functions of the AIRTRANS CLA and AVO (see Figure 5-3). In addition, the AUTP hardware provides AIRTRANS operational capability for both lead passenger and utility vehicles complete with interface simulation. "Passenger" and "Employee" modes of operation are selectable on the test/control panel. The utility system hardware was removed from T-365 and simulated inputs and interfaces are provided by the Test/Control panel to simulate the functions such as container "locked" in position, etc. The CLA functions for the utility vehicle were provided in the VCE by simply adding the utility CLA program and providing the proper mode controls on the Test Panel. The VCE is a microprocessor based digital system utilizing a National Semiconductor IMP-16 chip. An objective of the VCE design was to develop a more flexible, cost effective control system that would meet present and future requirements for automatic ground transportation systems. Design features include:

(1) The capability to make system changes with minimum of redesign,

(2) Reduced complexity,

(3) Improved maintainability,

(4) Reduced size, and

(5) The ability to display and record vehicle data.

5.3.1 DESIGN APPROACH - The approach chosen for this development was the incorporation of all non-vital control functions (CLA, AVO, AAU) into a general purpose microprocessor based computer. All possible hardware was converted into software models to provide maximum flexibility and minimum cost.

The microprocessor chosen was the National Semiconductor IMP 16C/300. It provided a well documented 16 bit computer with support equipment available from National Semi-Conductor Corporation.

5.3.1.1 Baseline VCE Hardware - The baseline VCE hardware consists of the following basic units:

Processor - Imp 16C/300 Microprocessor

Memory - 3.5K PROM, 256 WORDS RAM, 512 X 1 Bit RAM,

Memory access delay circuitry

I/O Decoding - 16, 16 bit input ports
16, 16 bit output ports

Input Buffers - 76, 28 volts buffers
16-15 volt buffers
12-5 volt buffers

Output Buffers - 28, 28 volt buffers

A/D Conversion - 8 bits bipolar conversion for 8 analog inputs

D/A Conversion - Two 10 bit D/A converters

Velocity Counter - measures tach rate

Distance Counter - counts tach pulses

Delay Timer - .1 Hz rate

Discrepancy Counter - .1 Hz rate

Interrupt Controls - 4 interrupts and status word

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Front Panel - contains CLA functions including relay board with 21 relays, LED display for processor, 16 bit switch input to processor, initialization switch

Power supplies - +5, 10 amp
±15, 1.5 amp
±12, 1.5 amp

Cooling Fan - .1 amp, 110 volt

5.3.1.2 Baseline VCE Performance

Power

Total power consumption of the VCE and power supplies on the test bench was 3.5 amps at 28 volts.

Size

The size was approximately the same as the CLA. Weight was 23 lbs. and the external power supplies were approximately 7 lbs.

Cost

In the quantities of parts ordered, the total cost of the baseline VCE was $4600 including power supplies.

Processing Time

Average instruction time for the IMP is approximately 7.0 seconds. A better indication of capability using microprocessors, however, is the total time required to execute specifically implemented modules. These are:

AVO Program including I/O	10 ms
CLA Equations, command search, message and AAU program	10 ms
CLA I/O and WORD 1 Processing	7 ms

Interrupts and processor dedication are discussed in the software paragraphs.

5.3.2 VCE MODIFICATION REQUIREMENTS - For the AUTP special additions and modifications not required for a production system are summarized as follows:

(1) CLA only operation as well as combination CLA/AVO operation,

(2) Improved control law implementation,

(3) Semi-Automatic operation (manual speed control),

(4) Utility vehicle as well as passenger or employee vehicle operation, and

(5) Wayside analyzer logic processing and reporting.

The semi-automatic mode of control provides an on-board potentiometer for setting up a constant vehicle speed command. The vehicle will respond to either the pot setting or the wayside speed command whichever is lowest. This mode of operation is useful when an accurately controlled constant speed is desired such as when block signals are being mapped using the Wayside Analyzer. Since the vehicle speed is always equal to or lower than the commanded speed from the wayside there are no safety problems related to use of the Semi-Automatic mode of operation.

5.3.3 AUTP VCE HARDWARE - Modifications to enlarge the baseline VCE to AUTP specifications are shown in Table 5-1. Increased I/O and memory were necessary to provide the added functions of Paragraph 5.3.2.

5.3.4 AUTP VCE SOFTWARE - Vehicle Control Electronics (VCE) software for the AUTP is structured to perform the functions of automatic vehicle control and operation and control logic data manipulation and reporting in response to commands from the wayside and the Front Panel.

The automatic vehicle control and operation portion of this program is executed repeatedly, at an iteration period of approximately 16MS, until an interrupt in the form of a data communication is received from the wayside. When an interrupt occurs, program control is passed to an interrupt handler routine which analyzes the interrupt and passes control to the indicated control logic and data manipulation task. Upon completion of the task, the automatic vehicle control program is either resumed or restarted, depending on which interrupt task was executed.

The interrupt handler is the executive routine for VCE software and the automatic vehicle control program is a background task which is executed repeatedly between interrupts. Provisions are made in the software to permit the VCE to operate as a CLA only, or as a combined AVO/CLA.

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TABLE 5—1 HARDWARE MODIFICATIONS VCE (BASELINE TO AUTP UNITS)

BASELINE		AUTP
PACKAGE	IMP-16 Breadboard and Rack	Standard Augat wire wrap boards and rack. Modular functions. Input 1 - 56, 28 volt buffers Input 2 - 56, 28 volt buffers Input 3 - 56, 28 volt buffers Control - I/O Decoding, velocity circuit, interrupts, GRS interface, distance, time delays Memory 1 - 4K Memory Memory 2 - 4K Memory Output 1 - Output Registers Output 2 - Output Drivers D/A, A/D - Analog Interface
PROCESSOR	IMP 16C/300	Same
MEMORY	4K	8K to accommodate added functions
INPUT BUFFERS	MCL 600 Optic Isolator	MCL 600 discontinued. MCL 601 used. Filter resistor changed to lower part count and increase filtering
OUTPUT DRIVERS	28 volt driver, optic isolation, current limiting	Design changed to provide current limiting and short circuit protection for limited period.
PROCESSOR I/O BUS LINES	DM8097 Input Bus DM7475 Output Registers	DM 80L97 lower power tristate DM 74L575 lower power Schottky registers, and change memory and registers
INCREASED I/O PORTS	16, 16 Bit Input 16,16 bit output	I/O decoding increased to 24, 16 bit input 24, 16 bit output
CONTROL PANEL PROCESSOR	16 input data switches 16 Led's display	Imp control card added to provide full control for single step, halt, display memory and registers, and change memory and registers
VCE PANEL	CLA front panel lead	Combined lead and utility and simulation test panel (remote located from VCE) Includes semi-automatic mode, running route Combined AVO/CLA or CLA only operation, simulation, PSC and Berth indications, route and vehicle ID. Select switches. The VCE front panel space is utilized as a programmer's general purpose computer control panel.
POWER SUPPLY	5,10 amp 15, + 1.5 amp -12, 2 amp	15 volt separate outputs for + and - -12 volt increased to 4 amp
FAN	110 AC	28DC

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5.3.4.1 Automatic Vehicle Control and Operations - The AVO portion of the program performs five primary tasks. These are:

(1) Input and scaling of vehicle parameters,

(2) Computation of current limits, grade, DV/DT and stopping profiles,

(3) Analysis of wayside commands to determine cruising or stopping modes,

(4) Implementation of control laws to determine motor current, brake and power contactor commands, and

(5) Output of motor current, brake and power contactor commands and output of an analog velocity report to the velocity meter.

Table 5-2 describes some important parameters and terms either measured or computed by the program.

Provisions are made in the software for altering certain parameters by entering values via the VCE front panel. These parameters include the stopping profile count, the airbag pressure and the current rate term (IDOT). The grade portion of the low current limit term may be suppressed by entering the appropriate flags via the VCE front panel. The speed command analysis portion of the program consists of analyzing the wayside speed command tones, F1, F2, F3 and F4, and the remotely commanded speed modifier bits, W36 and W37, to determine the commanded cruising or stopping commands. The table below shows cruise or stop modes versus wayside commands.

Wayside CMD Configuration	Cruise or Stop Mode
F1.F2.F3	H/H (High Limit/High Command)
F1.F2	H/M (High Limit/Medium Command)
F2.F3	M/L (Medium Limit/Low Command)
F1.F4	L/S (Low Limit/Short Profile Stop)
F2.F4	M/P (Medium Limit/Normal Profile Stop)

The control law implementation portion of the program examines velocity, velocity error, VDOT, (derived acceleration) and measured acceleration to determine motor current and braking commands. During cruise modes, there are three different control laws, the selection of which depends on velocity error magnitude. These are:

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TABLE 5–2 GLOSSARY OF TERMS USED IN AVO PROGRAM.

TERM	DESCRIPTION/USE
C93	Manual Speed Command from Front Panel Control $X.XX_1$ FPS
F	Brake pressure feedback 1 PSI/BIT
L	Line Voltage input 18 BITS/VOLT
R27	Used in control law implementation for brake precharge limits. NEG = F <3PSI POS = F >3PSI
LFLG	CLA only flag. Set true when cond. code 15 - 1. Used in AVO & CLA software to signify CLA only
WTFLAG	Flag set by CLA program to indicate that a door opening/closing sequence has occurred. Permits one measurement of airbag pressure and one solution set of terms dependent on airbag pressure between door closing sequences
T	Airbag pressure term $= 111_{10}$ count crush weight $= 52_{10}$ count empty weight
X	An intermediate term which is a function of vehicle weight $X = 2.9375 + 1.109T$ $X = 169_{10}$ crush weight $X = 104_{10}$ empty weight
IDOT	A constant used in computing the rate of change of the current command. It is located in low address RAM so that its value may be altered for test purposes during operation
R15	The value by which the motor current command is incremented or decremented. It is scaled @ 0.1284 AMPS/BIT. R15 = (X) (IDOT). This should provide current command rates of approximately 100 AMPS/SEC empty and 160 AMPS/SEC Crush
SHONT	A constant, located in low address RAM, used in computing the short profile used in computing the short profile count. Its nominal value is 535_{10}, but the value may be changed by hand load for test purposes.
SPC	The short profile count computed as a function of vehicle weight. SPC = 0.8(X) + SHONT. SPC = 618_{10} empty, 670_{10} crush
MEDCNT	A constant, located in low address ram, used in computating the medium profile count. The nominal value is 1126_{10}, but the value may be changed by hand load for test purposes.
MPC	The medium profile count computed as a function of vehicle weight. MPC = (2) (X) + MEDCNT MPC = 1334_{10} empty MPC = 1464_{10} Crush
ULI	The upper limit of the motor current command. It has two parts, (1) as a function of weight and (2) as a combined function of velocity and line voltage. It is scaled @ 0.1284 AMPS/BIT

p

TABLE 5—2 GLOSSARY OF TERMS USED IN AVO PROGRAM (cont'd)

TERM	DESCRIPTION/USE
LLI	The lower limit of the motor current command as a function of vehicle weight and the slope (grade) of the guideway. It is scaled @ 1.1284 AMPS/BIT
MSS	A factor in the grade modifier for the low motor current limiter MSS = (604) (X) 1256
R22INT	The grade modifier for the low current limit R22INT - (MSS) (GRADE) It is scaled @ 0.1284 AMPS/BIT
VEL	Measured velocity in FPS It is scaled A $X.XX_{16}$ FPS
VE	Velocity Error, X.XX FPS
A	Measured vehicle acceleration in FPS^2. It is scaled @ $X.X_{16}$ FPS^2
VEABS	Velocity Error Absolute Value, $X.X_{16}$ FPS
VDOT	Computed DV/DT in FPS^2 Scaled @ $X.X_{16}$ FPS^2
GRADE	Computed Guideway slope in FPS^2. Grade = A-VDOT. Scaled @ $X.X_{16}$ FPS^2
R18	The motor current command Scaled @ 0.1284 AMPS/BIT
AB	Apply brake command
RB	Release Brake command. Logic for AB/RB command is: AB RB BRAKE ACTION 0 0 Apply brakes 1 0 Hold brake pressure 1 1 Release Brakes
PC	Power contactor start command

1. When (VE) is greater than 2.82 FPS motor current and brakes are commanded such that VE is driven toward zero while acceleration and VDOT are maintained at or below an absolute value of 4.5 FPS^2,

2. When 0.25 < VEABS < 2.82 motor current and brakes are commanded such that the velocity error is driven toward VDOT**2/5, and

3. When VEABS < .25 the brakes are not commanded and the motor current is commanded to drive the velocity error toward zero.

Figure 5-6 shows the general control law logic.

During stopping sequences, the velocity is commanded to 5FPS until the profile is intersected. By definition, intersection occurs when the distance to go is 330 tachometer counts remaining (D). Following profile intersection, the velocity command is computed as a function of the remaining distance (VC = 0.016D). When the velocity command has been computed, the VDOT**2/5 control law is executed. When the distance has decreased to a count of 32, control law execution is discontinued, the current command is held at minimum (including the grade modifier) and full brakes are applied. Two hundred and fifty milliseconds following application of brakes, the grade modifier is removed from the low current limit and 50 MS later (300 MS after full brake application) the power contactor is dropped. Figure 5-7 shows the stopping logic.

During control law implementation, brakes and current are never applied simultaneously except when the VE≤2.82 FPS or during stopping sequence. During these cases, the brakes are precharged and held at approximately 3 PSI to permit rapid, linear application of braking forces when required.

The output sequence contains logic which prevents closing of the power contactor and release of brakes until a valid speed command is received. It also contains logic which maintains the command current at the minimum value (grade modifier supressed) until one cycle after the power contactor has closed on start-up sequences.

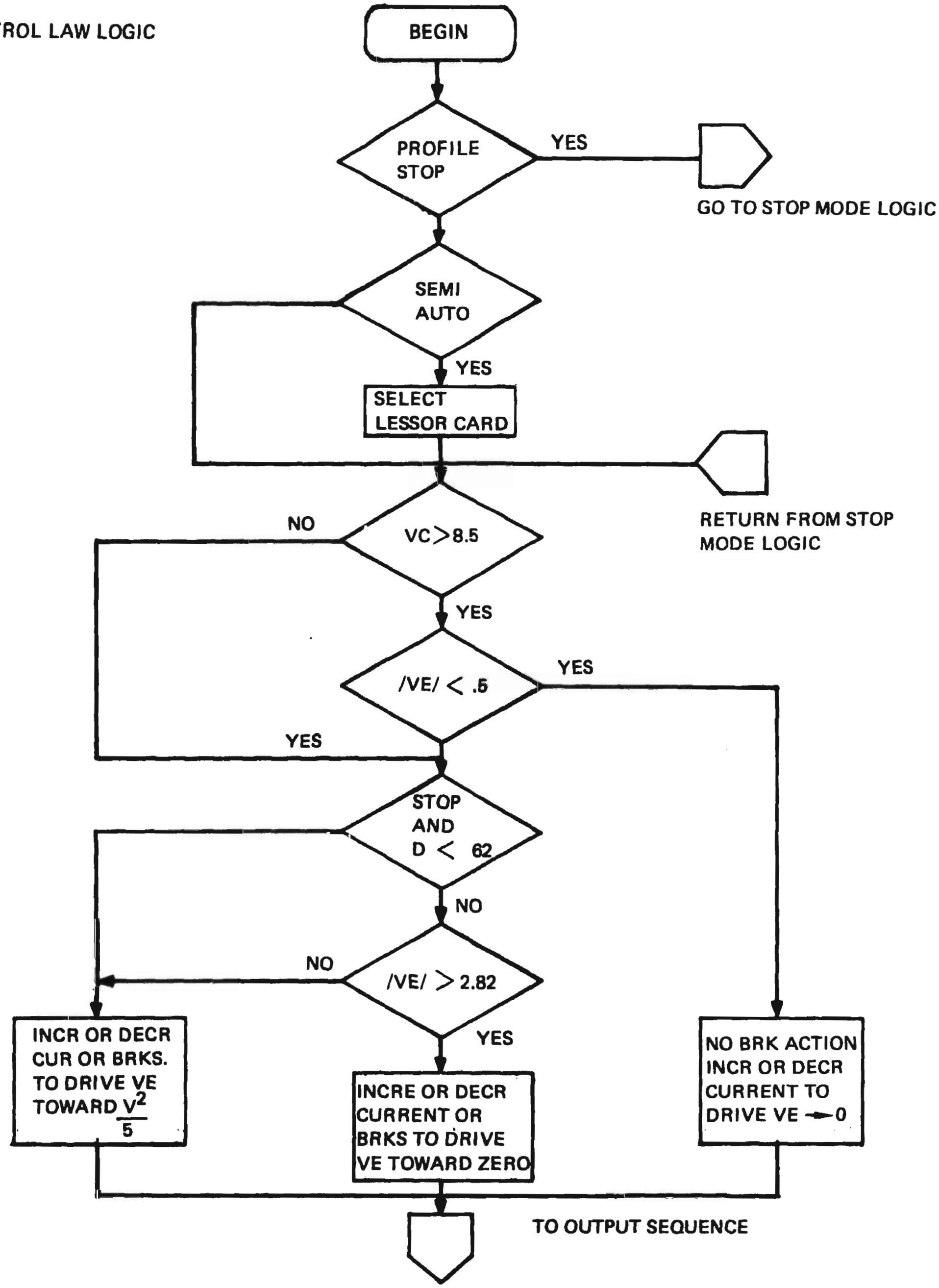

FIGURE 5–6 CONTROL LAW LOGIC

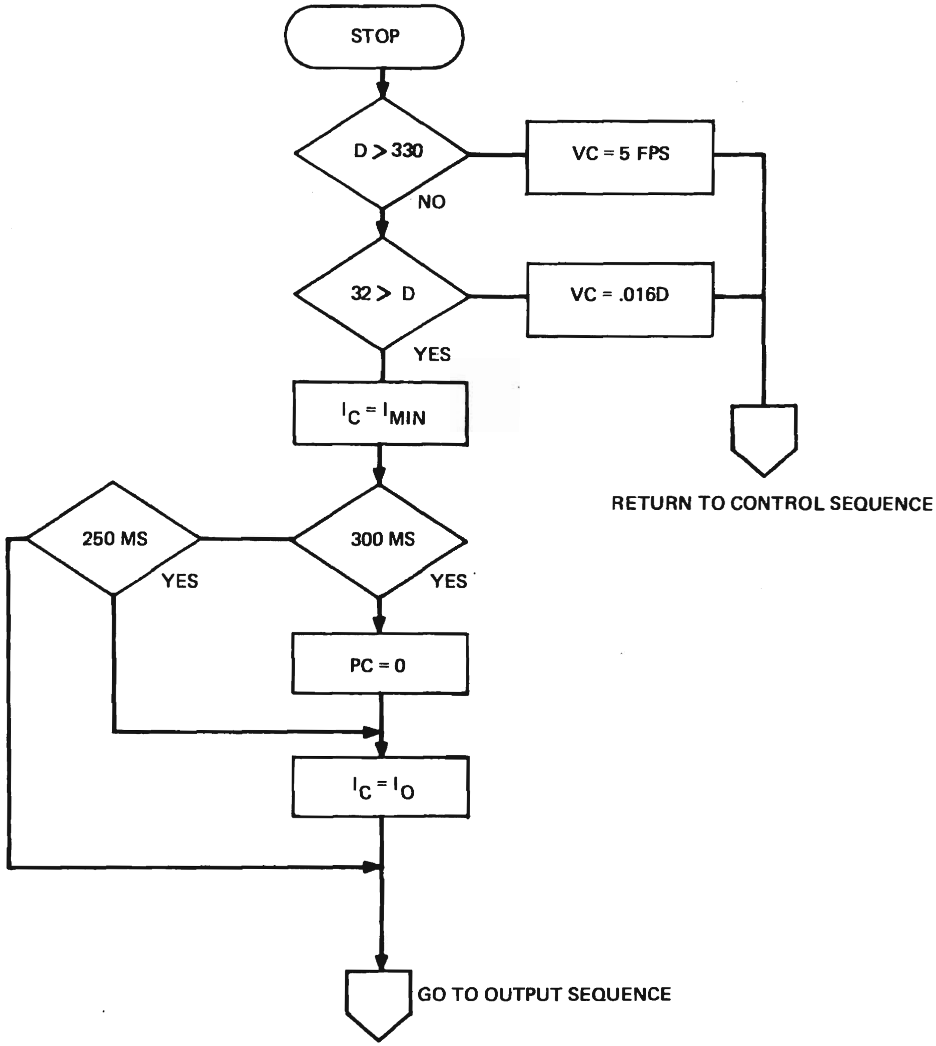

FIGURE 5—7 STOPPING LOGIC—SIMPLIFIED FLOW

5.3.4.2 Control Logic and Data Manipulation - The CLA portion of the program performs tasks in response to interrupt analysis. The start-up, synchronization and interrupt handler routines are considered to be part of the CLA portion of the program. The tasks performed by this portion of the program include start-up initialization, interrupt processing, input of vehicle discretes (logic and status signals), analysis of wayside commands, solution of a boolean equation set and format and output of reports to the wayside.

Upon power-up or VCE front panel initialization, the START routine sets base page RAM and one bit RAM locations to zero, transfers certain essential constants from PROM to base page RAM for direct access, inputs the route code from the thumbwheels, establishes initial status for certain logic functions and sets the interrupt address to the SYNC routine and returns control to the start of the automatic vehicle operation program.

When the next interrupt occurs, the SYNC routine is called. This routine performs the first interrupt analysis, outputs the first word and sets the interrupt address to the interrupt (INTRT) routine, sets a flag to indicate that an interrupt has been received following initialization and returns control to the AVO program at the point where it was interrupted. The purpose of the SYNC routine is to establish synchronization with the wayside communication cycle following initialization. Thereafter, the normal interrupt routine INTRT is used for interrupt processing. The interrupt processing routines acts as the executive for the entire VCE software system. When an interrupt is received, execution of the AVO program ceases and the interrupt routine tests the interrupt word to determine which interrupt is present. Four system interrupts are possible, and the sequence in which they are tested is: F4 interrupt, Read Lin Interrupt, Message Valid interrupt and Transmit Second Word Interrupt. The presence of the F4 interrupt signifies that the F4 (stopping) speed tone is present on the signal rails. The remaining interrupts are synchronous with the wayside communications cycle and signify that certain events should occur in the VCE software. If the interrupt is not one of the four system interrupts, i.e., a processor stack full interrupt, or programmer panel interrupt, no action is taken and control returns to the automatic vehicle operation program at the point of interruption. When an F4 interrupt is present, the interrupt processor sets a flag (LOFF) and resets and enables the distance to go counters which are used by the automatic vehicle control and operation program in the stopping sequence. Control is then returned to the AVO program at the point of interruption.

Two read line interrupts occur during a communication cycle. The read line interrupt in conjunction with a flag (Fl WORD) signify which action is to take place. In response to the 1st readline interrupt (Fl WORD = 1) the routine will refresh constants in base page RAM, output the 1st word to the wayside, input vehicle discrete logic and status data and return program control to the beginning of the AVO program. The 2nd read line interrupt (F1 WORD = 0) causes the flag to toggle and control is returned to the AVO program at the point of interruption. Upon detecting a message valid interrupt, the MESVINT sequence is called. This sequence inputs the command word from the wayside and compares the addressed vehicle ID with the on board vehicle ID. If the ID's don't match, control is returned to the beginning of the automatic vehicle control and operation program. If the ID's match, the command word is analyzed to determine what the command from the wayside is, the boolean equation set is solved, the reply word is formatted, and output, and control is returned to the beginning of the AVO program.

When a transmit 2nd word interrupt is detected, the XMITINT sequence is called and a signal is output which signifies to the wayside that a reply message has been output from the VCE and is not ready for transmission. Control is then returned to the AVO program at the point of interruption. The boolean equation set is structured as a subroutine which is called from the MESVINT sequence and from the automatic vehicle operation program when communicaitons are lost for more than 450 MS. Either of two boolean equation sets may be solved - one for lead passenger vehicle logic and one for utility vehicle logic. Selection is determined by the front panel vehicle mode switch which sets a condition code. Upon entry into the boolean equation routine, the condition code is tested and the desired equation set solved. Time delays in the boolean equation set are accomplished by a time delay subroutine which utilizes a free running counter, a table of time delay values and a corresponding table of elapsed time buffers which are updated and tested by the time delay routine.

Wayside Analyzer logic equations are solved each time data is input during the readline interrupt sequence to assure a fresh solution set each time it is requested.

The output word formatting sequence, called when a message valid interrupt is detected, is structured to accommodate lead passenger output format or utility vehicle output format as determined by tests of the appropriate flags. The sensor A and C output formats are modified upon request to accommodate the wayside analyzer report.

5.3.4.3 VCE Software Development - Vehicle Control Electronics Systems was developed in the laboratory using an IMP-16 micro computer with standard support software and peripherals to assemble and debug the program. Vehicle and Wayside functions were simulated in the Test Set. A photograph of the laboratory test set up including the test set are shown in Figure 5-8. An interface cable permitted use of the IMP-16P processor and RAM memory to exercise VCE software. Performance of the software was measured by indications on the simulator hardware and by real time recording of vehicle control commands and responses, using IMP-16 micro-computer. Data was recorded in real time and

FIGURE 5–8 VCE EMULATOR AND TEST SET

printed subsequent to the real time test to permit performance evaluaion. Support software obtained from National Semiconductor, Inc. and modified by Vought was used to assemble, edit, and load VCE source programs. In addition to an assembler resident on the IMP-16P, a cross assembler, written in Fortran, was installed on Vought's CDC 6600 system. The cross assembler permits the assembly of larger program segments than the resident assembler will accommodate. Portions of the VCE program were assembled on the cross assembler. Software for the dynamic data recorder was developed by Vought.

5.3.5 TEST/CONTROL PANEL - The front panel functions of the CLA plus additional AUTP unique functions were implemented in a separate unit from the VCE. This method was chosen to permit use of a general purpose computer control panel on the VCE to provide good location access for the AUTP test vehicle operator; to provide multi-mode vehicle operation selection capability; to provide a semi-automatic speed control mode; to provide VCE and Wayside Signal Analyzer interface; and to provide various vehicle simulation functions.

The front panel requirements for the AUTP test vehicle were unique in that the vehicle was to be operated selectively in all AIRTRANS vehicle modes of passenger or employee lead as well as the utility configuration. The standard CLA front panel was modified to add the functions of vehicle mode selection entailing signal collector configuration switching, and accommodation of vehicle steering and drive wheel anomalies compared to the standard vehicle types and modes. Function expansion included an indicating speedometer, running route display, vehicle station docking display functions of berthed and position sequence complete, and a selectable semi-automatic mode which the vehicle speed control loop uses if that command is less than the normal speed commands.

The panel functions also include vehicle lighting control, vertical alignment manual control, CLA only or CLA and AVO combination operation selection, and the various door, passenger action and container bay simulation switching. The front panel is functional only with the VCE unit in place. A temporary light control panel is utilized when the AIRTRANS CLA and "GRS" AVO are operated in lieu of the VCE. The front panel is shown in Figure 5-9.

5.3.6 VCE LABORATORY TESTING - In order to bench test the AUTP VCE hardware and debug the software, test panels used on the baseline VCE verification were enlarged for the AUTP added functions. The final laboratory test system consisted of the following units.

(1) Vehicle Dynamics Simulator

Analog feedback circuits which simulate vehicle dynamics for velocity, acceleration, drag, weight, motor current, and braking action.

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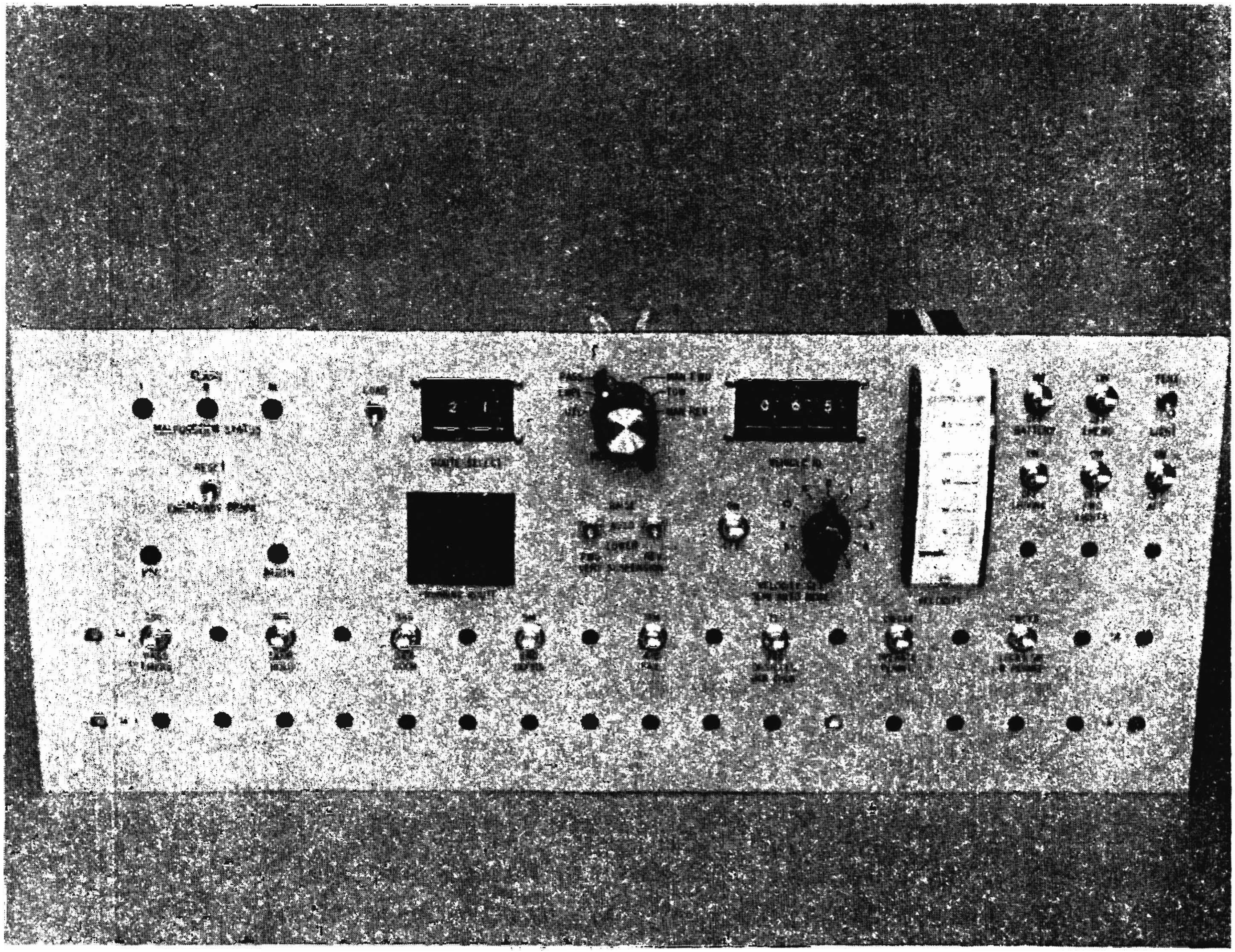

FIGURE 5–9 FRONT PANEL

(2) CLA Discrete Inputs and Outputs

Toggle switches which provide CLA discrete inputs. Outputs are indicated by incandescent lamps.

(3) CLA Wayside Communications Data

Simulates communications between VCE and wayside. Displays data word from VCE and inputs command word to VCE.

(4) Wayside Analyzer Discretes

Toggle switches to simulate wayside analyzer inputs.

To debug software in a real time simulator, an emulator interface between the VCE and the Laboratory IMP-16 development system was designed. This is shown in Figure 5-10.

This feature enabled the programmer to use the IMP-16 development system to interface with the VCE. The development system includes a programmer control panel, RAM memory and control, peripheral control, card reader, paper tape reader, paper tape punch and line printer.

5.4 WAYSIDE SIGNAL ANALYZER (WSA)

5.4.1 WSA FUNCTIONAL REQUIREMENTS - The Wayside Signal Analyzer (WSA) is a test unit designed to provide a means of quantitatively and qualitatively measuring the three functional areas of wayside signals consisting of speed command frequencies, communications carrier frequencies and direct current track voltage as received on board the vehicle. A feature of this unit is that it interfaces measurements to the VCE for remote reporting to AIRTRANS Central SDS as well as on board monitoring. The WSA is ultimately intended as a maintenance instrument for wayside signal trouble shooting and problem anticipation. Special VCE and Central SDS software programs were written and implemented to provide hard copy outputs of signal samples with control signal block resolution. During the testing the WSA signal threshold settings were adjusted to the AIRTRANS design values as shown in Table 5-3 below.

TABLE 5–3 WAYSIDE ANALYZER THRESHOLD SETTINGS

SIGNAL	LEVEL 1	LEVEL 2	LEVEL 3
F1	50 mv	250 mv	500 mv
F2	50 mv	250 mv	500 mv
F3	250 mv	500 mv	900 mv
F4	250 mv	500 mv	900 mv
WVC	50 mv	100 mv	250 mv
VWC	5000 mv	12000 mv	15000 mv
DC	2 vdc	5 vdc	10 vdc

(2) CLA Discrete Inputs and Outputs

Toggle switches which provide CLA discrete inputs. Outputs are indicated by incandescent lamps.

(3) CLA Wayside Communications Data

Simulates communications between VCE and wayside. Displays data word from VCE and inputs command word to VCE.

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F4	250 mv	500 mv	900 mv
WVC	50 mv	100 mv	250 mv
VWC	5000 mv	12000 mv	15000 mv
DC	2 vdc	5 vdc	10 vdc

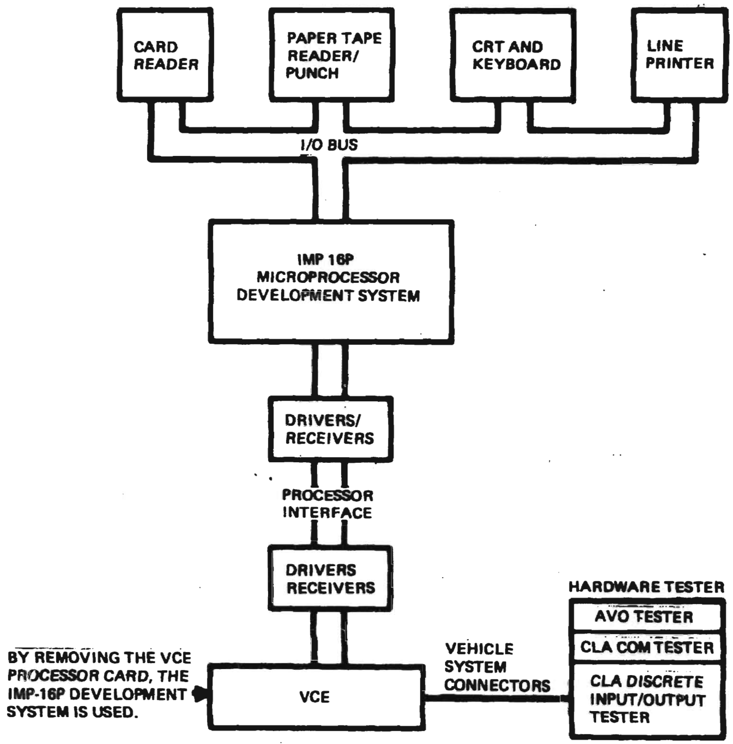


FIGURE 5—10 VCE EMULATOR BLOCK DIAGRAM

The Wayside Analyzer can be used in the totally automatic mode or in a semi-automatic mode. In the automatic mode, the Wayside Analyzer monitors signals in the above three functional categories and relates this information to Central Control via the VCE logic and data communication link. Central Control utilizes its normal tracking software, along with additional wayside analyzer processing, prints out resultant informaion on a block by block data set. This yields a hard copy map of the guideway signal quality. Analysis of this data will isolate trouble spots which may then be examined with the WSA on board using its visual test indicators and manual select switches to obtain a detailed data set of a specific area of guideway conditions. In addition to the switches and indicators, a set of test points and jacks are easily accessible for interfacing signals to standard instrumentation and recording devices such as the visicorder, spectrum analyzer and scope. The WSA front panel is shown in Figure 5-11.

5.4.2 WSA FUNCITONAL DESCRIPTION - All data for analysis is derived from the signal rails via the AUTP test vehicle signal brushes. The WSA resolves the various signals available at the vehicle collectors into component frequencies and for each signal provides three discrete levels of detection for display and output. The WSA functional schematic diagram is shown on Figure 5-12.

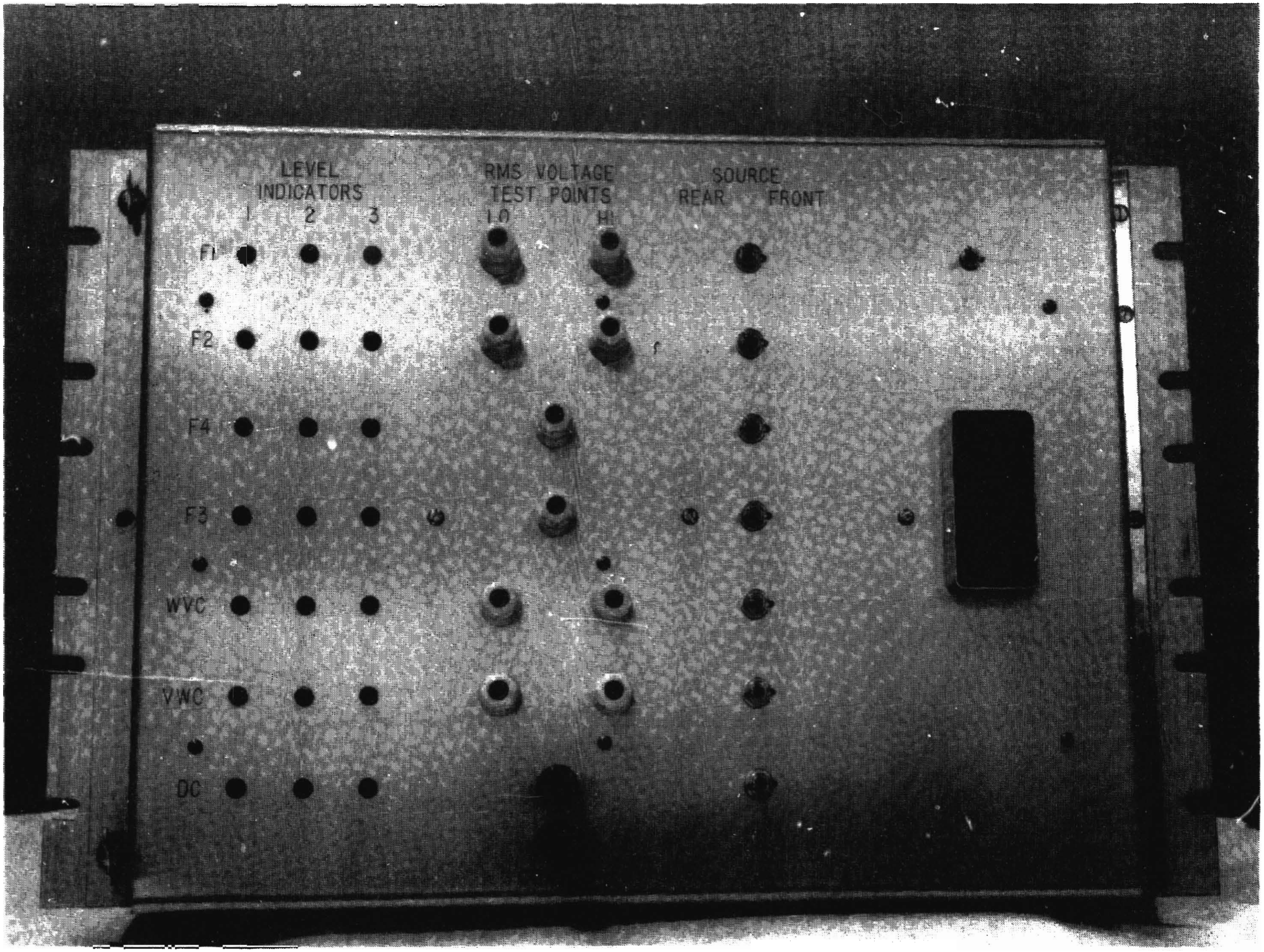


FIGURE 5–11 WAYSIDE SIGNAL ANALYZER

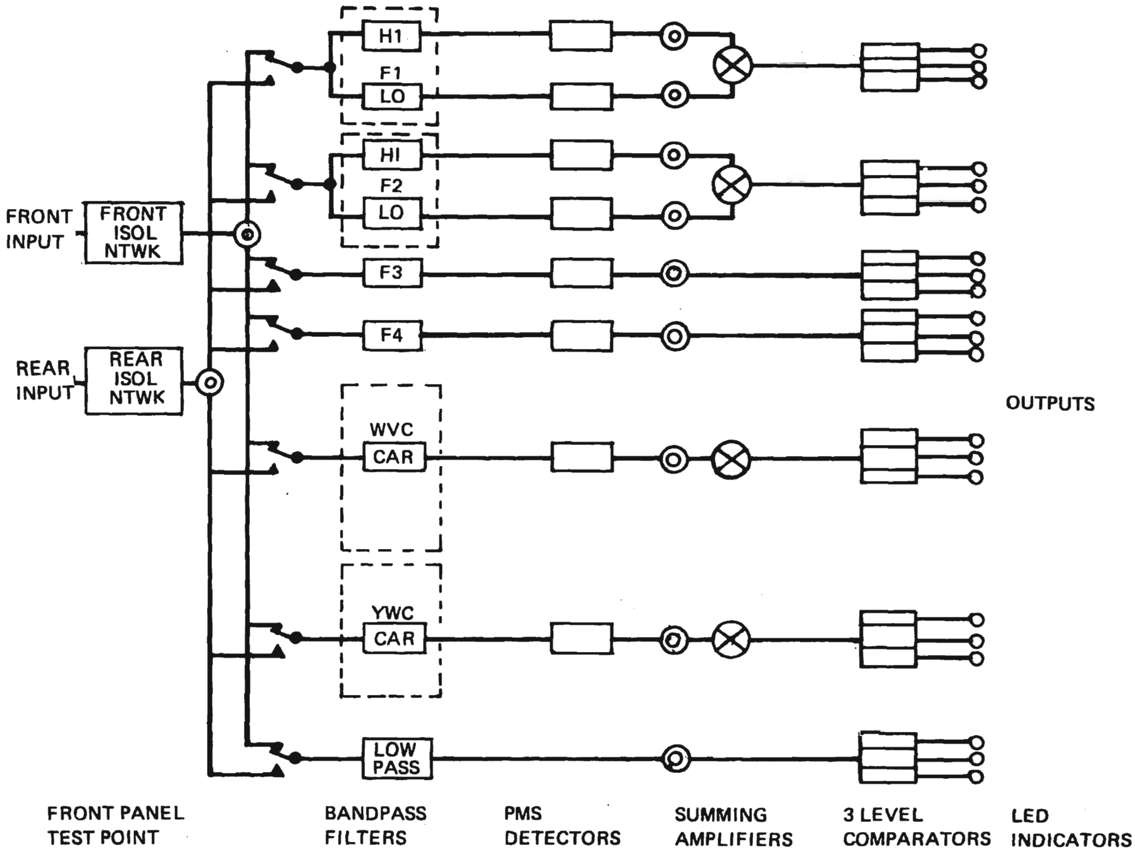


FIGURE 5–12 WAYSIDE SIGNAL ANALYZER FUNCTIONAL SCHEMATIC

In the speed command signal level verification, "crosstalk" between blocks and signal quality within blocks (i.e., signal level variation or "drop-outs") can be monitored.

In the DC track circuit level verification, marginal DC track voltages may be detected. In addition, the DC voltages at the collectors are used as control signals within the Wayside Analyzer as decision points in signal and crosstalk detection sampling for remote communicaitons.

In the Wayside to Vehicle Communications (WVC) signal level verification, communication's carrier power levels available at the rails are level evaluated for detecting marginal conditions.

The WSA uses bandpass filters to separate the wayside signal frequencies of Fl (11,867 - 10,953 Hz, High/Low), F2 (9,468 to 8,740 Hz, High/Low), F3 (4,695 Hz), F4 (5,780 Hz), the FSK modulated carrier frequencies of the WVC (13,800 Hz) and Vehicle to Wayside communications (VWC) (20,900 Hz) and the signal rail

DC voltage. The WSA bandpass filter characteristics are listed in Table 5-4. The two vital frequencies, F1 and F2, are low frequencies which provide the vital protection encoding in speed limit decoding. The upper and lower frequencies of the F1 and F2 vital tones are differenced and inputted to the high signal comparator. For the other signals, the filtered frequencies are each fed into three adjustable comparators for low, mid and high level discrete output detection. These discrete levels are available at the WSA interface and are sampled logically by the VCE for

TABLE 5—4 BANDPASS FILTER CHARACTERISTICS

F1-HI	Center Frequency - 11,867 Hz Plus/Minus 1 Percent-Adjustable Filter Q - 50 Plus/Minus 5 Percent Filter Gain Equal or Less 40 DB
F1-LO	Center Frequency - 10,953 Hz Plus/Minus 1 Percent-Adjustable Filter Q - 50 Plus/Minus 5 Percent Filter Gain Equal or Less 40 DB
F2-HI	Center Frequency - 9468 Hz Plus/Minus 1 Percent-Adjustable Filter Q - 45 Plus/Minus 5 Percent Filter Gain Equal or Less 40 DB
F2-LO	Center Frequency - 8740 Hz Plus/Minus 1 Percent-Adjustable Filter Q - 45 Plus/Minus 5 Percent Filter Gain Equal or Less 40 DB
F4	Center Frequency - 5780 Plus/Minus 1 Percent-Adjustable Filter Q - 50 Plus/Minus 5 Percent Filter Gain Equal or Less 40 DB
F3	Center Frequency - 4695 Plus/Minus 1 Percent-Adjustable Filter Q - 50 Plus/Minus 5 Percent Filter Gain Equal or Less 40 DB
WVC	Will be Built With Two Stagger - Tuned Filters Centered at The Two Side-Band Frequencies, 13250 and 14350, With a Tolerance of Plus/Minus 1 Percent and Each Individually Adjustable. Each of the Filter Q's Will be 50 Plus/Minus 5 Percent With Filter Gains In Excess of 40 DB.
VWC	Will be Built With Two Stagger - Tuned Filters Centered at the Two Sideband Frequencies, 19850 Hz and 21950 Hz, With a Tolerance of Plus/Minus 1 Percent and Each Individually Adjustable. Each of the Filter Q's Will be 50 Plus/Minus 5 Percent With Filter Gains In Excess of 40 DB.

transmitting to the Central SDS system. The WSA threshold settings are given in Table 5-3.

5.4.3 WSA SOFTWARE DESIGN - The WSA software is designed in two parts: the VCE logic and the Central SDS processors. The VCE software utilizes the WSA discrete output interfaces and sampling logic to compact the data for remote data transmission to Central. The Central SDS processors are designed to request, assimilate, and output the WSA data transmissions. When sampling for remote data, the WSA is switched to monitor the DC level present on either forward or aft signal collector to monitor the speed tone frequencies on the rear signal collector and both communication frequencies on the forward signal brush pair. This configuration permits use of the DC level to determine block boundary transitions and when the signal collectors (fore and aft) are in different blocks. The DC level is measurably altered by the loading of front and rear collector vehicle circuitry. The VCE software samples the WSA discretes for crosstalk when the rear signal collector is isolated in the aft block - which should have no signals.

Crosstalk is defined as presence of any guideway signals in the control block immediately aft of any "occupied" signal control block. The VCE samples the signal quality of a control block a short time after both signal collectors occupy that block - as decided by the DC signal level. Communication frequency levels (WVC and VWC) are sampled by the VCE while the signal collectors are in the same block. The VCE logic solutions formatted for remoting to Central contain two bit codes for signal quality, two bit codes for crosstalk, and single bit code for the communications sample. The data format utilized for remoting the WSA data is a modification of existing Sensor A and Sensor C words in the AIRTRANS vehicle/SDS communications format. The change of data content is accomplished in the VCE logic by the use of spare bits in the previous Sensor A and Sensor C data words. The WSA processing specifics. data formatting and data output sample are shown in Figures 5-13, 5-14, and 5-15.

- REAR BRUSH MONITORING OF LOW, MID AND HIGH SPEED TONE LEVELS.
- FRONT BRUSH MONITORING OF MID AND HIGH D.C. VOLTAGE LEVELS.
- FRONT BRUSH MONITORING OF COMMUNICATIONS CARRIERS LEVELS.

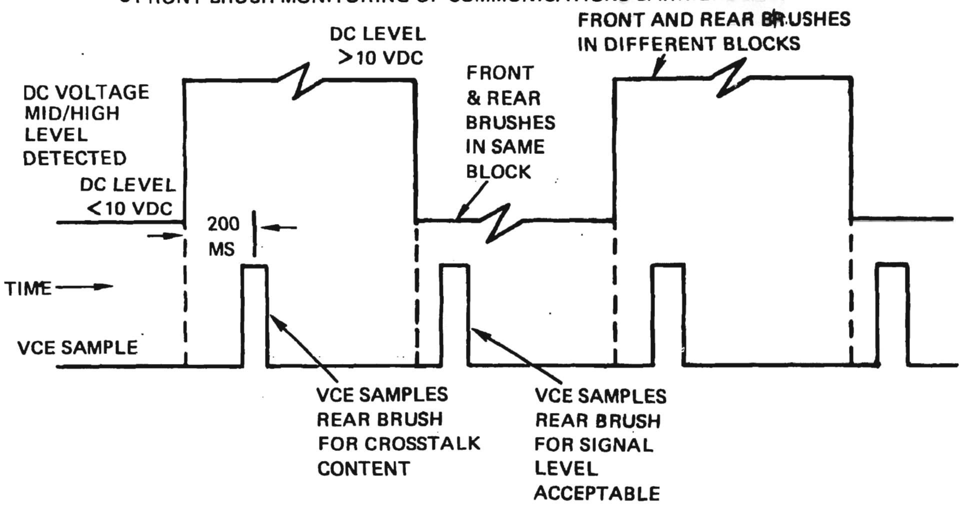
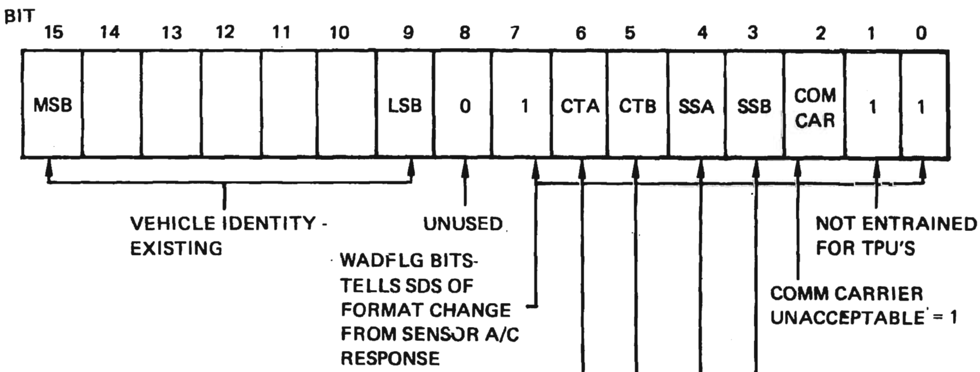


FIGURE 5—13 WAYSIDE ANALYZER PROCESSING SPECIFICS

SUBSTITUTED SENSOR A OR SENSOR C RESPONSE FORMAT

IF WAYSIDE ANALYZER IS ACTIVE - ON



CTA	CTB	CROSSTALK
1	1	NO SAMPLE
0	0	NO CROSSTALK
0	1	CROSSTALK DETECTED
1	0	INVALID STATE

SSA	SSB	SIGNAL LEVEL
1	1	NO SAMPLE
0	0	GOOD
0	1	LOW
1	0	HIGH

FIGURE 5—14 WAYSIDE ANALYZER DATA FORMATTING

PAGE 19 STARTING TIME 3:42 FOR TRAIN 365

BLOCK	SIG	CTLK	COM	TIME
1ECL05	H	P	P	2562
1ECL06	H	P	P	2574
1ECL07	H	P	P	2586
1ECL08	H	P	P	2593
1ECL09	H	P	P	2601
1ECL10	H	P	P	2608
1ECL11	H	P	P	2616
1ECL12	H	P	P	2624
1ECL13	H	F	P	2631
1ECL14	H	P	P	2639
1WNP01	H	P	P	2647
1WNP02	H	P	P	2655
1WNP02	H	P	P	2655
1WNP03	H	P	P	2659
1WNP04	H	P	P	2663
1WNP05	P	P	P	2667
1WNP06	P	P	F	2670
1WNP07	H	P	P	2674
1WCP01	H	P	F	2677
1WCP02	?	F	F	2707
1WCP03	?	F	P	2712
1WCP04	H	P	P	2715
1WCP05	H	P	P	2719

PAGE 20 STARTING TIME 3:45 FOR TRAIN 365

BLOCK	SIG	CTLK	COM	TIME
1WCP06	H	P	P	2722
1WCP09	P	P	P	2731
1WCP09	?	P	P	2726
1WCP10	H	P	P	2735
1WCP11	H	P	P	2739
1WCP12	H	P	P	2743
1WCP12	H	P	P	2743
1WCP13	H	P	F	2746
1WCP13	?	P	P	2750
1WCP15	P	F	P	2755
1WCP16	?	P	P	2757
1WCP16	H	P	F	2760
1WSP01	H	P	F	2764
1WSP02	L	P	F	2793
1WSP03	H	P	F	2801
1WSP04	H	P	P	2805
1WSP05	?	P	P	2810
1WSP06	H	P	P	2818
1WSP07	H	P	P	2825
1WSL01	H	F	P	2833
1WSL01	H	F	P	2833
1WSL02	H	P	P	2839
1WSL03	?	P	P	2847

SIG	=	Speed Command Signals
CTLK	=	Aft Block Crosstalk
COM	=	Communications Signals
TIME	=	Seconds into Current Hour
H	=	High
L	=	Low
P	=	Pass/Accept
?	=	No Sample This Block
Block	=	Guideway Control Block

FIGURE 5—15 SDS WAYSIDE ANALYZER DATA OUTPUT SAMPLE

5.5 RADIO

The radio system demonstration portion of the AUTP was accomplished by Motorola Corporation supported by Vought. Deliverable items under the contract were a Micor 2-way radio and power supply. The Radio Frequency (RF) data communication demonstration utilized a Motorola Metrocom radio control head and a central base station installed in the AIRTRANS 6W Maintenance Facility.

The Motorola Transit RF Data System is a flexible, expandable concept. It provides both voice and data communication for use on all types of transit vehicles.

Basic system features include two-way voice communication, data communications, selective calling, alarm reporting and the ability for extended monitoring to include features to be added at a later date. The channel capacity of the system is inadequate to handle the AIRTRANS data requirements but systems with fewer vehicles could be accommodated. The original AIRTRANS design proposed on RF data system requiring a continuous transmission of information in the voice spectrum around 450 mHz. Such a system could not be licensed. The Motorola Metrocom technique causes little or no disturbance to voice communications in the same channel. This type of system can be licensed. As indicated above however the capacity of such a system must be measured against the data rates required of the transportation system. The RF data system would have application at AIRTRANS to provide a backup mode of operation whenever the hardwired system has malfunctions. The only constraint being the amount of information to be handled by the system during the malfunction. The Motorola System uses a four digit address for each vehicle up to 10,000 vehicles. The basic alarm capability is eight with a capacity for expansion to additional functions. The data scheme is FSK at 500 bits per second, return to 0. Data error checking is accomplished using double frame bit by bit comparison. The basic vehicle identification is accomplished in 0.064 seconds, an alarm in 0.218 seconds repeating continuously in cyclical fashion, 2 seconds on, 8 seconds off, and the basic select call made to a vehicle requires 0.080 seconds.

The system is all solid-state employing modular design. The base or central control data logic is identical to that used in the vehicle and provides for real time operation. The demonstration of this system was effected from the AUTP test vehicle (in motion) while monitoring the base station. Vehicle identity, address, and command polls were initiated, as well as, on board "discrete" events (simulated malfunction or data response) initiated data exchanges. Figures 5-16 and 5-17 show the Metrocom system functional diagrams.

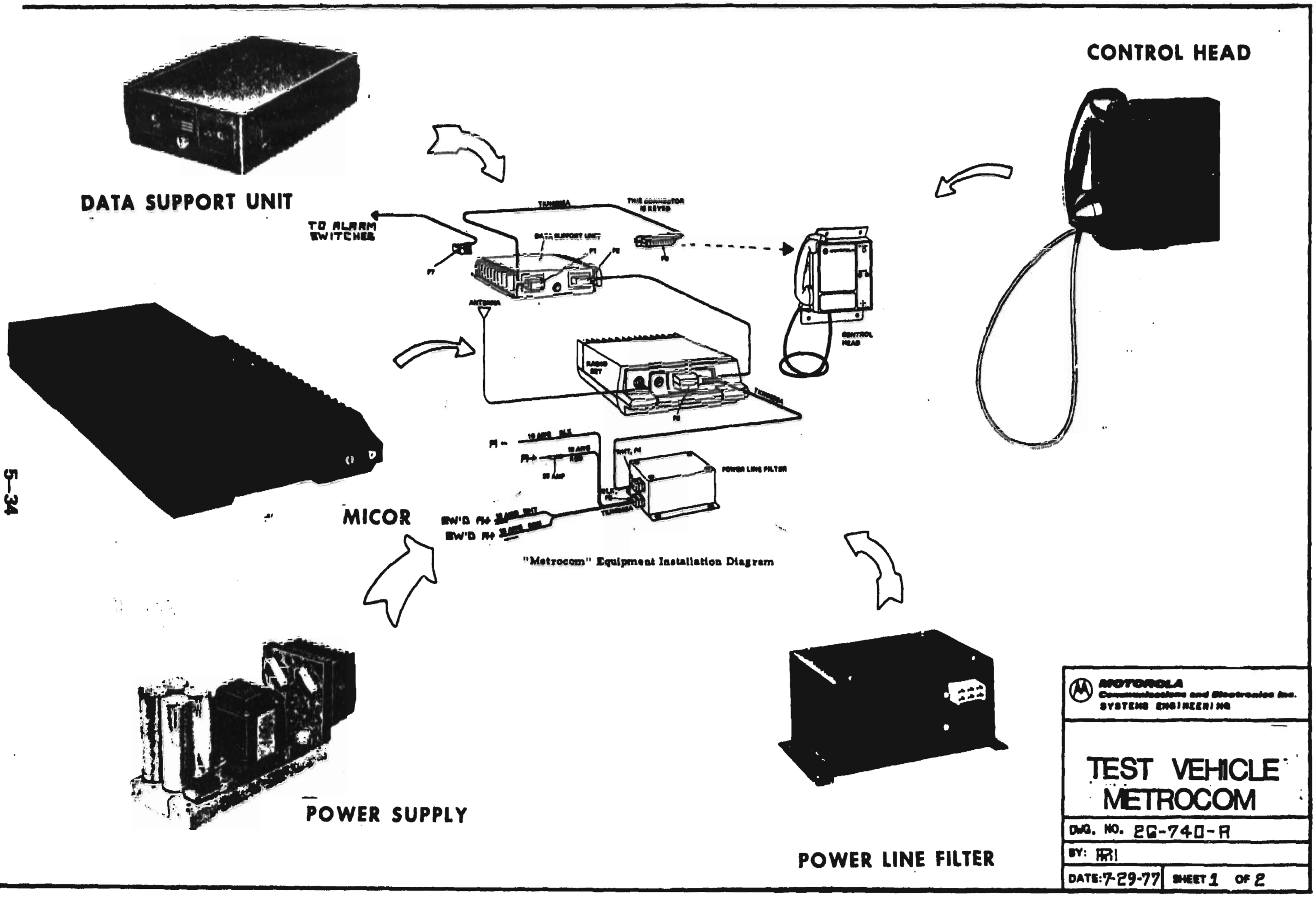
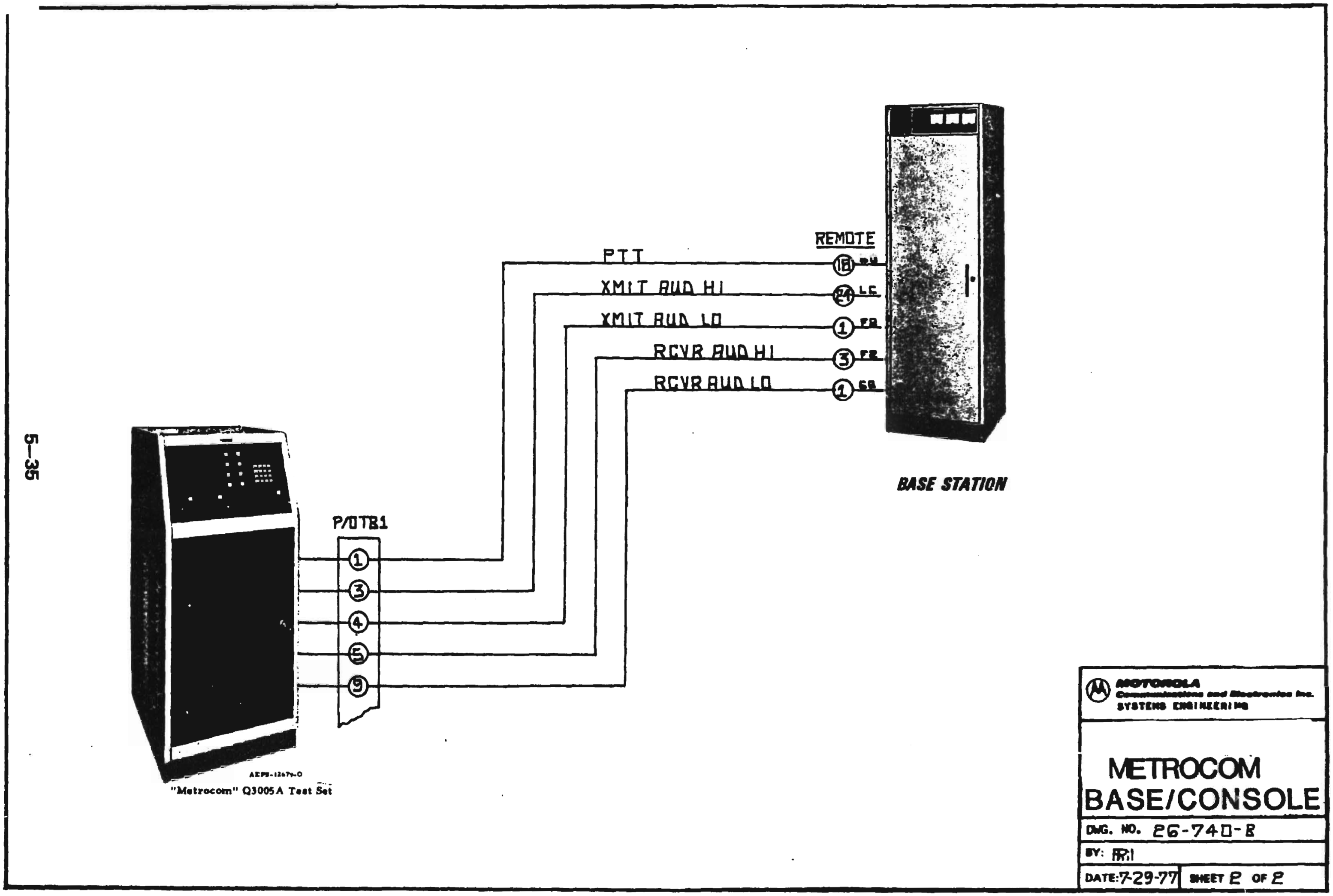


FIGURE 5 — 16 TEST VEHICLE METROCOM



FIGURES 5–17 METROCOM BASE/CONSOLE

5.6 VEHICLE SAFETY EQUIPMENT DESIGN AUDIT

A safety evaluation was obtained from Battelle Institute for the Vought designed Vehicle Safety Equipment (VSE) module. The VSE unit was functionally equivalent to the safety equipment used on AIRTRANS although redundancy techniques were used to supplement the fail-safe techniques. Majority voting logic was used to define a malfunction and/or an unsafe condition and cause the vehicle to stop. In the AIRTRANS system this unit is the "vital" portion of the AIRTRANS vehicle control, which receives and decodes the wayside speed signals and acts to prevent vehicle violation of wayside speed limits. The Vought design attempted to determine the feasibility of replacing the analog circuitry with modern digital devices and to improve system operability by providing a fail/operational mode of operation if possible.

Basically, the intent of the Battelle analysis was to consider the safety effects of failures which might occur under three conditions of operation. These are:

(1) Normal operation without failures and with proper signal inputs,

(2) Operation with proper input signals and all plausible single component malfunctions, and

(3) Operation with no component malfunctions, but with improper input signals.

Battelle did a preliminary analysis based on a Vought Failure and Effects Model Analysis and the hardware design that existed at that time.

Comparing the evaluation of the VSE design with the existing AIRTRANS safety system showed that the existing system was superior to the new design and that any redesign of the new VSE to meet the existing requirements would not have been cost effective.

5.7 CONTROL AND COMMUNICATION TESTING

The objectives of the Control and Communications test operations may be summarized as follows:

(1) Demonstrate the capability of the Vehicle Control Electronics (VCE) to perform in employee-passenger and utility vehicle modes,

(2) Calibrate the Wayside Signal Analyzer and perform a signal quality mapping of the D/FW system,

(3) Demonstrate transmission of Wayside Signal data to Central Control through SDS system and

(4) Demonstrate feasibility of RF data transmission through existing UHF communications link.

These tests involved laboratory checkout at Vought, Automatic Train Control (ATC) checkout at the D/FW Maintenance Facility, and vehicle operations in the AIRTRANS guideway. Laboratory checkout of the VCE and AUTP front panel utilized the previously discussed vehicle simulator to evaluate and verify the CLA and AVO functions of the VCE and are described in paragraph 5.3.4. The laboratory test phase of the command and control efforts began in April of 1977. The Automatic Train Control (ATC) checkout D/FW Airport began at the end of April and continued throughout guideway testing period as train and VCE configuration updates and corrections were effected. Guideway tests for support of high speed vehicle tests were accomplished in late April. After a short vehicle layup period, guideway tests for the Command and Control tasks were begun 3 June 1977. A total of thirteen guideway tests operations were conducted in this phase of the program. These tests consisted of continuing evaluations of VCE AVO/CLA performance, generation of Wayside Analyzer mapping (two valid data maps were obtained) and demonstration of the Motorola Metrocom RF data system was completed. In all test modes, operations data was accumulated from test log notes, visicorder data of command and control instrumented parameters and AIRTRANS Central SDS data printouts.

5.8 CONCLUSIONS AND RECOMMENDATIONS

5.8.1 COMMAND AND CONTROL - The feasibility of combining AIRTRANS Control Logic Assembly (CLA) and Automatic Vehicle Operations (AVO) into a single unit has been previously demonstrated but was further sustantiated during the AUTP Phase I program. The rational for amalgamation of these two vehicle functions is that the microprocessor approach, once applied to the CLA, allows logical extension to the closely related AVO functions without increase in hardware requirements. In addition, a great deal of functional commonality exists between the CLA and AVO as well as a large number of interfacing signals between the two. By combining the CLA and AVO into the VCE, a significant parts count reduction has been achieved. Decreasing the hardware complexity has increased the probability that a significant increase in system reliability can be accrued in the future. Additionally, the use of a microprocessor provides a vastly improved method of unit troubleshooting, testing and flexibility for subsequent operational changes. This feature will be utilized in the expanded efforts of Phase II AUTP. The program objective have been met and demonstrated in this Phase I effort.

5.8.2 WAYSIDE ANALYZER - The Wayside Analyzer testing and development was completed successfully in the AUTP. The unit has been left in an operational status for future use in T-365 by the Dallas/Fort Worth AIRTRANS maintenance personnel. It is anticipated that future use of this system will be beneficial to AIRTRANS maintenance efforts in long term signal degradation detection and in troubleshooting specific signalling problem areas. The specific unit provided permits adjustable signal level threshold monitoring with a "hands-off" remote reporting (by SDS hard copy) of results.

5.8.3 RADIO DEMONSTRATION - This effort was accomplished primarily by Motorola and supported by Vought. The new radio and remote data reporting capability described in paragraph 5.6 are state-of-the-art demonstrations of an improved audio communications and extended data reporting backup to the existing AIRTRANS SDS.

APPENDIX A

ANALYSIS of DOWNTOWN PEOPLE MOVER SPEED AND PROPULSION POWER REQUIREMENTS

SPEED ANALYSIS

The city's proposals for the Downtown People Mover Program contain a desired maximum cruise speed and also a discription of proposal alignments. These were investigated to determine the most effective speed for each of the DPM finalists.

Round trip times were calculated for vehicles operating at maximum speeds of 35, 30, 25 or 24, 20 and 17 miles per hour. Round trip times were attained by developing the route scenario including the number of and distance between each station and guideway geometrics. Travel times between each station were calculated using 0.10 g maximum rate for acceleration and deceleration, and 0.10 g/sec maximum jerk rate. These times were summed together with dwell times of 20 seconds for each station and time penalties for small radii turns. The results for St. Paul are shown in Table A-1. Similar analyses were performed for each of the other DPM cities and the results are shown in Tables A-2 through A-11. These are summarized and displayed graphically in Figure A-1.

The analysis shows the range of "best" maximum speeds to be 20 to 32 MPH with a mean of 26.8 MPH. A cursory investigation of the "slowest" system, Houston, indicates a potential for alignment improvements which could allow higher speeds. It is reasonable to assume that each DPM alignment could be improved in a similar manner. This, coupled with the fact that 30 MPH is the desired speed most often specified for other urban applications of AGT, led to the recommendation of 30 MPH as the maximum speed objective for the AUTP.

PROPULSION MOTOR RATING REQUIREMENT

Motor thermal rating requirements and trip performance were calculated using a Vought propulsion/route simulation routine. The routine computes the speed-distance-power profile of a train operating over a route in response to wayside commands. Basically, the routine attempts to have the train attain the commanded speeds under the limitations imposed by the following:

(1) Propulsion system torque or current limits,

(2) Ride comfort limits, and

(3) Velocity/RPM, limits.

The characteristics of the vehicle, propulsion system and a route description are used as input data. Basic output data includes

TABLE A–1 ST. PAUL SPEED ANALYSIS

MAIN LINE (EAST – WEST)

MAXIMUM SPEED (MPH)

ROUTE LINK	LENGTH (FT)	35	30	24	20	17
A – B	3200	79	86	103		
B – C	1220	41	42	47		
C – D	920	35	36	38		
D – E	1160	40	41	45		
E – F	1360	44	46	50		
F – G	870	34	34	37		
Totals Route (Ft.)	8730	–	–	–	–	–
Added for Curves	–	5	3	–	–	–
Station Dwell	–	120	120	120	120	120
One Way Total Time (Sec)	–	398	408	440	478	524
Round Trip Time (Sec.)	–	796	816	880	956	1048

CAPITAL SHUTTLE (NORTH – SOUTH)

ROUTE LINK	LENGTH	35	30	24	20	17
E – H	1140	39	40	44	49	54
H – I	1100	39	40	44	48	53
I – J	1200	40	42	46	51	57
Total Route (Ft.)	3440	–	–	–	–	–
Added for Curves		7	3			
Station Dwell		60	60	60	60	60
One Way Total (Sec.)		185	185	194	208	224
Round Trip Time (Sec.)		270	270	388	416	448

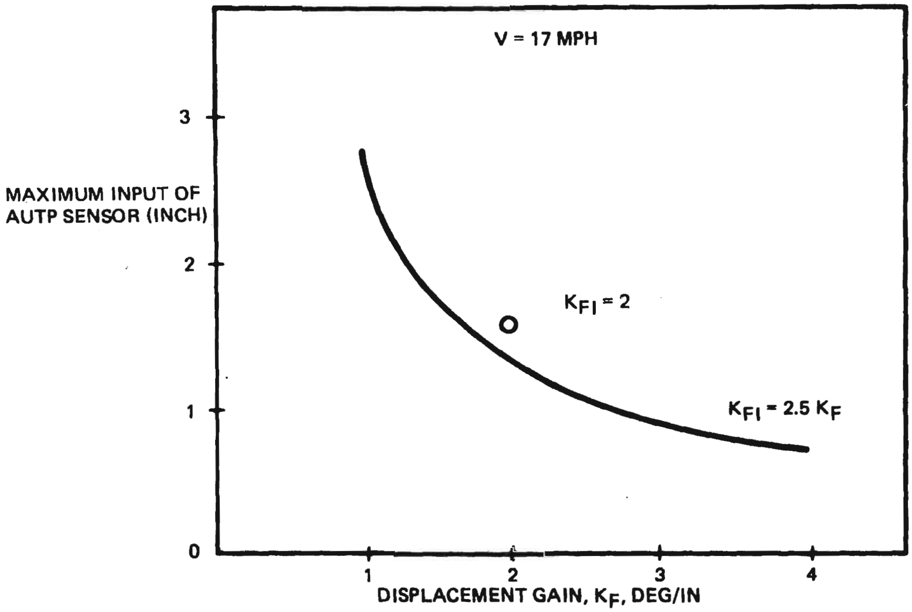


FIGURE B–4 PEAK ERROR OF FRONT SENSOR WHILE ENTERING A 150 FOOT RADIUS TURN

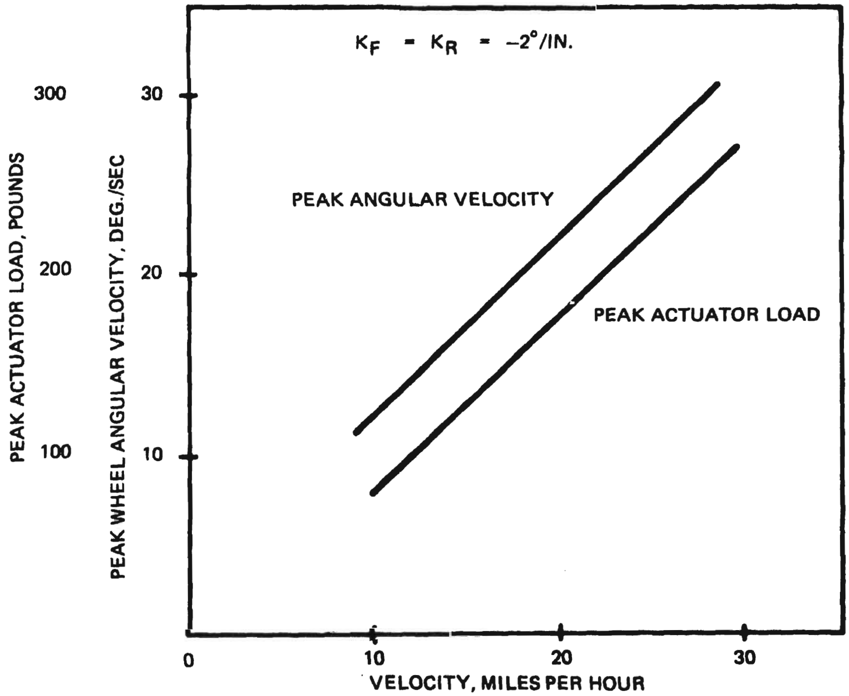


FIGURE B–5 CONTACTLESS PEAK WHEEL ANGULAR RATE VS VEHICLE SPEED – 2 DEGREE SWITCH

2° SWITCH, SPRING RATE – 2,000 LB/IN., VEHICLE SPEED = 17 MPH

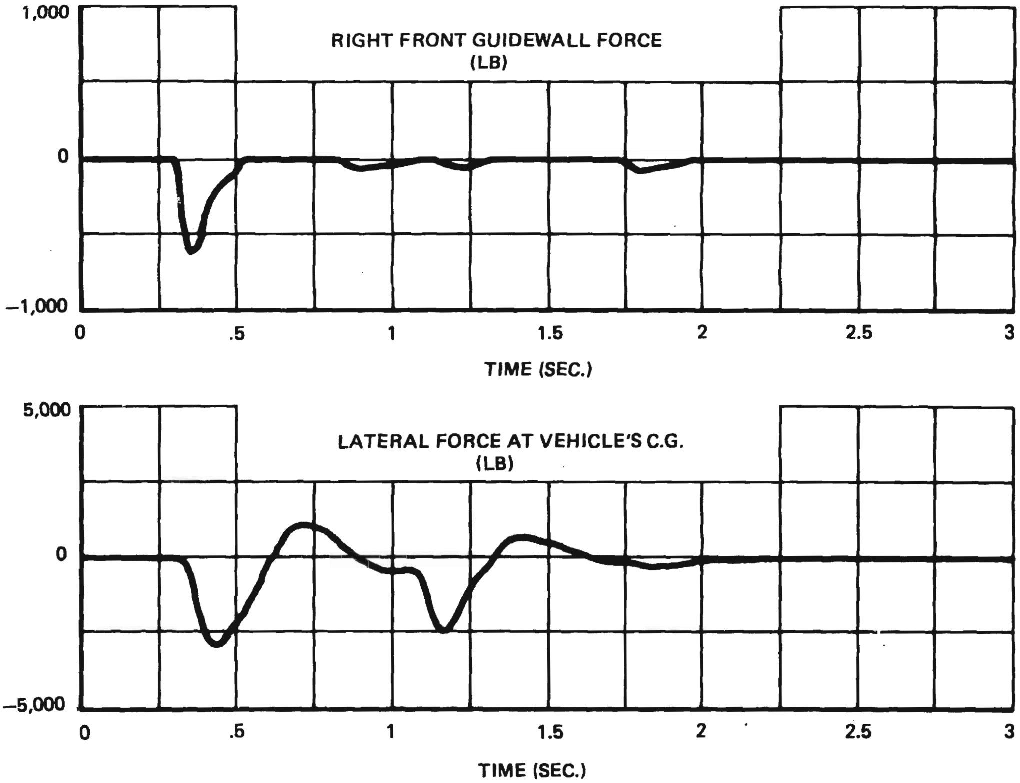


FIGURE B–6 IMPROVED MECHANICAL STEERING

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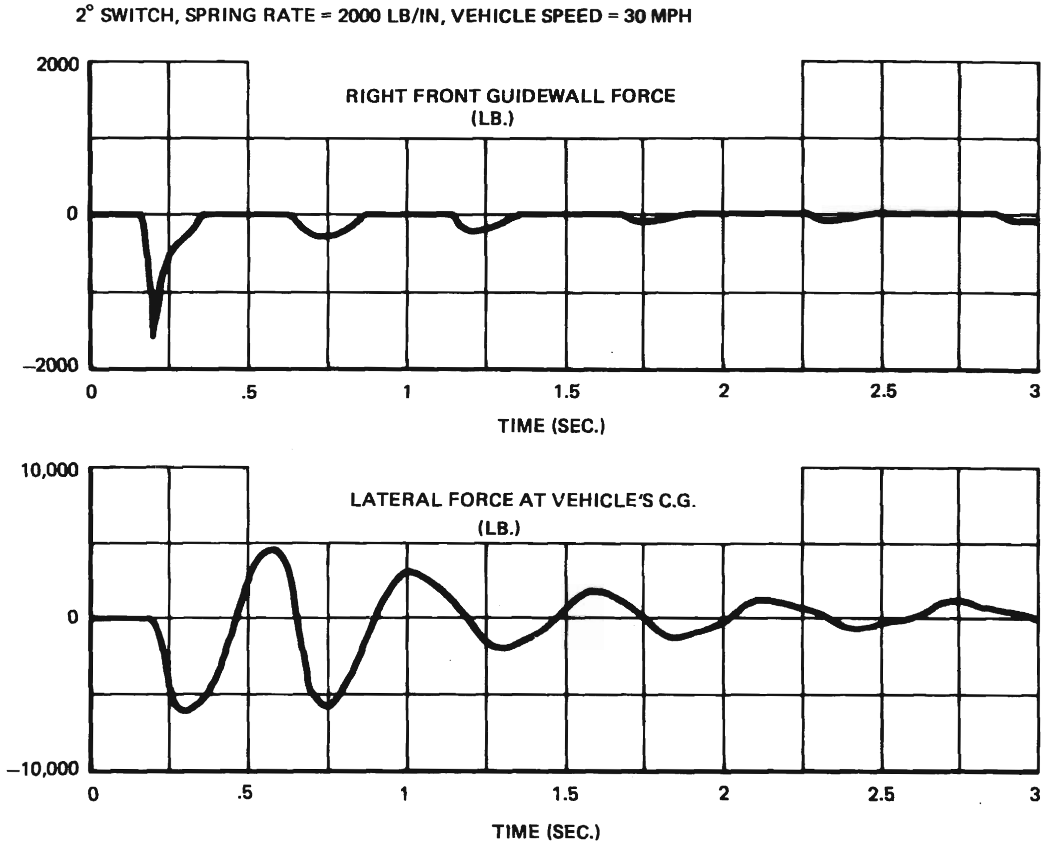

FIGURE B–7 IMPROVED MECHANICAL STEERING

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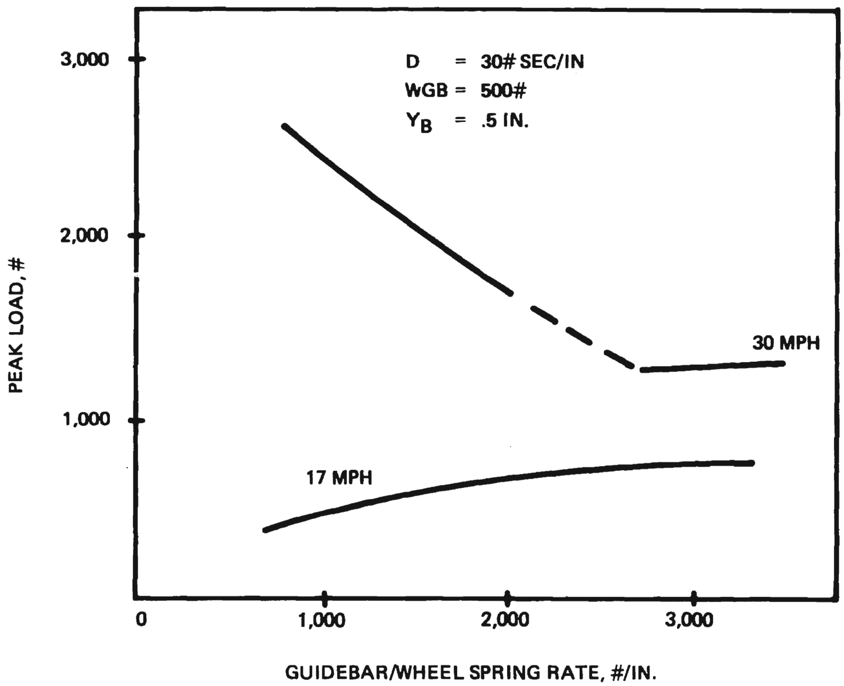
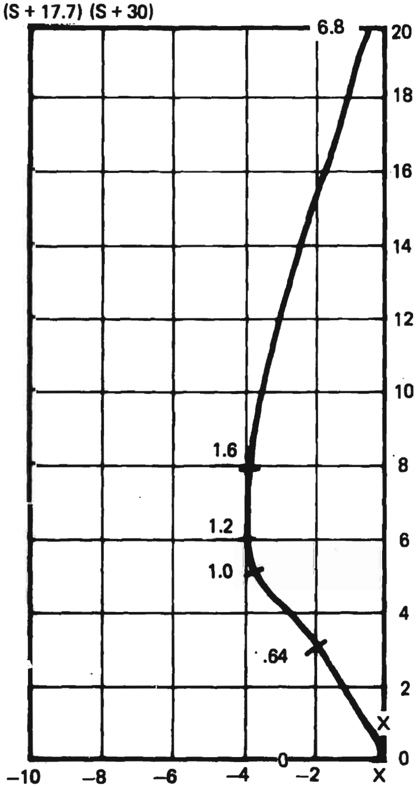


FIGURE B–8 IMPROVED MECHANICAL STEERING PEAK GUIDEWALL LOAD THROUGH 2° SWITCH

$V = 17$ MPH

$$1 + \frac{2780\,K_F\,(S+2.5)}{S^2\,(S+17.7)\,(S+30)} = 0$$



$M = 57\# - SEC^2/IN$
$I_2 = 2.74\,(10)^5\ IN - \# - SEC^2$
$C_F = 5.7\,(10)^4\ \#/RAD.$
$a = 80$ INCHES
$K_F = K_R$
$K_{FI} = 2.5\,K_F$

$V = 30$

$$1 + \frac{2780\,K_F\,(S+2.5)}{S^2\,(S+10)\,(S+30)} = 0$$

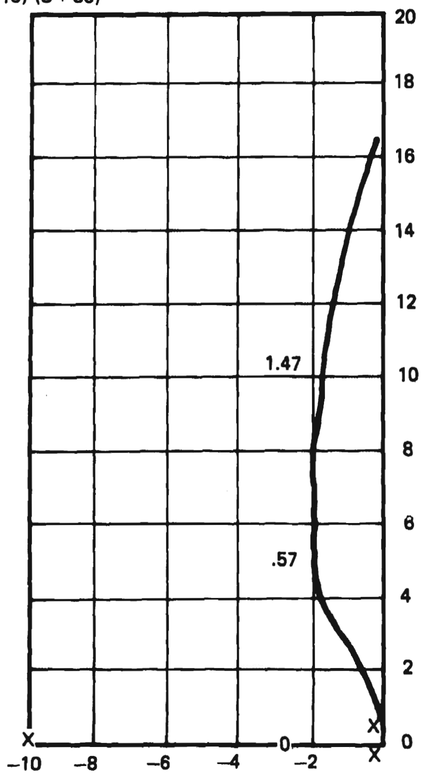


FIGURE B–9 ROOT LOCI OF VEHICLE/CONTACTLESS INTEGRAL PLUS DISPLACEMENT FEEDBACK

V = 17 MPH

$$1 + \frac{2780\ K_F\ (S+1)}{S^2\ (S+17.7)\ (S+30)} = 0$$

M = 57 # – sec² /in

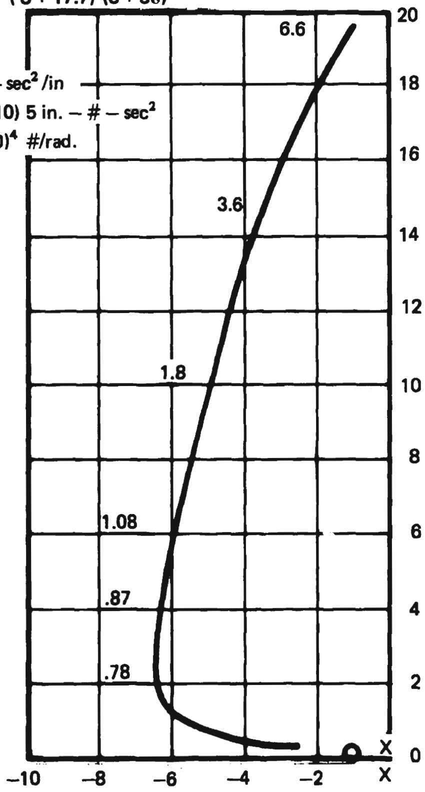
I_Z = 2.74 (10) 5 in. – # – sec²

C_F = 5.7 $(10)^4$ #/rad.

a = 80 in.

K_R = K_F

K_{FI} = K_F



V = 30 MPH

$$1 + \frac{2780\ K_F\ (S+1)}{S^2\ (S+10)\ (S+30)} = 0$$

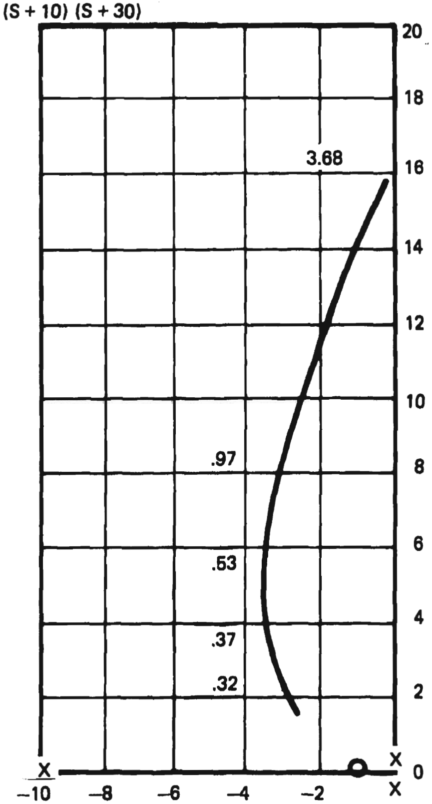


FIGURE B–10 ROOT LOCI OF VEHICLE/CONTACTLESS INTEGRAL PLUS DISPLACEMENT FEEDBACK the damping is too low for any value of displacement gain. Figure B-10 contains the case where the integral gain is equal to the displacement gain. A displacement gain of 2 at 17 mph gives adequate damping. At 30 mph, adequate damping is obtained with a gain of 1.0. The AUTP active steering has a velocity programmed gain changer to give these values.

2.2 PARAMETER SELECTION

Based on the simulation studies and the stability analyses, the gains shown below will provide adequate damping and maintain the sensor error below its saturation level:

SPEED, MPH	K_F DEG/IN.	K_{FI} DEG/SEC/IN	DAMPING RATIO	GAIN MARGIN
17	2	2	.42	3
30	1	1	.36	3.5.

The actuator requires a velocity of 2 inches per second and a force capability of 300 pounds.

APPENDIX C

HYDRAULIC SYSTEM DESCRIPTION

The onboard hydraulic system provides power for vehicle steering in the power boosted and contactless steering modes. The test vehicle system was developed using commercially available components. Various hydrualic circuit designs were studied to determine the system best suited to the AUTP Phase I program constraints or criteria which included:

(a) to consist of readily available commercial components,

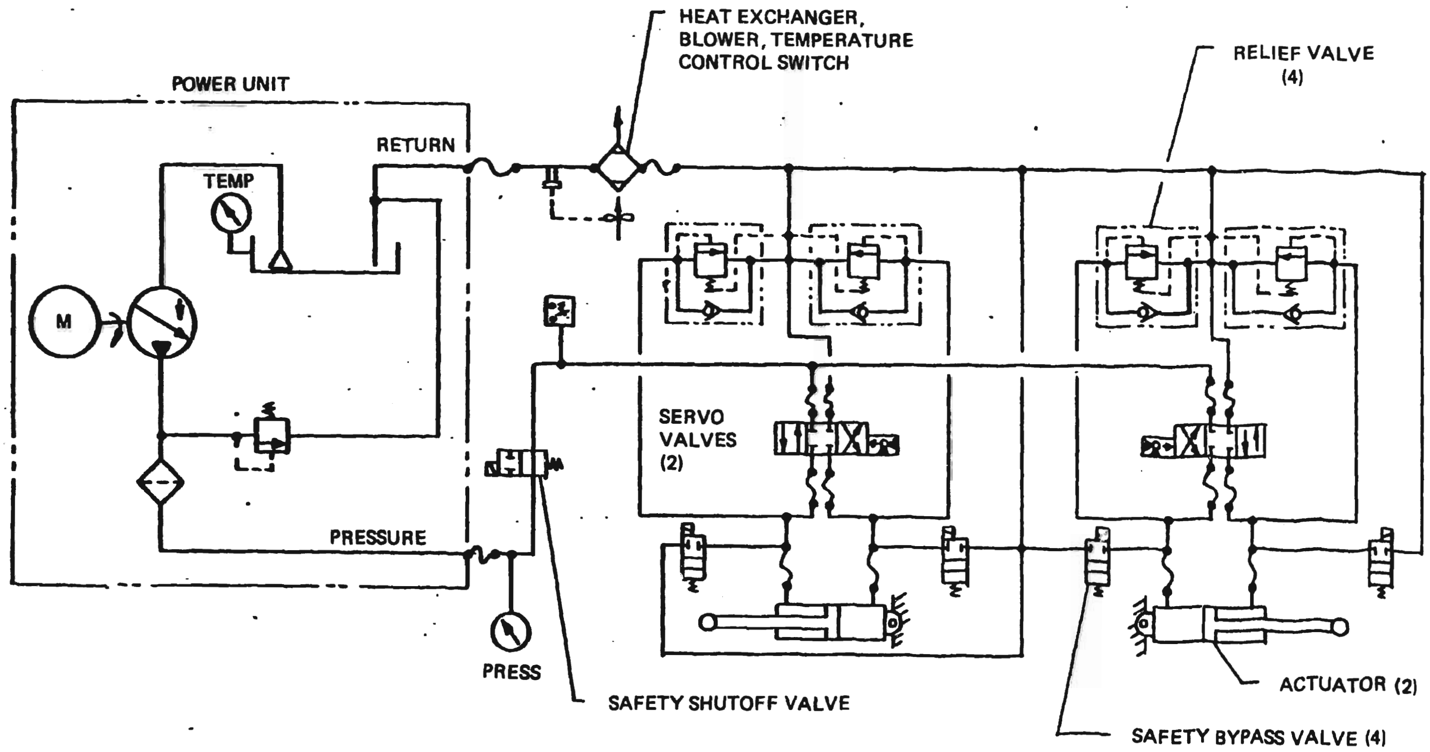
(b) to be optimized around the contactless steering concept, and

(c) to be compatible with the power boosted steering concept with minimum component changes.

These constraints led to the choice of a variable displacement pressure compensated pump, best for the contactless system and acceptable for power boost. Neither contactless nor boost system performance was compromised by this choice. However, cost and energy efficiency might lead to different hydraulic systems for a production installation. Figure C-1 and C-2 depict the contactless and power boosted hydraulic systems, respectively, as ultimately configured for the T-365 test vehicle.

Each system consists of a common hydraulic power package, common supply and return oil distribution plumbing, common relief valves and actuators and individual flow control valves. The power package includes a three-phase 480 VAC electrical motor driving a variable displacement, pressure compensated vane pump. The motor and pump are mounted atop a standard ten gallon reservoir along with a pilot-operated bypass relief valve and a ten-micron high pressure filter. An air-to-oil heat exchanger is installed to cool the return oil before it enters the reservoir. Forced air circulation across the heat exchanger is furnished as required by a thermostatically controlled tangential blower. These components along with interconnecting plumbing are integrated into a bolt-on package which is attached to the undercar structure.

The contactless system uses a two-stage electro-hydraulic servo valve with a closed center spool at each steering actuator to provide steering response to commands from the steering controller. With the steering system in a quiescent state, pump output is at full pressure (approximately 1000 psig) and low flow. (Quiescent flow through all the system valves is approximately .8 gpm). The variable volume feature of the pump permits this high pressure/low flow condition with minimum energy loss and small resultant heat buildup. As flow is demanded by servo



NOTE: SOLENOID VALVES SHOWN IN ENERGIZED POSITION

FIGURE C–1 CONTACTLESS STEERING HYDRAULIC SYSTEM

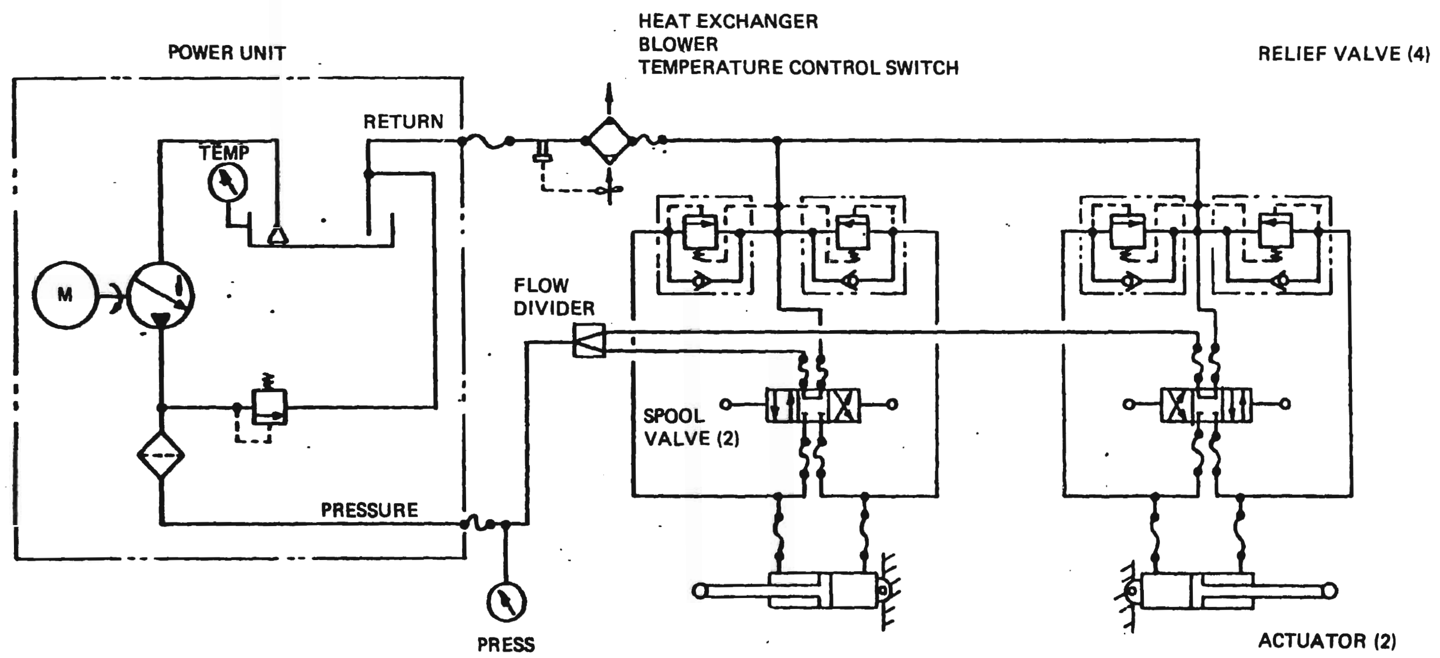


FIGURE C–2 POWER BOOSTED STEERING HYDRAULIC SYSTEM valve spool motion, the pump output volume is increased to respond while the output pressure remains essentially constant. (See Figure C-3.) Fast response solenoid valves are located to bypass each actuator and interrupt pump flow in the event of a steering controller malfunction.

The power boosted system uses a mechanically actuated "valve-in-link" open center spool valve at each steering to provide power boosted steering as a function of inputs from the guidebar. Since the valves are of the standard truck type open centered configuration, neither series or parallel simultaneous operation of the valves is possible without the introduction of two independent pressure sources or by utilizing a means of artifically creating a flow split. In order to maintain maximum commonality between the two systems, the latter method was selected. A proportional flow divider divides pump output into two equal flows regardless of load variations on each output over the full range of pump flows. This method of operation does create inefficiencies and additional heat buildup in the hydraulic circuit but was deemed satisfactory for the test program. The same variable volume, pressure compensated pump is utilized and operates in the following manner. With the system in the quiescent state, pump output is at full volume (approximately 6 gpm) and low pressure. (System flow resistance is approximately 150 psig.) As flow is demanded by boost valve spool motion (one or both), pump pressure is increased in response to load at essentially constant flow up to full system pressure of 1000 psig or until the steering command has been completed. When only one valve demands flow or where the demands of both valves are unequal, the flow divider creates an artificial equal flow split to permit operation of both valves. This flow split creates a pressure drop through one leg of the flow divider which results in a temperature rise of the oil in that leg. The heat exchanger has been sized to accommodate the maximum temperature change under this condition.

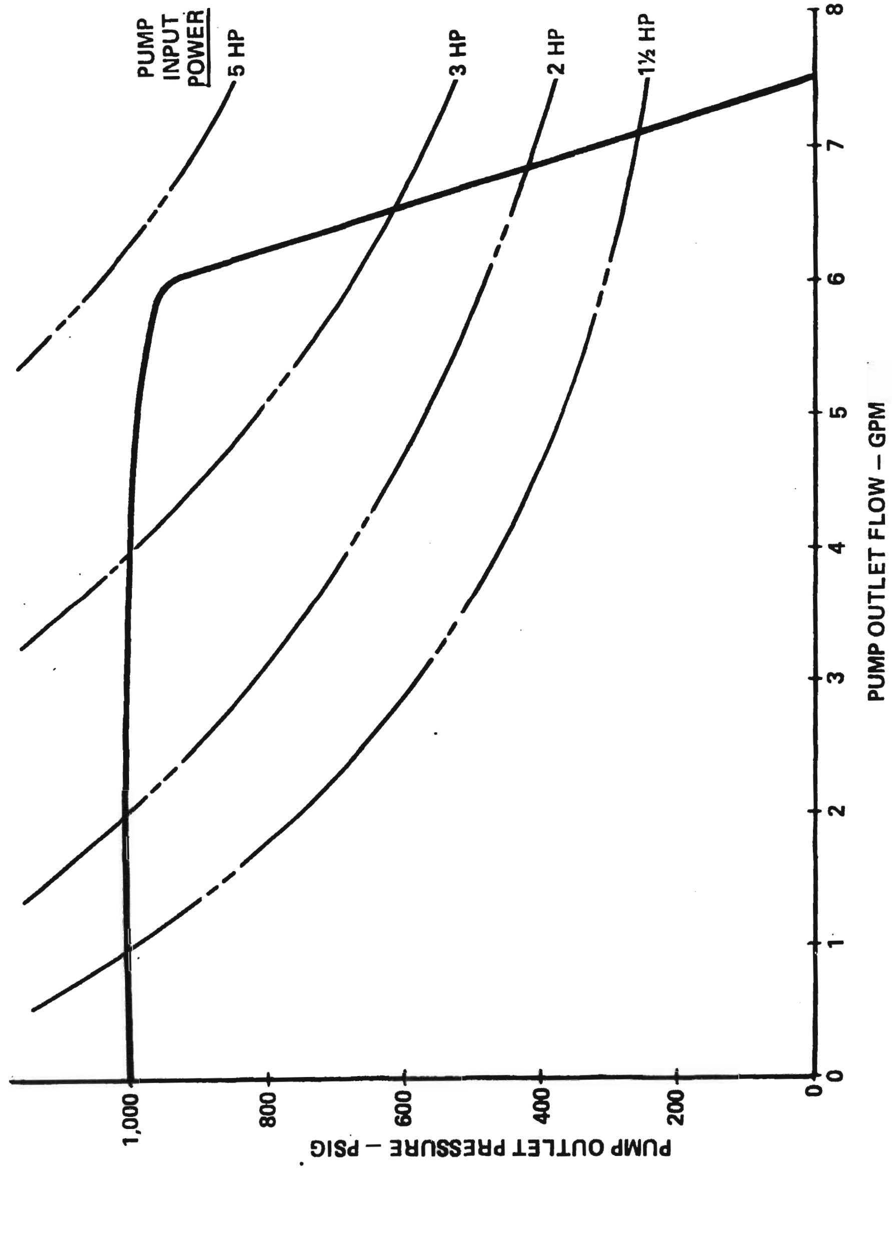


FIGURE C–3 HYDRAULIC PUMP CHARACTERISTICS

APPENDIX D

STRUCTURAL DESIGN CRITERIA

1.0 DESIGN CRITERIA

The following section presents the structural design criteria and design data used for design modifications to the existing AIRTRANS steering system during the AUTP. The design loads are based on AIRTRANS measurements and extrapolated to reflect a 30 MPH design speed. After completion of testing the modified steering systems, loads and criteria will be revised as required to reflect effects of the new designs.

1.1 DESIGN ALLOWABLES

Material design properties and allowables used during the design were based on reliable sources such as A.S.T.M. Specifications, AISC Manual, Aluminum Association and Mil Handbook #5. Fatigue allowables for steels were obtained from the AISC and Americal Welding Society. Fatigue allowables for aluminum products were obtained from the Vought Fatigue Data Manual.

1.2 DESIGN SAFETY FACTORS

Safety factors used during the AUTP design are presented in Table D-1. These factors were obtained from the Aluminum Association Handbook and represent allowables used for bridge type structures. The factors in the Aluminum Association Handbook are similar to the safety factors used in the AISE and AISC Specification.

1.3 STRENGTH AND FATIGUE REQUIREMENTS

1.3.1 IMPROVED MECHANICAL SYSTEM

The peak steering system loads presented in Table D-2 were used to design major steering system components. The appropriate strength safety factor presented in Table D-1 was applied. The loads of Table D-2 were combined with the inertia loads of Table D-3 to produce the most critical loading condition. G_x or G_y were combined separately with Table D-2 to give the critical loading. For the strength design, the Safety Factors of Table D-1 were adhered to. Inertia loads for the power boosted and contactless design were combined as above.

The loads and occurrences presented in Table D-4 were used to design the major steering system components for fatigue. Designing to this spectrum and loads will produce no failure within 20 years of service life. For a greater or smaller service life, the occurrences can be ratioed lineraly. The inertia loads of Table D-3 were used for the fatigue design of

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TABLE D–2 SUMMARY OF PEAK NORMAL OPERATING LOADS (30 MPH)

COMPONENT	LOAD LBS COMPRESSION	TENSION
Guidewheel	4752	—
Switchwheel	5456	3168
Eye Bolt	1672	986
Steering Link	4213	2485
Spring	1056	2746

TABLE D–3 INERTIA LOAD FACTORS (30 MPH)

COMPONENT		LOAD FACTOR [(3), (4), (5)] G_x	G_y	G_z
Guidebar and Guidebar Supports		(1)	(2)	±23
Collectors	Collector Arms	±125	±250 (2)	±175
	Support Tube Support Arms	± 27	± 18	± 13

(1) To be Defined at a Later Date.

(2) Not to be Reacted Statically as G_x and G_z Since Guidebar and Collectors are Free to Move Laterally.

(3) For Design Purposes, Use Component Weight Times the Inertial Load Factor.

(4) For Fatigue Design, Use 2×10^6 Cycles (Fully Reversible)'

(5) For Strength Design, Combine G_x or G_z with Factors in Table D–1.

Loads will be Updated as Required Based on Baseline, High Speed, and 18' Drum Tests.

TABLE D–4 SUMMARY OF STEERING LOADS AND OCCURRENCES FOR FATIGUE DESIGN (30 MPH)

LOAD (LBS)	CYCLES X 10^{-6}					
	SWITCHWHEEL				GUIDEWHEEL	
	L/H		R/H		L/H	R/H
	+	–	+	–	+	–
4230	.33		.14		–	
3525	1.11		.46			1.2
2820	8.7		.81		2.4	3.7
2115	.6	.74	1.34		17.0	10.8
1410	1.9	5.01	2.35	7.31	91.4	32.4
705	31.38	216.2	6.49	120.5	445.0	198.4

CYCLES X 10^{6}								
EYEBOLT			SPRING			STEERING LINK		
LOAD	+	–	LOAD	+	–	LOAD	+	–
1270	.48		1974		.35	3194	.48	
1128	1.18		1672		.53	2839	1.18	
987	3.83		1410		1.53	2484	3.83	
846	13.34		1128		5.37	2129	13.34	
705	41.88	1.18	846	.84	70.75	1774	41.88	1.18
564	130.9	15.50	564	6.41	635.6	1420	130.9	15.50
423	148.2	42.42	282	85.7		1065	148.2	42.42

components in the steering system and collectors. The loads generated by using the inertia factors of Table D-3 with the appropriate component weight were considered acting separately for 2 X 10^6 cycles of fully reversible loads. Inertia loads for fatigue consideration, in the power boosted and contactless design, were combined as above.

1.3.2 POWER BOOSTED CONCEPT - The power boosted actuator and its back-up structure were designed to withstand the loads associated with a malfuncton which results in a "hard over" steering signal.

The steering system has sufficient strength to withstand the peak loads of Table D-2. This is the result of a boost system failure with the vehicle encountering a switch blade and/or parapet wall.

The steering system has sufficient strength to withstand the loads associated with the vehicle being powered through the guideway with the tires positioned 7.2° relative to the direction of motion. This is equivalent to 7100# applied to the guidebar to react the cornering force at the front axle. A safety factor of 1.5 against ultimate strength was used to design for this conditon.

The following components were designed to the loads associated with 2 X 10^6 cycles of full boost actuator load (fully reversible).

(1) Boost Actuator and Back-up Structure

(2) Kingpin arm and support

(3) Tie rod (50% output)

The boost actuator is of sufficient size to produce the following torque about the kingpin:

$$T = 10.7\ (3375\#) = 35{,}100\#".$$

This torque is equivalent to the maximum steering link load for the existing AIRTRANS mechanical system adjusted for 30 MPH operation.

The following components have sufficient fatigue strength to withstand the loads and occurrences presented in Table D-4.

(1) Guidebar,

(2) Reversing Mechanism, and

(3) Steering Link.

1.3.3 CONTACTLESS CONCEPT - The contactless concept is similar to the power boost concept with the exception that the guidebar

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does not encounter the guideway and switches as closely as the power boost system. In the failure, however, the two concepts are the same.

The steering system components of the contactless concept were designed to the same strength criteria as the power boosted concept.

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REFERENCES

1 Smithson, F.D. and Horzegh, F.H., "Investigation of Tire - Road Traction Properties," SAE Paper 710091

2 Johnson, D.E., "Wet Pavement Braking Traction," SAE Paper 700463, SAE Journal, Vol 79, 1978, p. 1636

3 Hodges, Henry C., "The Role of Tread Design in Skid Resistance Under Winter Driving Conditions," Highway Research Record, No. 477

4 Ichihura and Mizoguchi, "Skid Resistance of Snow or Ice Covered Bridges," Proceedings of International Symposium on Snow Removal and Ice Control Research, HRB Special Report 115, 1970

5 Kaye, "An Investigation of Intercity Highway Truck Drive Traction," SAE Paper 68058

6 NASA TN-D-6098, 1970

7 MPC Corporation Report on Transit Expressway, Phase II

8 Bourbeau, Frank J., "Wide Speed Range Cycloconverter - AC Motor Drives Operating from Utility Frequency Power," Delco Electronics Division, General Motors Corp.

9 Bedford, B.D. and Haft, R.G., Principles of Inverter Circuits, Wiley, New York, 1964

10 Canton, F.W. Mechanical Design of the Power Collection Equipment for a Low Speed Rubber Tired, Roadway Guided, Electrically Propelled, Mass Transit Vehicle, University of Texas at Arlington Masters Theses, 1978

11 Urban Mass Transportation Administration, Office for Technology Development and Deployment, Downtown People Mover Project Implementation Guidelines. UTD Document Control Number 77-10, March, 1977.