REPORT NO. UMTA-TX-06-0020-79-5

AIRTRANS URBAN TECHNOLOGY PROGRAM
PHASE II

VOLUME 4: VEHICLE FABRICATION, TESTS AND DEMONSTRATION

Vought Corporation
P. O. Box 225907
Dallas, Texas 75265

OCTOBER 1979

FINAL REPORT

Prepared for
Dallas/Fort Worth Regional Airport Board
Dallas/Fort Worth Airport, Texas 75261

and

U. S. Department of Transportation
Urban Mass Transportation Administration
400 Seventh Street SW
Washington, D. C. 20590

NOTICE

This report and the contents herein do not necessarily reflect the opinions of Dallas/Fort Worth Airport personnel.

Technical Report Documentation Page

1. Report No.
UMTA-TX-06-0020-79-5

2. Government Accession No.

3. Recipient's Catalog No.
PB 80 179062

4. Title and Subtitle
AIRTRANS Urban Technology Program Phase II.
Volume 4: Vehicle Fabrication, Tests and
Demonstration

5. Report Date
October 1979

6. Performing Organization Code

8. Performing Organization Report No.

7. Author's)
S. B. Gerald, et al.

9. Performing Organization Name and Address
Vought Corporation
P. O. Box 225907
Dallas, Texas 75265

10. Work Unit No. (TRAIS)
TX-06-0020

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Urban Mass Transportation Administration
400 Seventh Street, S.W.
Washington, D. C. 20590

13. Type of Report and Period Covered
Final Report. Phase II.
Vol. 4 of 6 Vols.

14. Sponsoring Agency Code
UTD-60

15. Supplementary Notes

16. Abstract

The AIRTRANS system at the Dallas/Fort Worth Airport, Texas, is representative of automated guideway transit (AGT) as it will likely develop in cities in the United States and around the world. AIRTRANS has provided transit service for passengers at the airport since January 1974. The system is operating with a high percentage of availability and degree of passenger acceptance.

This report describes the fabrication, test and demonstration activities of the AIRTRANS Urban Technology Program (AUTP) performed under a federal grant from UMTA to the Dallas/Fort Worth Airport Board. Improvements to the AIRTRANS AGT system in speed, reliability, cost, and all-weather capability for urban application have been evaluated in AUTP. The primary objective of fabrication was to convert the Phase I test vehicle (T365) into a prototype AGT system suitable for urban application. Vehicle tests were made to evaluate and verify system and subsystem designs. Demonstration and revenue operations were accomplished at the airport. Detailed results of the above activities, conclusions, and implications for urban usage are presented in this report. Other AUTP Phase II final report volumes are as follows: 1) Control System Improvements; 2) Passenger Communications; 3) Vehicle and Wayside Subsystems; 4) Vehicle Fabrication, Test and Demonstration; 5) Systems Operation; and 6) Severe Weather (UMTA-TX-06-0020-79-2 through UMTA-TX-06-0020-79-7). A separate report of this AUTP program is titled Inspect and Repair as Necessary (IRAN) Program (UMTA-TX-06-0020-79-1).

17. Key Words

Automated Guideway Transit (AGT)
AIRTRANS
Acoustics
Performance
Ride Quality
Steering
Airport
Urban Transit

18. Distribution Statement
Available to the public through the
National Technical Information Service
Springfield, Virginia 22161

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
138

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

PREFACE

This report covers the Vehicle Fabrication, Test Activities and Demonstration Operations conducted during Phase II of the AIRTRANS Urban Technology Program by the Vought Corporation, an LTV Company. 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).

AUTP is documented in the following reports:

- AIRTRANS Urban Technology Program Phase II Executive Summary (UMTA-TX-06-0020-79-8)

- AIRTRANS Urban Technology Program Phase II

  Volume 1 - Control System Improvements (UMTA-TX-06-0020-79-2)

  Volume 2 - Passenger Communications (UMTA-TX-06-0020-79-3)

  Volume 3 - Vehicle and Wayside Subsystems (UMTA-TX-06-0020-79-4)

  Volume 4 - Vehicle Fabrication, Tests and Demonstration (UMTA-TX-06-0020-79-5)

  Volume 5 - Systems Operation (UMTA-TX-06-0020-79-6)

  Volume 6 - Severe Weather (UMTA-TX-06-0020-79-7)

- Inspect and Repair as Necessary (IRAN) Program Report No. UMTA-TX-06-0020-79-1

- AIRTRANS Urban Technology Program Phase I Final Design Report (UMTA-TX-06-0020-78-1)

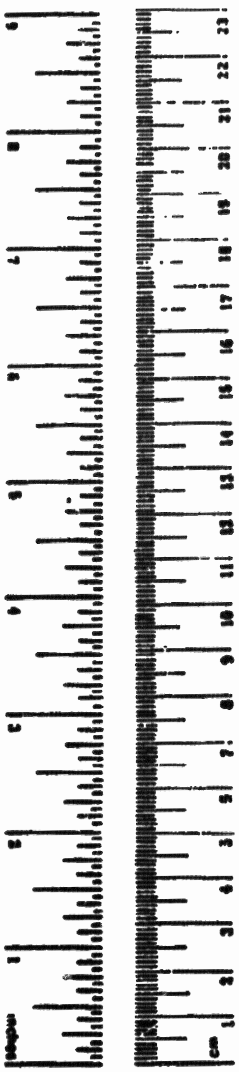
The cooperation of a large number of people and the use of Dallas/Fort Worth Airport as a test facility contributed to this program's success. Special thanks go to Dalton Leftwich and the entire operations and maintenance staff of the Dallas/Fort Worth Airport.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

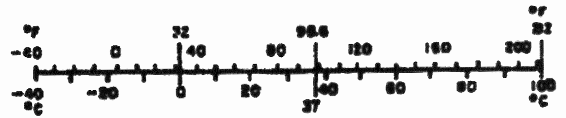
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

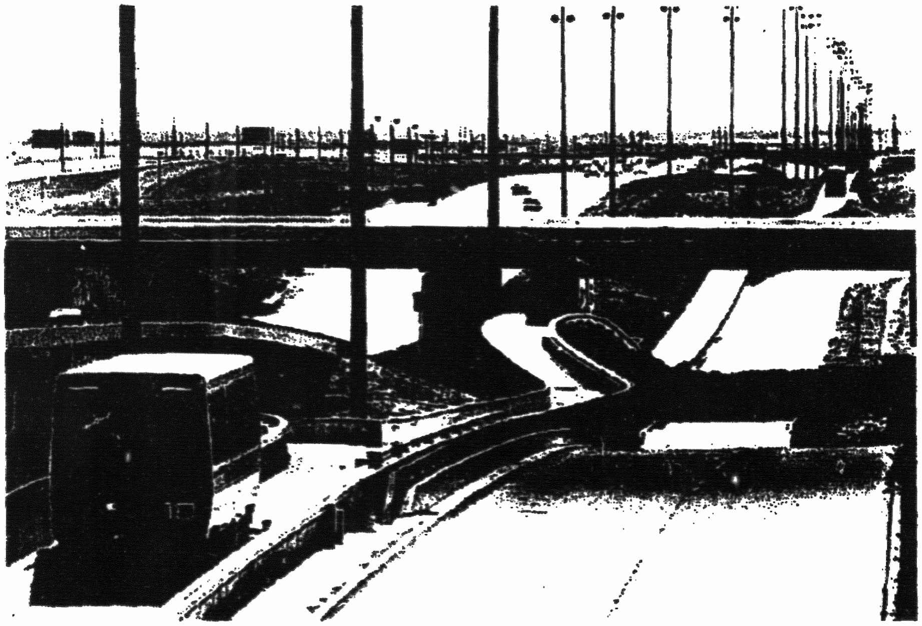
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers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



GS-1594-80

AUTP PROGRAM DESCRIPTION

AIRTRANS, an Automated Guideway Transit (AGT) system built by the Vought Corporation, has provided transit service for passengers at the Dallas/Fort Worth Airport since January 1974. This successful deployment of AGT technology prompted the United States Congress, the Department of Transportation (DOT) and Vought to investigate the extension of this technology. Independent assessments were made by the Transportation Systems Center of DOT (Reference (1)) and by Vought Corporation to determine what changes or improvements would be required to operate AIRTRANS in an urban application.



AIRTRANS SYSTEM AT D/FW AIRPORT

The recommendations were:

(1) Higher operating speeds

(2) Better passenger acceptance

(3) Reduced capital and operating costs

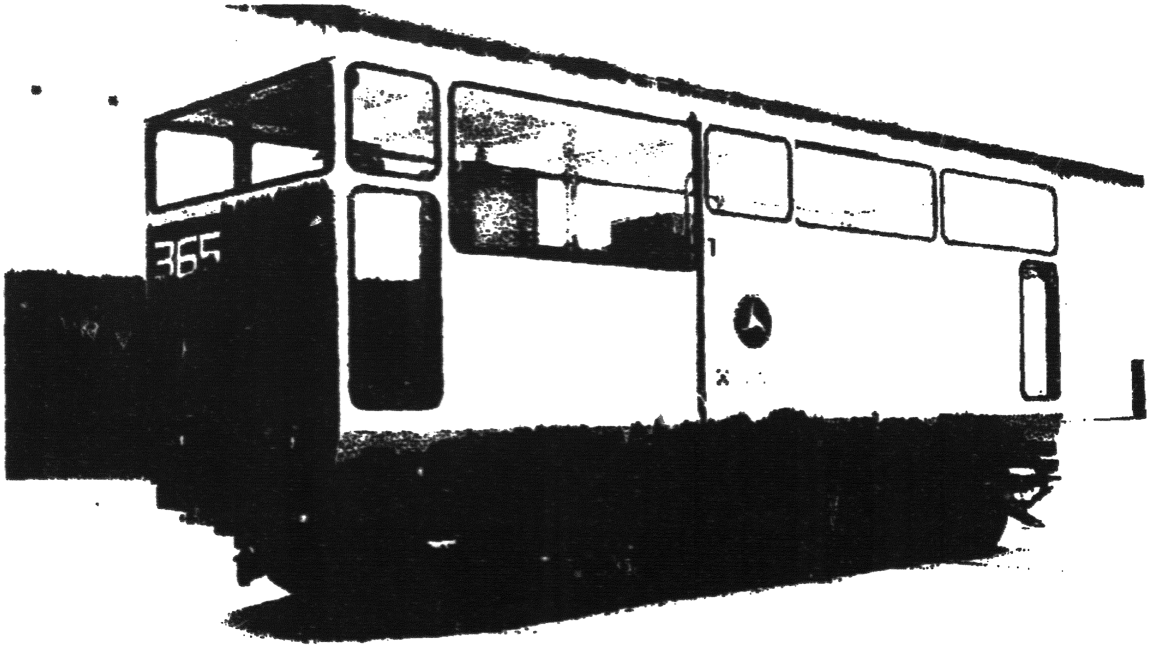
(4) Increased reliability

(5) Enhanced all-weather capability

(6) Increased energy efficiency

The successful achievement of these improvements would provide an energy-efficient 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 movements 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 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 in urban settings.



PHASE I TEST VEHICLE T365

The AUTP (AIRTRANS Urban Technology Program) was structured into a two-phase program. Phase I of AUTP was completed in 1977 (Reference (2)). Briefly, the first phase covered the development and demonstration of the improvements necessary for higher speed operation, while maintaining or improving reliability, availability, cost and performance characteristics of the overall system.

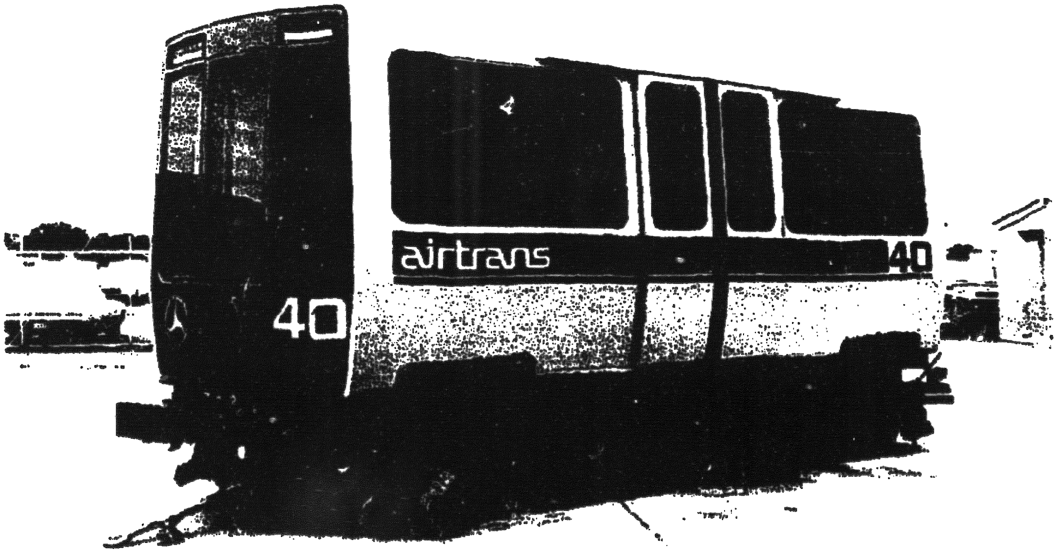
A highly instrumented engineering test vehicle (named T365) was used to demonstrate baseline and improved performance of the system.

PHASE II OVERVIEW

Using Phase I as a building block, other recommendations for improvements in AIRTRANS for urban applications were addressed in Phase II. The AUTP Phase II activities involved:

(1) Completing the propulsion and control system improvements and testing begun on test vehicle T365 in AUTP Phase I

(2) Design, fabrication and demonstration of passenger communication improvements



PHASE II PROTOTYPE URBAN VEHICLE P40

(3) Design, fabrication, test and demonstration of a prototype urban vehicle (P40), incorporating:

   (a) AUTP Phase I changes to the propulsion, collectors, steering, controls and communication

   (b) Doors on both sides

   (c) Powered reversing

   (d) Improved suspension

   (e) Improved vehicle coupling

   (f) Interior rearrangements

(4) Wayside electrical power improvements, including:

  (a) Solid-state wayside power controller

  (b) Power distribution simulation studies

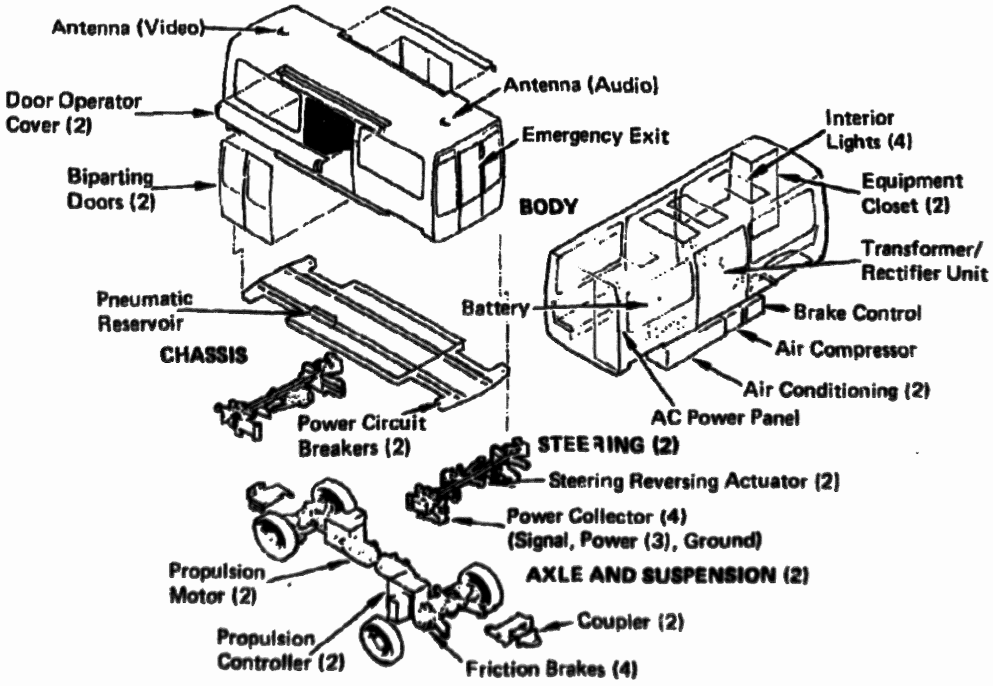
(5) AIRTRANS systems performance, operation and maintenance tasks, including:

  (a) Potential service improvements by use of higher speed, three-car trains, the addition of bypass sidings, and demand mode operation

  (b) An IRAN (Inspect and Repair as Necessary) program

(6) Analysis, design and test evaluation of subsystems affected by severe weather operation

The Phase II effort began with the continuation of the propulsion and control system tests that were begun in Phase I. Concurrent with the effort, the design and procurement for the



PROTOTYPE URBAN VEHICLE MAJOR SUBSYSTEMS

subsystems of the Phase II prototype vehicle were in work. The chassis was modified as required for the redesigned systems, and the new prototype vehicle was assembled.

The dual propulsion system and features of the redesigned steering system from Phase I were retained along with the concept of the collectors and control system. Powered reversing to permit shuttle operation was incorporated in the steering system along with elimination of the steering interconnect linkage and an increase in wheel steer angle for a smaller turning radius. A new suspension system was designed and fabricated. New specifications were written and new sources found for a pneumatic system direct-drive motor/compressor and for the heating, ventilating and air conditioning units. The AIRTRANS alternator was replaced with a specially designed solid-state transformer/rectifier. Improvements were made in the friction brake system and the pneumatic door operator. Biparting doors were incorporated on both sides of the vehicle to accommodate stations on either side of the guideway.

Dynamic graphics and the onboard TV surveillance systems were installed. The microprocessor-based control system of Phase I was modified to incorporate provisions for the dual doors, slip/slide detection, automatic reversing, automatic announcement unit (AAU), dynamic graphics and master/slave vehicle operation.

To verify the design and performance of the urban prototype vehicle, it was subjected to tests and demonstrations, both at Vought and at D/FW Airport. The knowledge and data obtained from Phase II of the AIRTRANS Urban Technology Program has been a significant step toward providing technology suitable for use in an urban environment. At the conclusion of the AUT program, the P40 vehicle was turned over to the Dallas/Fort Worth Airport and was in revenue service. In this way, further data will be gathered on this unique urban prototype vehicle, and will further assure a successful deployment of AIRTRANS into an urban environment.

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1.0 INTRODUCTION AND SUMMARY

The AIRTRANS system at Dallas/Fort Worth (D/FW) Airport has been in operation since January 1974 and has accumulated more than 21 million miles of vehicle operation through 1979. The primary thrust of Phase II of the AUT Program was incorporating design modifications that would enhance operation of the highly successful airport vehicle in an urban application. This report documents the activities associated with the fabrication, test and demonstration of the urban application vehicle, designated P40.

Vehicle fabrication involved a complete teardown of test vehicle T365 used in Phase I of AUTP, retention or modification of those parts still applicable, use of body panels remaining from the original AIRTRANS production, fabrication or procurement of new components and subsystems and assembly of the P40 urban prototype vehicle. The finished product, externally similar to the AIRTRANS vehicles, has blended into the D/FW system during the vehicle's demonstration and revenue service operations.

The Phase II tests and demonstrations, other than severe weather tests reported in Volume 6, were conducted with the following objectives:

(1) Design information

(2) Design verification

(3) Performance evaluation

Table 1-1 presents a summary of the tests conducted during Phase II. Some tests produced satisfactory results, and some required changes before satisfactory results were obtained.

TABLE 1-1 PHASE II VEHICLE TEST SUMMARY (PAGE 1 OF 2)

System Tested	Summary of Results
Heating, ventilating and air conditioning	System meets performance requirements. Minor work needed to obtain uniform exit distribution.
Door operator	Minor rigging problems corrected. Excessive water leakage through seals requires future modifications.
Air compressor	Compressor capacity is slightly below rating but acceptable.
Steering system	Impedance tests prove the rotary damper on P40 is required. The "soft" guide/ switchwheel spring is more desireable. The steering reversal system demonstration was successful.
Suspension system	Dynamic suspension system characteristics show an improvement over AIRTRANS. The vertical and lateral spring rate test results compare favorably with the design values.
Coupler	Design verified by tests. Coupling between two vehicles was accomplished in the guideway.
Lighting	Lighting levels are adequate even though less than AIRTRANS.
Transformer/rectifier	Unit was considered adequate for prototype vehicle. A production unit, however, requires modifications.
Regenerative braking	System performed well. System provided very smooth stops compared to AIRTRANS.
Dynamic graphics	After EMI problems associated with the AAU were corrected, the dynamic graphics displays operated satisfactorily.
TV surveillance	Prototype system functioned satisfactorily throughout the Airport, with the only exception in the Braniff subterminal.

TABLE 1-1 PHASE II VEHICLE TEST SUMMARY (PAGE 2 OF 2)

System Tested	Summary of Results
VCE	The VCE as a prototype unit operated satisfactorily following considerable guideway testing. Tests and refinements are required to make a production unit.
Ride quality	The vehicle's ride quality is satisfactory when compared to the DPM guidelines.
Acoustical	Exterior noise levels are acceptable. Interior levels are acceptable also, except for a slightly noticeable "hum" associated with the motor controller.

Several significant test results were obtained during the Phase II tests. Among these are:

(1) Numerous miles of successful demonstration and revenue operation at D/FW Airport

(2) Suspension system characteristics are improved over AIRTRANS

(3) TV surveillance in vehicle improves passenger security

(4) Successful steering reversal in straight and curved sections of the guideway to permit shuttle operations

(5) Regenerative braking system provides smoother stops than AIRTRANS

(6) Addition of dynamic graphics display in vehicle and time-to-arrival display in station helps passengers use system more easily and with less anxiety

The test program associated with P40 and its positive test results are certainly steps in the right direction to gain confidence for the vehicle's successful future in an urban application. Additional refinements to P40 during future testing are necessary to make the vehicle suitable in an urban environment.

2.0 TEST OBJECTIVES

The objective of the AIRTRANS Urban Technology Program was to enhance the urban suitability of the existing AIRTRANS system. The fabrication, in-plant and guideway testing and the demonstration of a prototype urban vehicle were tasks completed during the Phase II program and documented in this report (Volume 4).

Objectives associated with the above tasks were:

(1) Conversion of the Phase I test vehicle (T365) to a prototype urban vehicle which is compatible with the AIRTRANS system

(2) Testing to evaluate component and system designs

(3) Demonstration and revenue operation

3.0 VEHICLE FABRICATION

Vought fabricated an urban prototype vehicle (P40) to be used to demonstrate vehicle suitability for urban environment. The Phase I test vehicle (T365), shown in Figure 3-1, was converted into an urban prototype vehicle (P40), shown in Figure 3-2, which was used for demonstration in the AIRTRANS system at the Dallas/Fort Worth Airport.

3.1 PLANNING AND CONTROL

Vought Materials, Manufacturing and Engineering organizations coordinated closely throughout the design and fabrication phase. Factors affecting cost, maintainability and reliability (such as maintenance access, quality, tolerances, types of fabrication and compatibility with manufacturing methods) were evaluated during design. As the design progressed, manufacturing planning and tool design activities were coordinated as shown in Figure 3-3.

Control of the work was accomplished as shown in Figure 3-4. To expedite the work, Engineering issued advance engineering material orders (AEMO) on all long-leadtime items. As subsystem designs were completed, they were advance-released also. This process was continued until the final engineering specifications and blueprints were released. The Materials organization placed material orders, followed the procurement, received the materials inspected by Quality, and then delivered them to the prototype control unit (PCU). Manufacturing prepared operation sheets and tool orders from which PCU released work order packages for shop fabrication. Quality performed shop inspections during the fabrication effort.

Ordering long-leadtime items as early as possible is necessary, especially in a low-volume production effort. There were several instances when, because of low quantities of parts and lack of follow-on production, suppliers did not respond to our procurement efforts. In those instances, work-around methods were implemented such as in-house design and manufacture of items normally procured.

Change control was organized about as shown in Figure 3-5. Engineering work instructions or revised drawings were released to the Manufacturing and Materials organizations as were the original releases.

3.2 VEHICLE ASSEMBLY

The vehicle was planned and fabricated utilizing assembly line production methods. The same tooling and methods will be used to fabricate urban vehicles. Production methods served to better control the work and resulted in a higher quality product. Figures 3-6 and 3-7 set forth the vehicle assembly sequence and portray where the subassemblies and details enter the assembly.

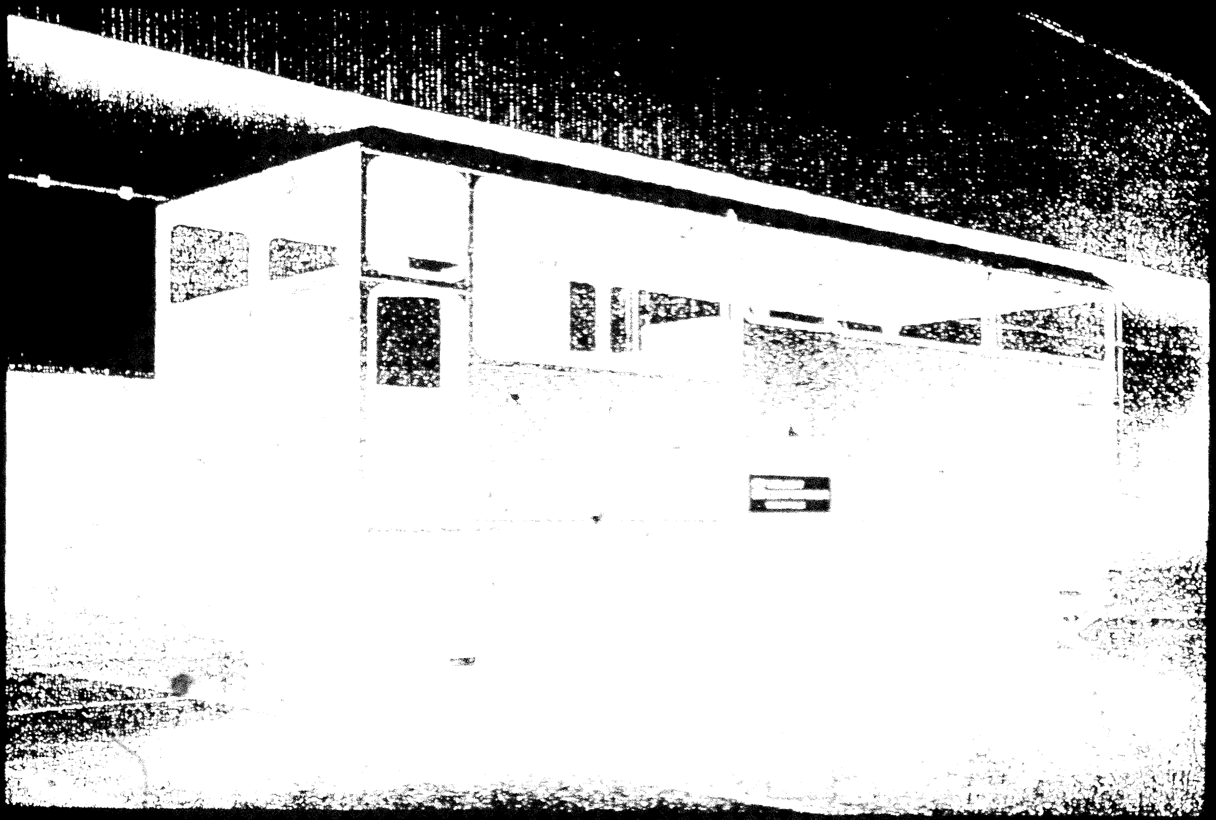


FIGURE 3-1 PHASE I TEST VEHICLE T365

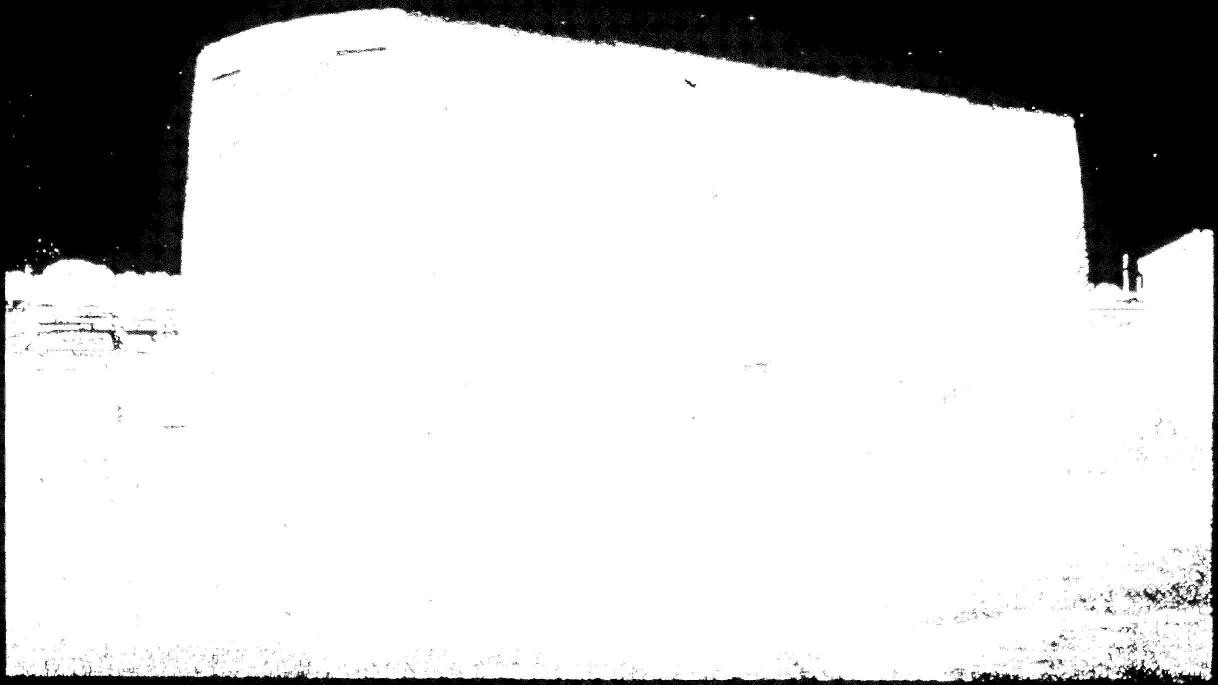


FIGURE 3-2 PHASE II PROTOTYPE URBAN VEHICLE P40

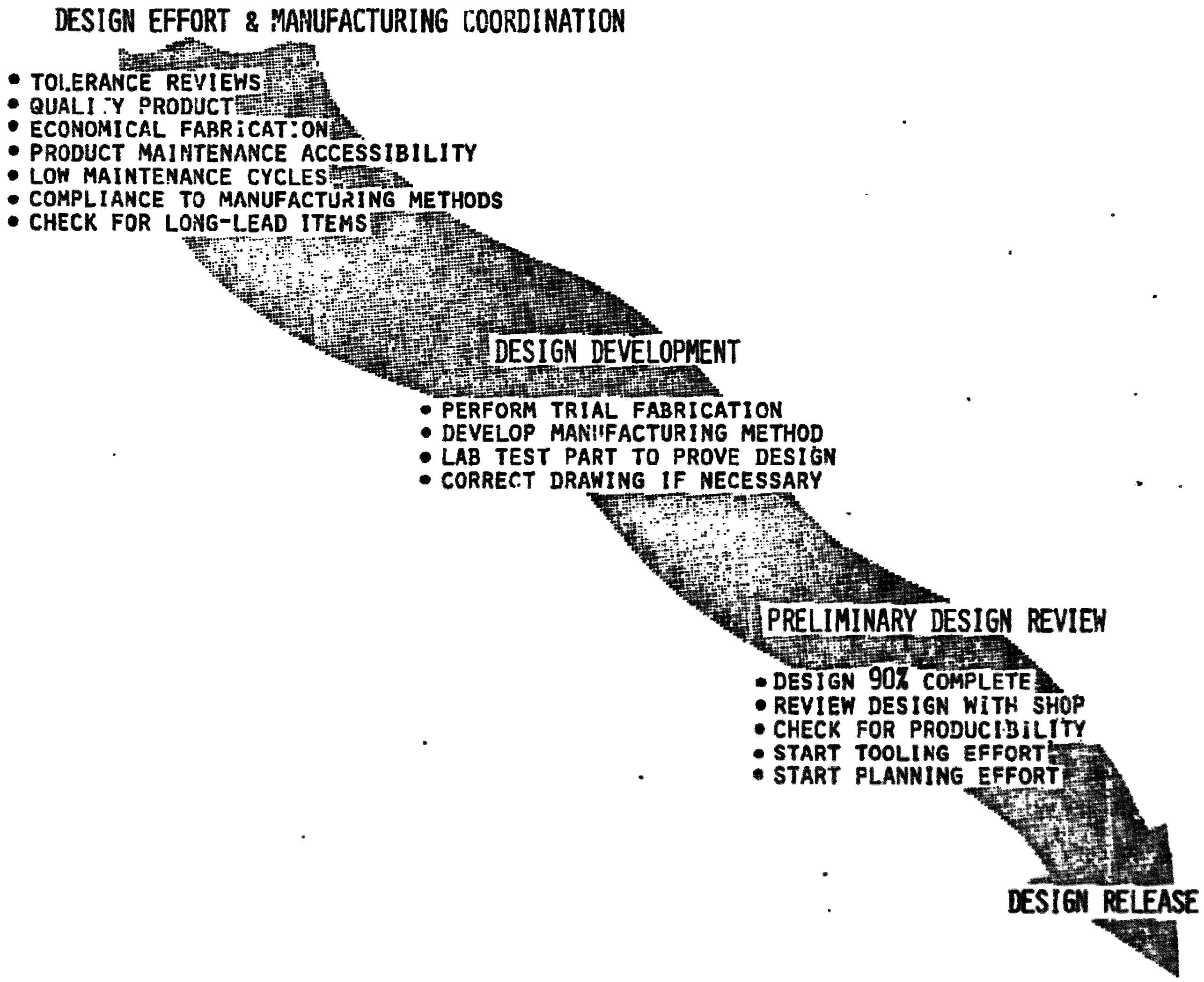


FIGURE 3-3 VEHICLE DESIGN-TO-COST ENGINEERING/MANUFACTURING COORDINATION

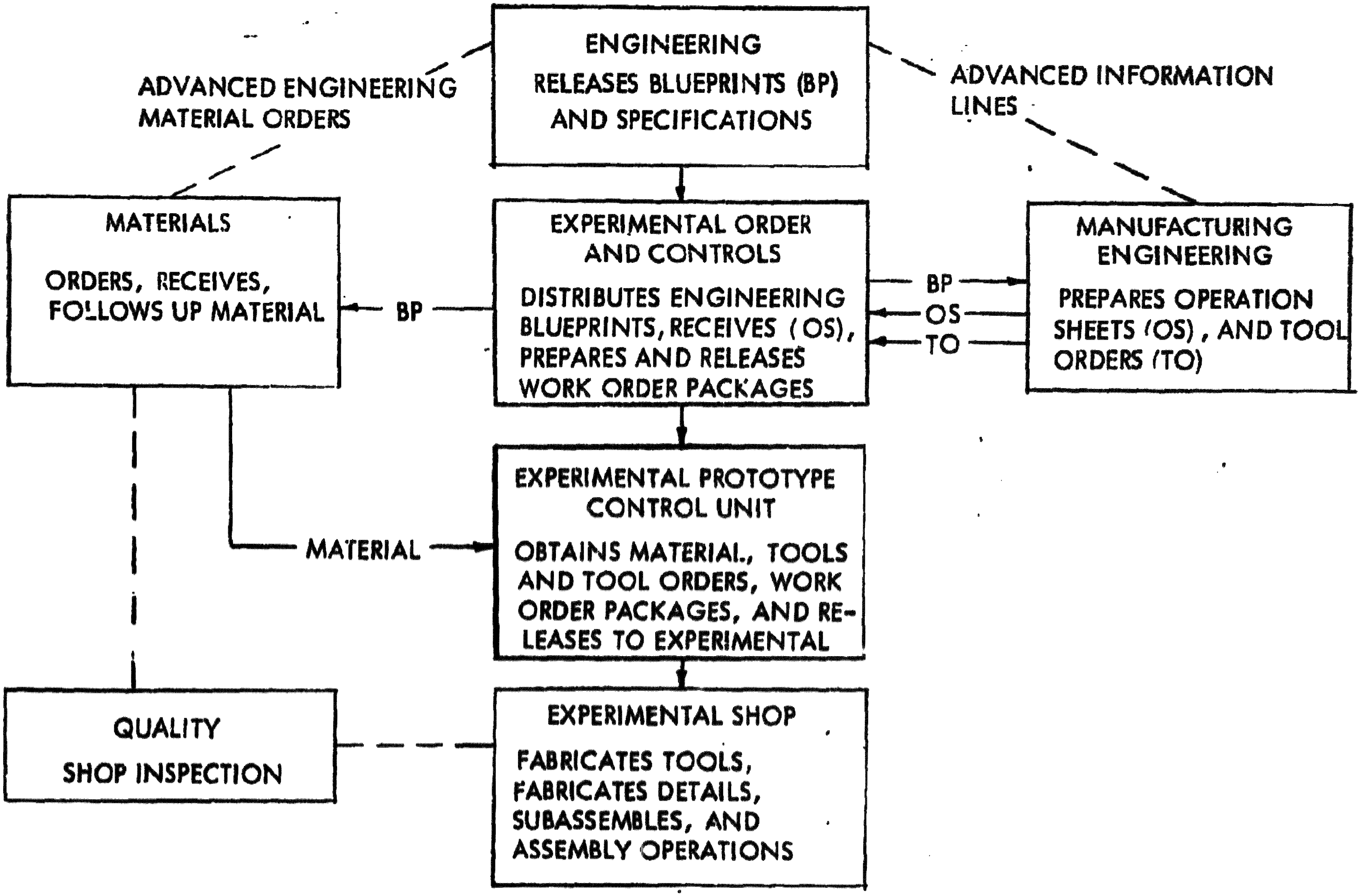


FIGURE 3-4 PROTOTYPE (EXPERIMENTAL) ORDERING AND CONTROL FLOW CHART

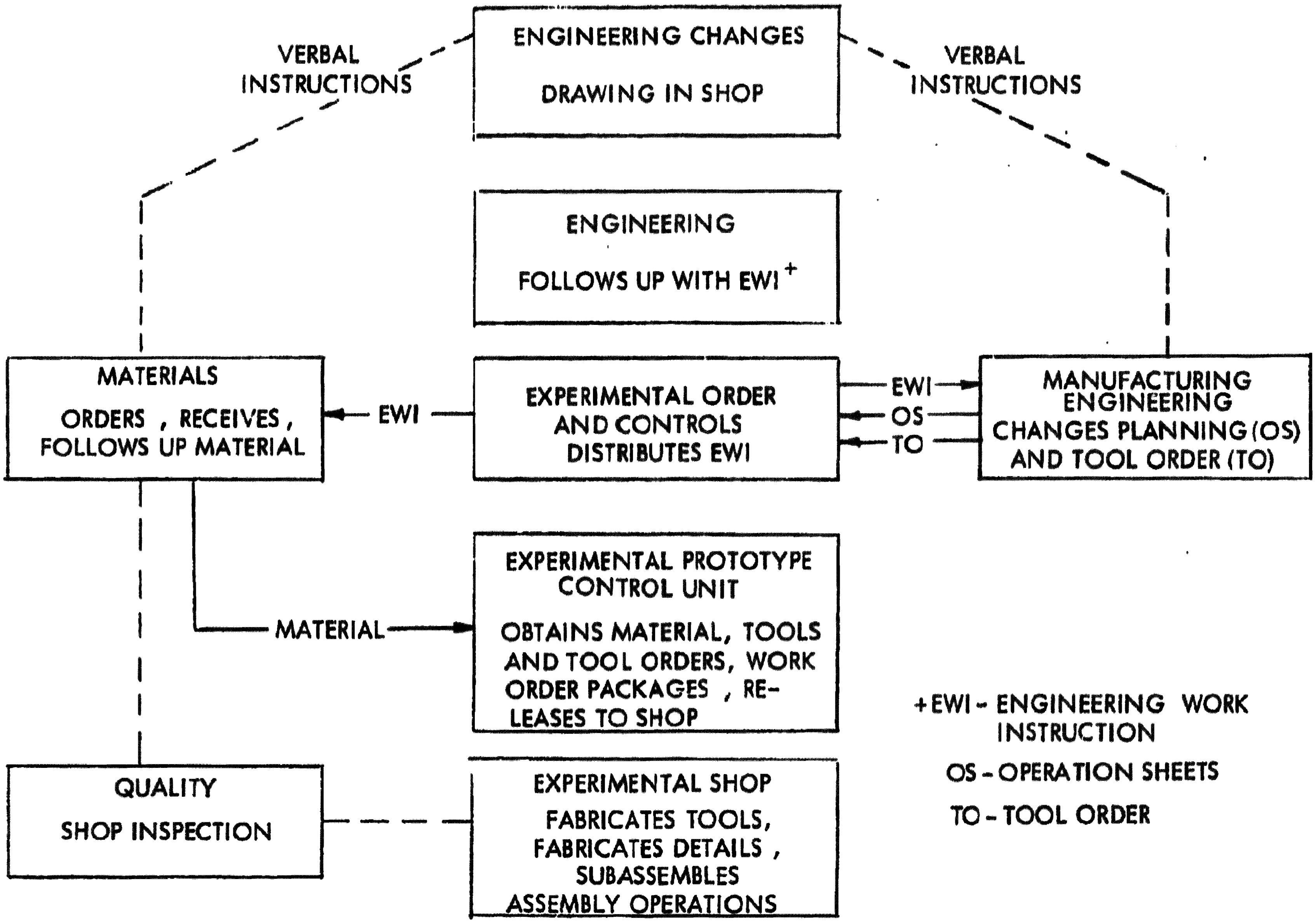


FIGURE 3-5 PROTOTYPE CHANGE CONTROL

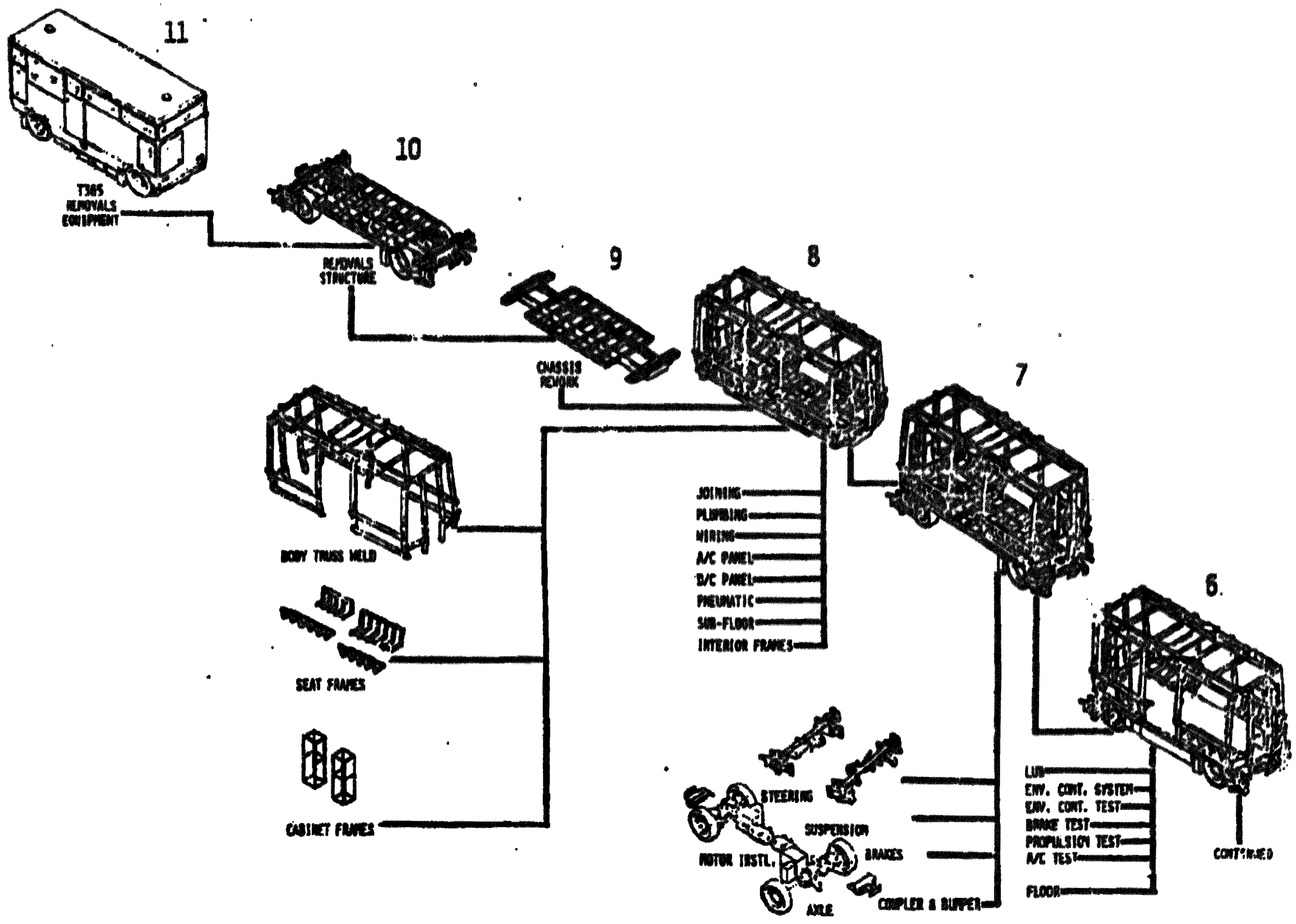


FIGURE 3-6 P40 PROTOTYPE VEHICLE ASSEMBLY

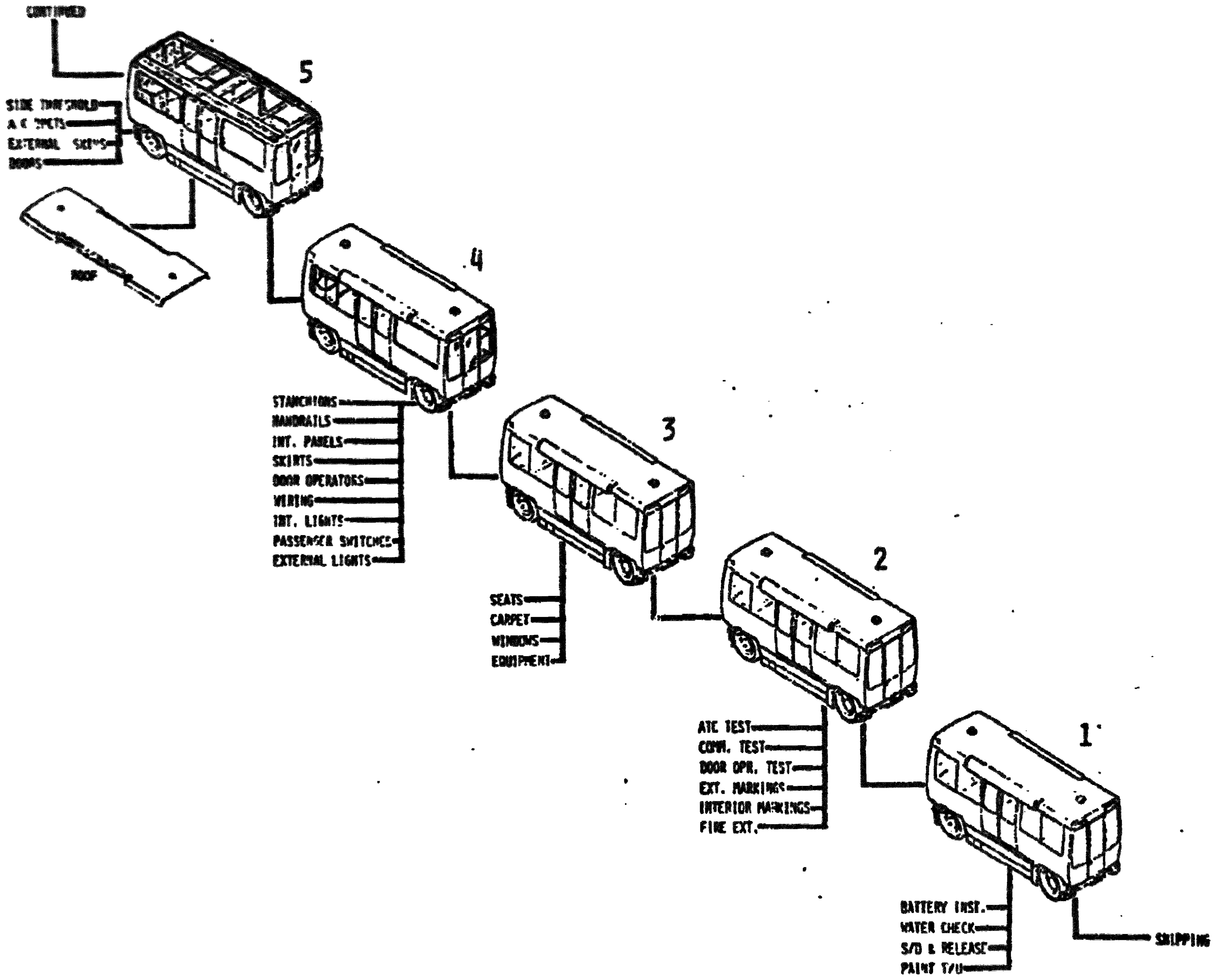


FIGURE 3-7 P40 PROTOTYPE VEHICLE ASSEMBLY

In Figure 3-6, station 11 denotes removal of T365 equipment. The T365 test vehicle had an aluminum body which housed test equipment and personnel. The aluminum body was removed along with all of the test equipment and vehicle subsystem equipment. Equipment planned to be a part of the P40 vehicle was retained in the fabrication area for installation. At stations 11 and 10, all T365 equipment and structure was removed. The chassis was reworked into the P40 configuration at station 9. The new body truss, seat frames, electronic cabinet frames, plumbing, electrical wiring, subflooring, pneumatic equipment and dc and ac panels) were installed at station 9. The assembly, installation and inspection efforts were continued as shown in Figure 3-7 until P40 was functionally checked out and delivered for testing and demonstration. Figures 3-6 and 3-7 present the assemblies as line stations for quantity production; however, P40 was fabricated in one location. Figure 3-8 presents the axle subassembly as an example of how the subassemblies were built up and in turn entered the next assembly.

3.3 FABRICATION SUMMARY

Prototype vehicle P40 was fabricated utilizing production line planning, tooling and methods. The same tooling and techniques can be used by Vought to produce urban vehicles.

A single-vehicle-unit fabrication effort such as the P40 vehicle encountered procurement problems peculiar to the situation. Some potential equipment suppliers did not respond to requests for equipment and materials, and some who did, placed a minimum buy in their response. This compelled Vought to design and fabricate the components in its shop or look for alternate methods to fill the fabrication need. This type of problem should be alleviated on a production run.

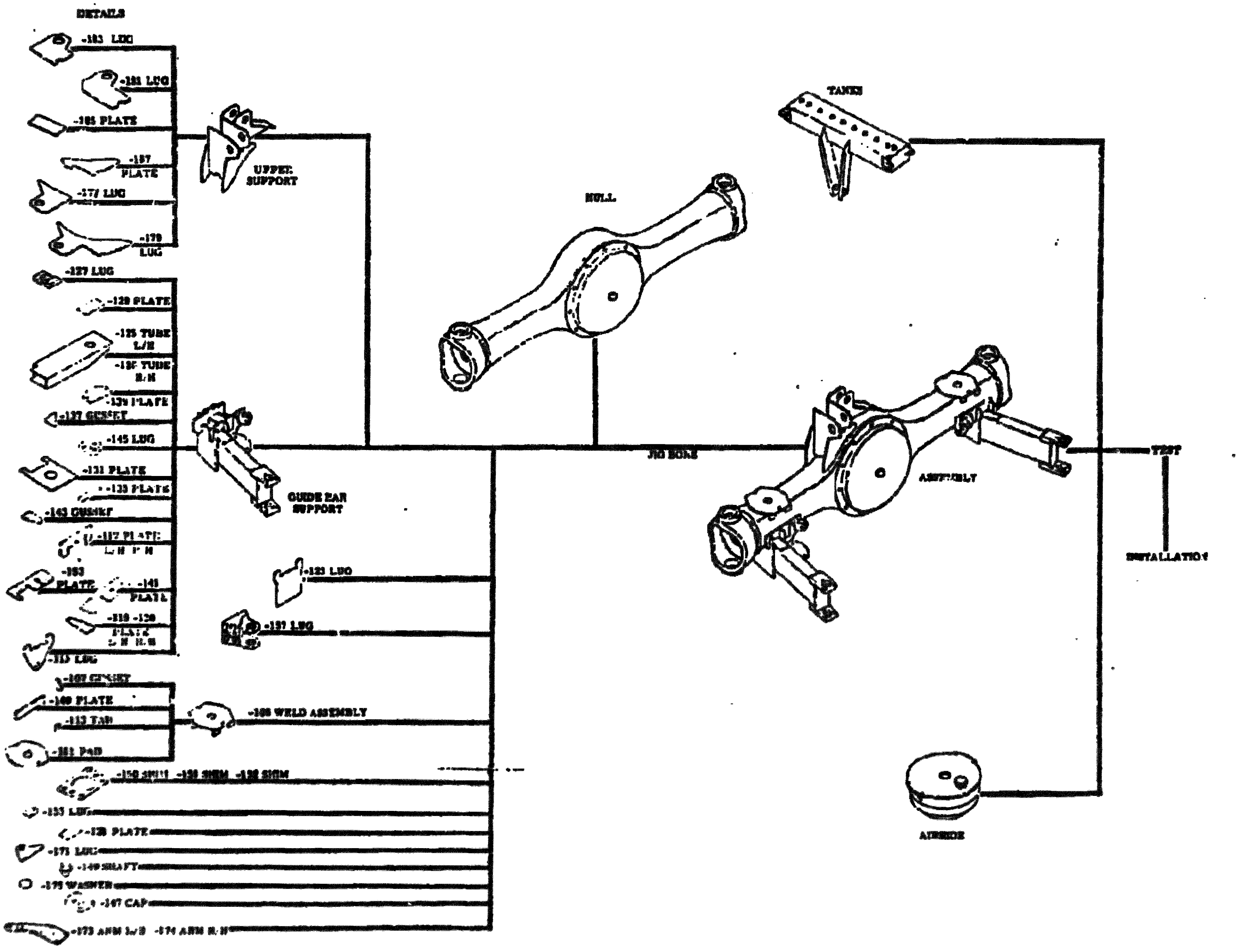


FIGURE 3-8 P40 AXLE ASSEMBLY

fixture with simulated door weights or installed on the vehicle, was as follows:

(1) Check clearances by cycling operator to ensure binding does not exist and that microswitches are functioning properly. Assure that the auto-locking solenoid and reel chords are functioning properly is during cycling operation.

(2) Run operator from fully open to fully closed and locked position. Movement should be smooth throughout travel. If motion is not smooth near the end of the stroke, adjust "close check" screw until smooth operation occurs.

(3) Run operator from fully closed and locked position to fully open position. Movement should be smooth throughout travel and if motion is not smooth near the end of the stroke, adjust "open check" screw until smooth operation occurs.

(4) Run operator from fully open to fully closed and locked position. If closing operation is not completed within 2 to 3 seconds, adjust "close speed" screw until closing operation time fails within these limits.

(5) Run operator from fully closed and locked to fully open position. If closing operation is not completed within 2 to 3 seconds, adjust "open speed" screw until opening operation time falls within these limits.

(6) If closing force exceeds 30 pounds, equally adjust spring-loaded screws in top of roller bearing block to provide 30-pound maximum closing force.

For the operator installed on the vehicle, the following additional tests were run:

(1) Initiate door closing cycle. While door is closing, obstruct one of the door sensitive edges. When the sensitive edge is depressed, door close cycle shall be interrupted and door shall stop. Remove obstruction from door; after a short time delay, door close cycle shall resume and door shall close and lock. Repeat this procedure for the mating sensitive edge.

(2) With door closed and locked, lift emergency door release handle inside vehicle; this action shall require no more than 8 pounds of force. Door auto-lock cam shall retract, allowing the door to be opened manually. Repeat this procedure using the external emergency door release handle.

Several problem areas were revealed in the performance of these tests, including:

(1) Rigging the electric operator is more sensitive than rigging the pneumatic operator. To increase rigging tolerance, the electric operator should continue to apply a closing force at the end of the closing action like the pneumatic operator rather than turn off. A modification has been incorporated to provide this capability.

(2) Inadvertent shorting of circuitry in the electric operator damaged several components in the dc motor control circuit. Better circuit protection is needed.

(3) Leads on rheostats in the motor control circuit were flimsy. Rheostats with stronger leads were installed.

(4) A cord reel on the electric operator is in a vulnerable position and was knocked off during operator cover removal. Care must be exercised by maintenance personnel to avoid damaging cord reels.

(5) Maintenance personnel must be cautious of hazardous 120-volt dc power in the electric operator.

(6) Retention of rod guides on the pneumatic actuator was inadequate and allowed the brushes which ride on the rods to drop off. Retention of the guides was improved.

After correcting some of the problems as discussed above, both the electric and pneumatic operators successfully performed the functions required for the biparting side doors.

The electric and pneumatic operators have demonstrated satisfactory performance at ambient conditions. For severe weather conditions, refer to Volume 6. Improvements should be incorporated in the operators during production design to eliminate or minimize the problems discussed.

4.3.3 AIR COMPRESSOR - The air compressor provides pressurized air for operating the left side biparting door, the suspension system, the friction brake system and the automatic steering reversing system. The direct drive, two-cylinder reciprocating compressor supplied by Atlas Copco is installed beneath the vehicle floor and is accessible from the outside of the vehicle. The compressor operates continuously while its output is controlled by a bypass unloader valve.

The three categories of testing were conducted in the following manner:

(1) The severe weather testing, which is documented in detail in Volume 6, consisted of installing the compressor and the remainder of the vehicle pneumatic system in an environmental chamber simulating the actual vehicle installation. The system was then subjected to various stabilized temperature conditions from room temperature to -30°F and operated with and without ice accumulations.

(2) During the severe weather testing, a failure of the 2-horsepower compressor drive motor was experienced which was attributed to excessive starting torques when started from the cold-soaked conditions. A development test was formulated to determine the starting characteristics of the compressor with 2- and 3-horsepower motors. Each motor/compressor combination was tested at room temperature and then cold soaked to stabilized temperatures to -30°F. Root-mean-square (RMS) current measurements were recorded on an oscillograph and analyzed at each starting condition.

(3) A design verification test was performed to verify the published compressor capacity which had been used in system performance calculations. In this test, the compressor was operated at various stabilized flow and discharge pressure conditions to establish a performance envelope. Two different compressor air intake configurations were tested.

The test results for each of the previously described tests are as follows:

(1) Severe weather testing results are described in Volume 6 and basically showed that:

    (a) Even though the compressor air intake did not exhibit ice blockage, it is apparent that this is a significant problem in other applications, particularly in blowing snow. Therefore, caution must be used in the selection of the location, type and capacity of the intake to guard against this blockage.

    (b) The compressor unloader valve and other critical valves require special attention to assure that protection in the form of heating or moisture-free air is supplied.

    (c) The output of the unloader valve heater should be approximately 50 watts to provide safety margin and to reduce the initial warmup time requirement.

(2) The motor-starting current tests and results are summarized in Table 4-2. Typical graphs of the data are shown in Figures 4-3 and 4-4. The 3-horsepower ASEA drive motor was selected for use on the AUTP vehicle. The excessive starting torque required for the compressor was attributed primarily to the lubricating oil recommended by the manufacturer. The use of a low-temperature or multigrade oil is desirable to reduce starting and running torques.

(3) The results of the compressor delivery capacity tests are shown in Figure 4-5. Capacity of all tested configurations was below the published capacity of the unit. The supplier (Atlas Copco, Wayne, New Jersey) attributed the condition to variations between the test hardware which was used to generate the published data and the production hardware tested by Vought. The front-access filter manifold configuration is used on the AUTP vehicle. The decreased capacity will result in a slight increase in the predicted 26% pumping (loaded) time of a typical urban application.

4.3.4 STEERING SYSTEM - The steering system of P40 incorporates design concepts developed during AUTP Phase I, in addition to the Phase II improvements. The system consists of single guide/switchwheels mounted on each end of the guidebar to steer the vehicle from the guideway wall. Guidebar motion is transmitted by the steering link to one wheel and to the opposite wheel through the tie rod. Volume 3 gives a detailed description of the system. Figure 4-6 shows a schematic of the steering system for reference in this volume. The P40 steering system, with the Phase II improvements, was tested to obtain stiffness and dynamic response characteristics.

4.3.4.1 Guidebar Tests - Guidebar impedence and load stroke tests were performed on the steering system to determine its static and dynamic response characteristics.

The tests were conducted on the aft end of a complete vehicle which weighed approximately 18,100 pounds. The tires were placed on dry concrete with the guidebar unrestrained. Frequency sweeps were made with an electrohydraulic shaker controlling a displacement of ±0.10 inch at the left rear switchwheel. Vehicle test runs were made with several parameters varied. A summary of the test runs conducted is shown in Table 4-3.

TABLE 4-2 AIR COMPRESSOR MOTOR CURRENT MEASUREMENTS (PAGE 1 OF 4)

Run	Motor Config	Ambient Temperature (oF)	Maximum Starting Current (Amperes)	Time Start to Full Speed (Seconds)	Full-Load Running Amps	Unload Running Amps
1	2-hp Toshiba Initial start	68 (room temp)	22.4	0.4	3.6 at 129 psig	2.2
2	2-hp Toshiba start after 30-minute warmup	68 (room temp)	22.0	0.4	3.6 at 129 psig	2.2
3	2-hp Toshiba Initial start from cold soak condition	-29 (compressor oil -20oF)	27.0	Motor did not reach running speed	-	-
4	2-hp Toshiba Second start attempt from cold soak condition	-29 (compressor oil -20oF)	24.4	6.68	4.6 at 129 psig after 140-second run time	3.0
5	2-hp Toshiba Repeat of run 3	-30 (compressor oil -19.3oF)	26.0	2.66	4.8 at 129 after 67-second run time	3.0
5a	2-hp Toshiba	-30 (compressor oil +10oF)	-	-	3.6 at 129 psig after 15-minute run time	2.0
5b	2-hp Toshiba	-30 (compressor oil +16oF)	-	-	3.6 at 129 psig after 30-minute run time	

TABLE 4-2 AIR COMPRESSOR MOTOR CURRENT MEASUREMENTS (PAGE 2 OF 4)

Run	Motor Config	Ambient Temperature (°F)	Maximum Starting Current (Amperes)	Time-Start to Full Speed (Seconds)	Full-Load Running Amps	Unload Running Amps
5c	2-hp Toshiba	-30 (compressor oil +20°F)	-	-	3.6 at 129 psig after 45-minute run time	2.0
6	2-hp Toshiba Start after 45-minute run	-30 (compressor oil +20°F)	21.0	1.42	-	-
7	3-hp Toshiba Initial start	74 (room temp)	35.2	0.266	-	-
8	3-hp Toshiba Second start	74 (room temp)	34.6	0.28	3.8 at 128 psig	2.6
9	3-hp Toshiba Initial start from cold soak	-33 (compressor oil -20°F)	38.9	0.7	5.2 at 129 psig after 61-second run time	3.6
10	3-hp Toshiba Second start immediately after run 9	-33 (compressor oil -20°F)	37.0	0.42	-	-
11	3-hp ASEA Initial start	73 (room temp)	36.0	0.283	4.74 at 119 psig after 57-second run time	3.63
11a	3-hp ASEA 10 minutes after initial start	73.3 (compressor oil 74.4°F)	-	-	4.37	3.53

TABLE 4-2 AIR COMPRESSOR MOTOR CURRENT MEASUREMENTS (PAGE 3 OF 4)

Run	Motor Config	Ambient Temperature (oF)	Maximum Starting Current (Amperes)	Time-Start to Full Speed (Seconds)	Full-Load Running Amps	Unload Running Amps
11b	3-hp ASEA 15 minutes after initial start	74.3 (compressor oil 79.1oF)	-	-	4.37	3.53
11c	3-hp ASEA 20 minutes after initial start	74.6 (compressor oil 82.0oF)	-	-	4.37	3.53
11d	3-hp ASEA 25 minutes after initial start	75.1 (compressor oil 84.8oF)	-	-	4.37	3.53
11e	3-hp ASEA 30 minutes after initial start	75.3 (compressor oil 86.4oF)	-	-	4.37	3.53
12	3-hp ASEA Start after 30-minute warmup	73	36.0	0.25	Data not taken	Data not taken
13	3-hp ASEA Initial start	0	39.0	0.283	5.21 at 119 psig after 66-second run time	4.00

TABLE 4-2 AIR COMPRESSOR MOTOR CURRENT MEASUREMENTS (PAGE 4 OF 4)

Run	Motor Config	Ambient Temperature (oF)	Maximum Starting Current (Amperes)	Time-Start to Full Speed (Seconds)	Full-Load Running Amps	Unload Running Amps
13a	3-hp ASEA	0	-	-	4.93 at 119 psig after 145-second run time	3.99
14	3-hp ASEA Initial start	+20	45.2	0.283	5.12 at 119 psig after 52-second run time	4.00
14a	3-hp ASEA Initial start	+20	-	-	4.93 at 119 psig after 120-second run time	3.81
15	3-hp ASEA Initial start	-23.8 (compressor oil -20.6oF)	40.0	0.35	5.30 at 119 psig after 52-second run time	4.09
15a	3-hp ASEA	-23.8	-	-	5.20 at 119 psig after 80-second run time	4.09

Note: All current values are amps/phase at 450 volts ac line-to-line, and are RMS values.

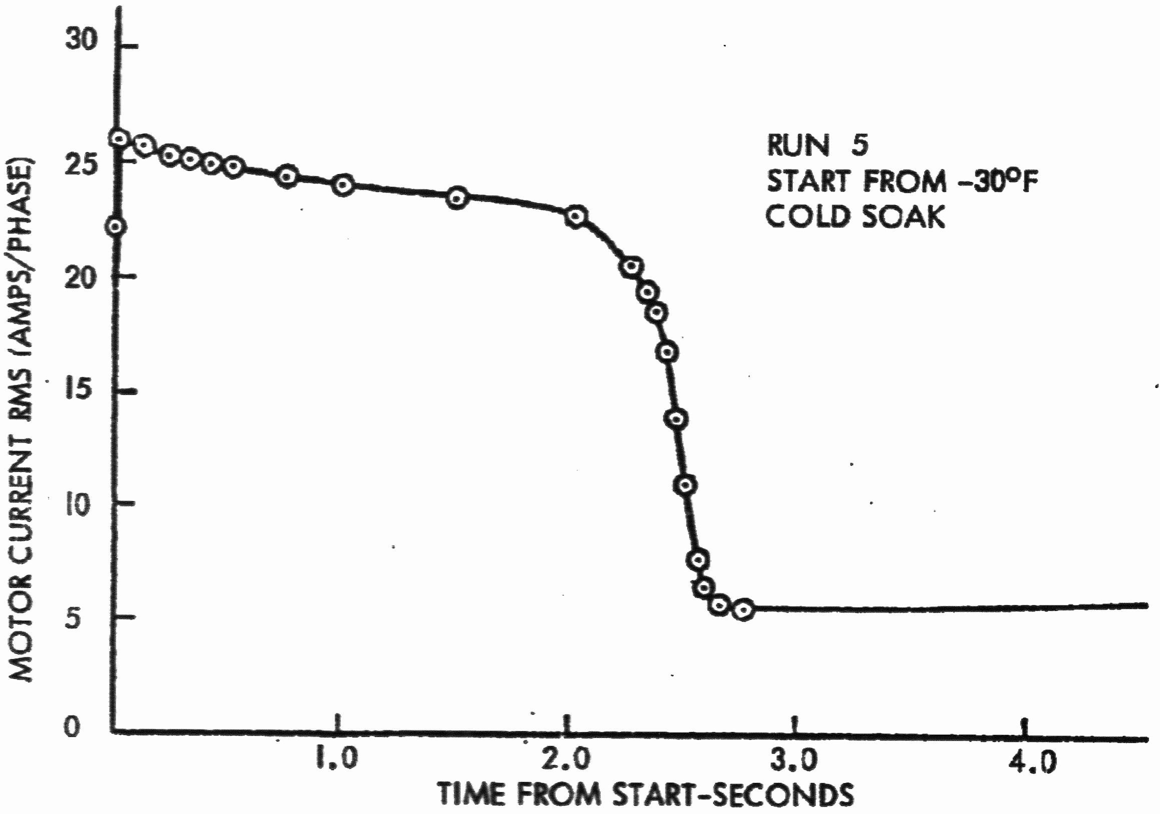


FIGURE 4-3 TWO-HORSEPOWER MOTOR STARTING CURRENT

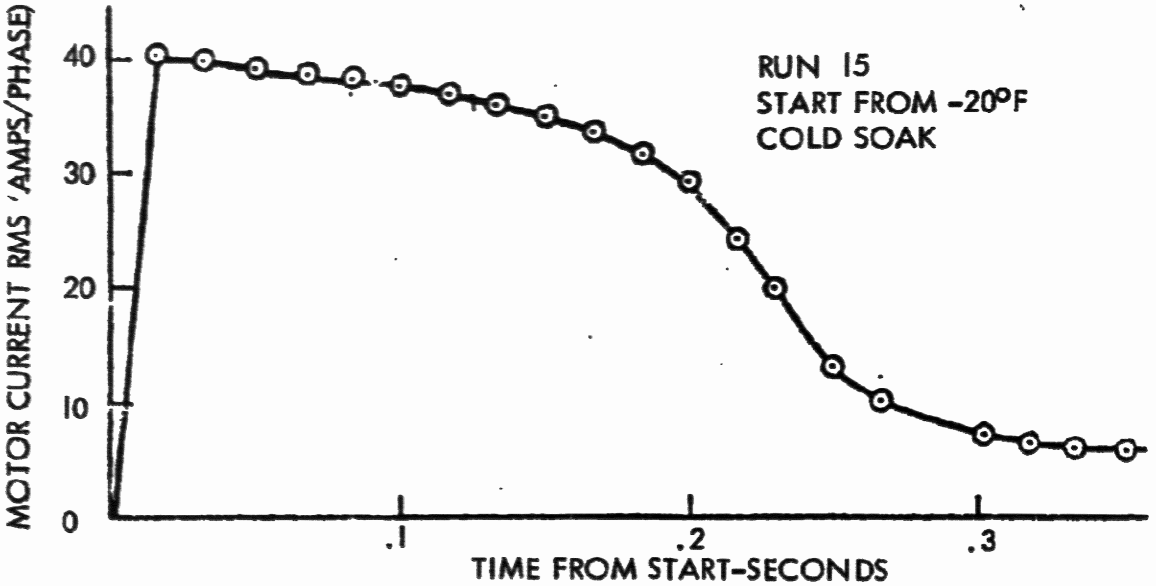


FIGURE 4-4 THREE-HORSEPOWER MOTOR STARTING CURRENT

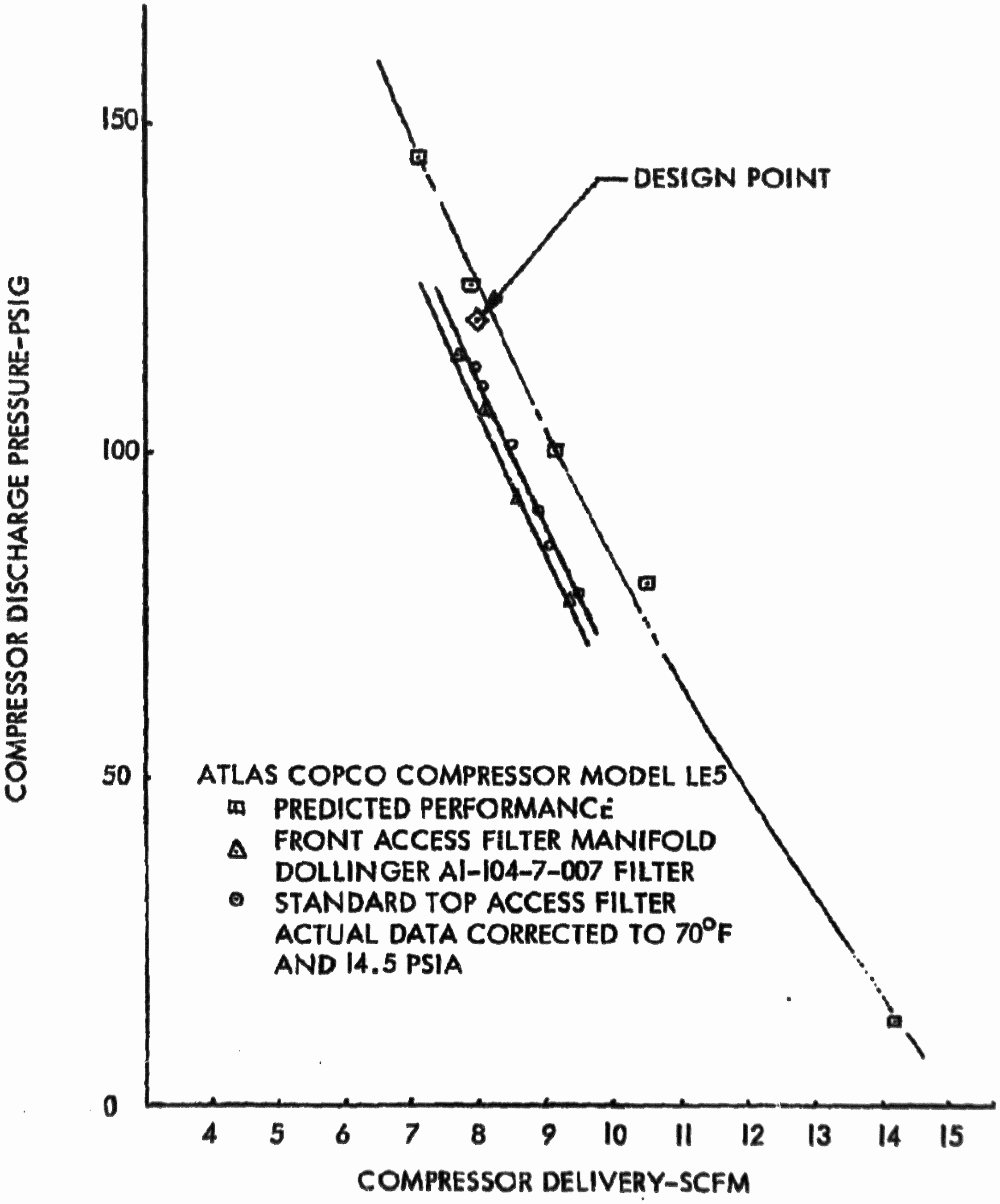


FIGURE 4-5 AIR COMPRESSOR PERFORMANCE

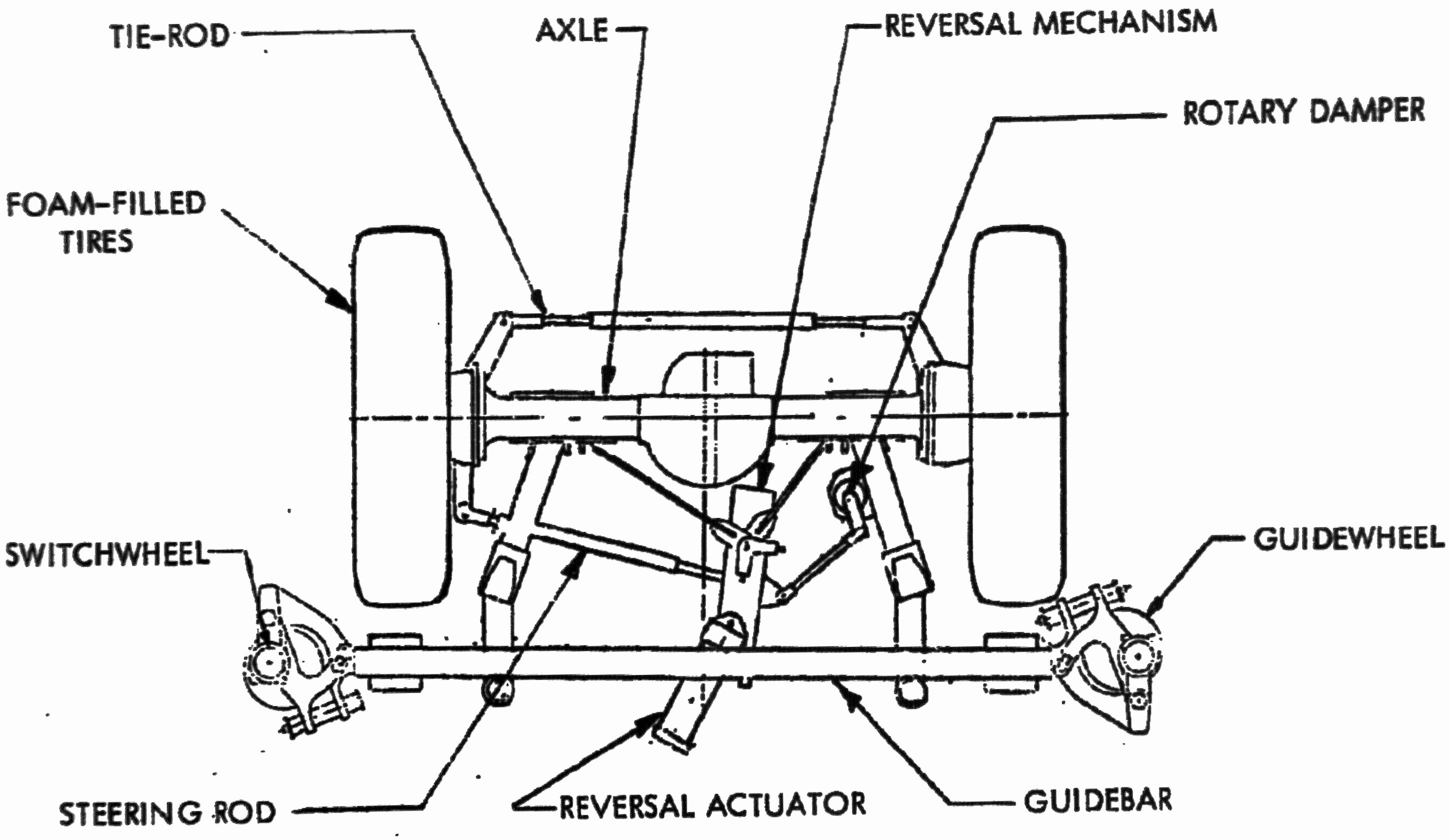


FIGURE 4-6 SCHEMATIC OF STEERING SYSTEM

TABLE 4-3 IMPEDANCE TEST CONFIGURATIONS

Run	Tires	Damper	Switchwheel Spring	Steering Direction
51	On jacks	Off	Soft	Forward
52	On jacks	On	Soft	Forward
53	On concrete	On	Soft	Forward
54	On concrete	Off	Soft	Forward
55	On concrete	Off	Medium	Forward
56	On concrete	On	Medium	Forward

Load/stroke tests were conducted under the same conditions as the impedance tests. The load/stroke tests were static (0.10 hertz) measurements and recorded by an X-Y plotter. The following plots were made for each test run:

(1) Guidebar displacement versus guidebar force

(2) Guidebar displacement versus steering link force

(3) Guidebar displacement versus kingpin rotation

Again, test runs were made with several parameters varied. A summary of the test runs conducted is shown in Table 4-4.

TABLE 4-4 LOAD/STROKE TEST CONFIGURATIONS

Run	Tires	Spring	Steering Actuator Position	Damper
26	On concrete	Medium	Extend	Connected
27	On concrete	Soft	Extend	Connected
28	On concrete	Soft	Retract	Connected
33	Slip	Soft	Retract	Connected
34	Slip	Soft	Extend	Connected
35	Slip	Soft	Extend	Disconnected
38	Slip	Soft	Retract	Disconnected

The single spring-loaded guide/switchwheel design was tested independently of the steering system. This test was run to define and verify the stiffness characteristics of the soft and medium rubber spring design from the Phase I steering system. The guide/switchwheel tests were conducted by blocking the guidebar against lateral movement while applying a lateral load to the switchwheel axle and then to the guidewheel axle. Figure 4-7 shows a schematic of the test setup, and Figure 4-8 presents a photograph of the test.

Impedance test results are presented in Figures 4-9 and 4-10. A resonance frequency of 9 hertz was measured for the steering system with the tires on and off concrete. There appears to be a trend to a second resonance that cannot be substantiated, since it is outside the limits of the test. The resonance points are much more predominant with the rotary damper removed, as shown in Figure 4-9, test runs 54 and 55. The damper connected test curves, runs 53 and 56, exhibit the requirement for a damper. These curves indicate the system is isolated from resonance points to the 22-hertz limits of the test. The soft-spring, damper connected configuration, run 53, is an acceptable design, based on the lower impedance values resulting in lower loads and furnishing resonance isolation.

Guidebar load/stroke curves are presented in Figures 4-11 through 4-17. These curves present effects on the steering system when varying the following parameters:

(1) Tires on concrete versus tires on slip plates

(2) Soft springs versus medium springs

(3) Damper on versus damper off

(4) Retract versus extend reversing actuator position

The test results show, in comparing the effects of items (1) through (3), that there is only a slight variation in the measured data. This is expected for items (2) and (3). For item (1), the slight difference is explained by the small guidebar displacement of ±0.60 inch, which represents tire deflection only and not the concrete or slip plate effects. There is a variation

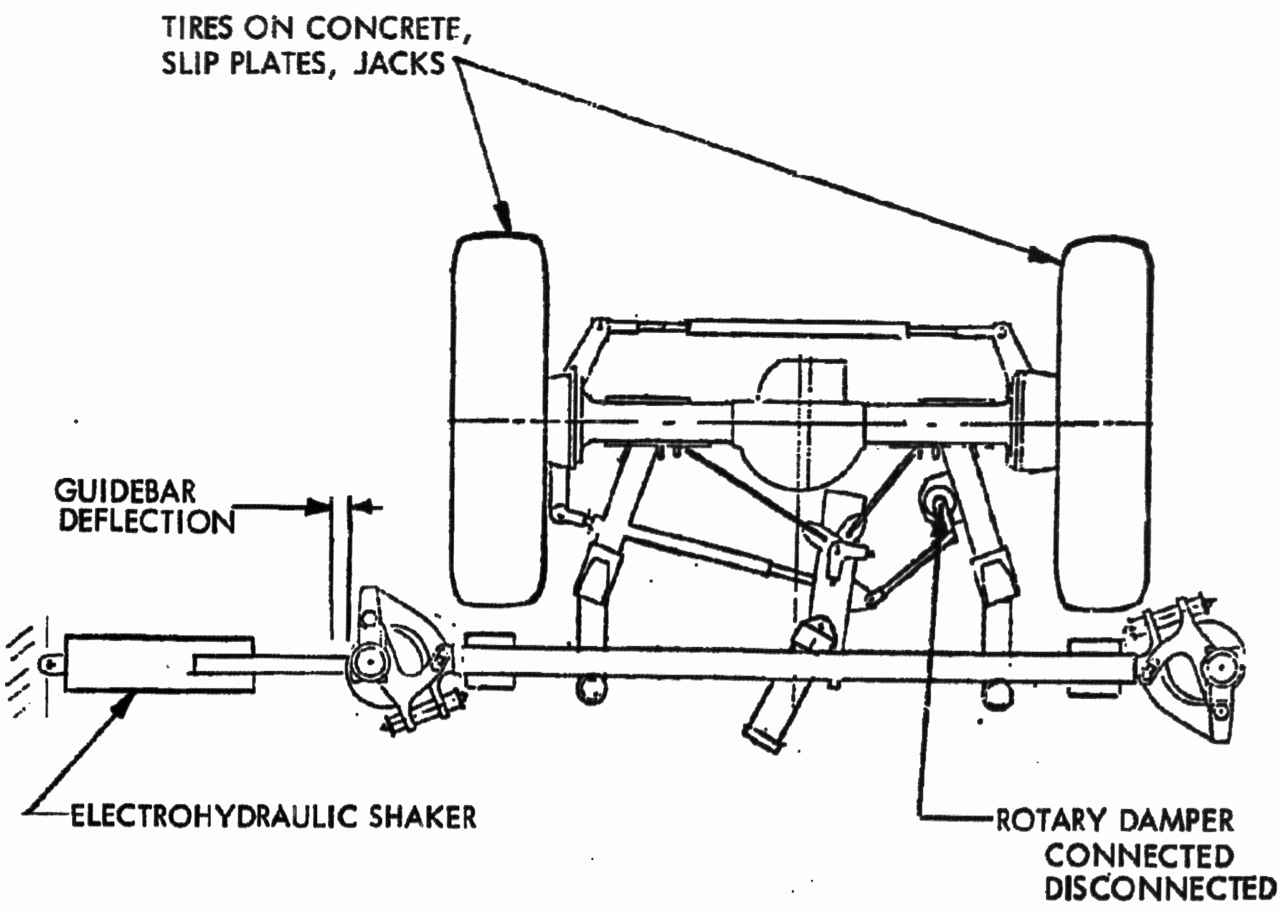


FIGURE 4-7 SCHEMATIC OF STEERING SYSTEM TEST SETUP

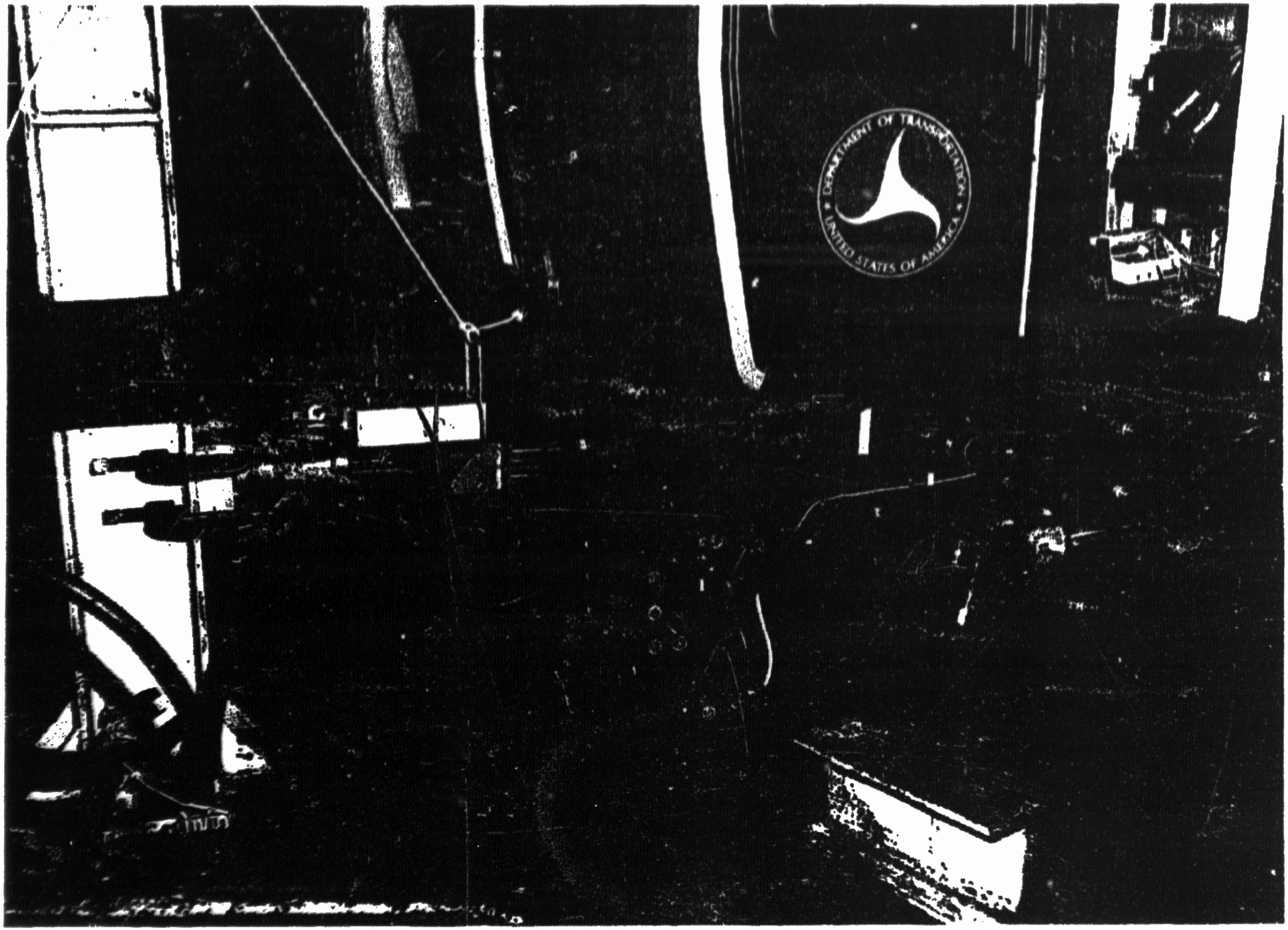


FIGURE 4-8 PHOTOGRAPH OF STEERING SYSTEM TEST

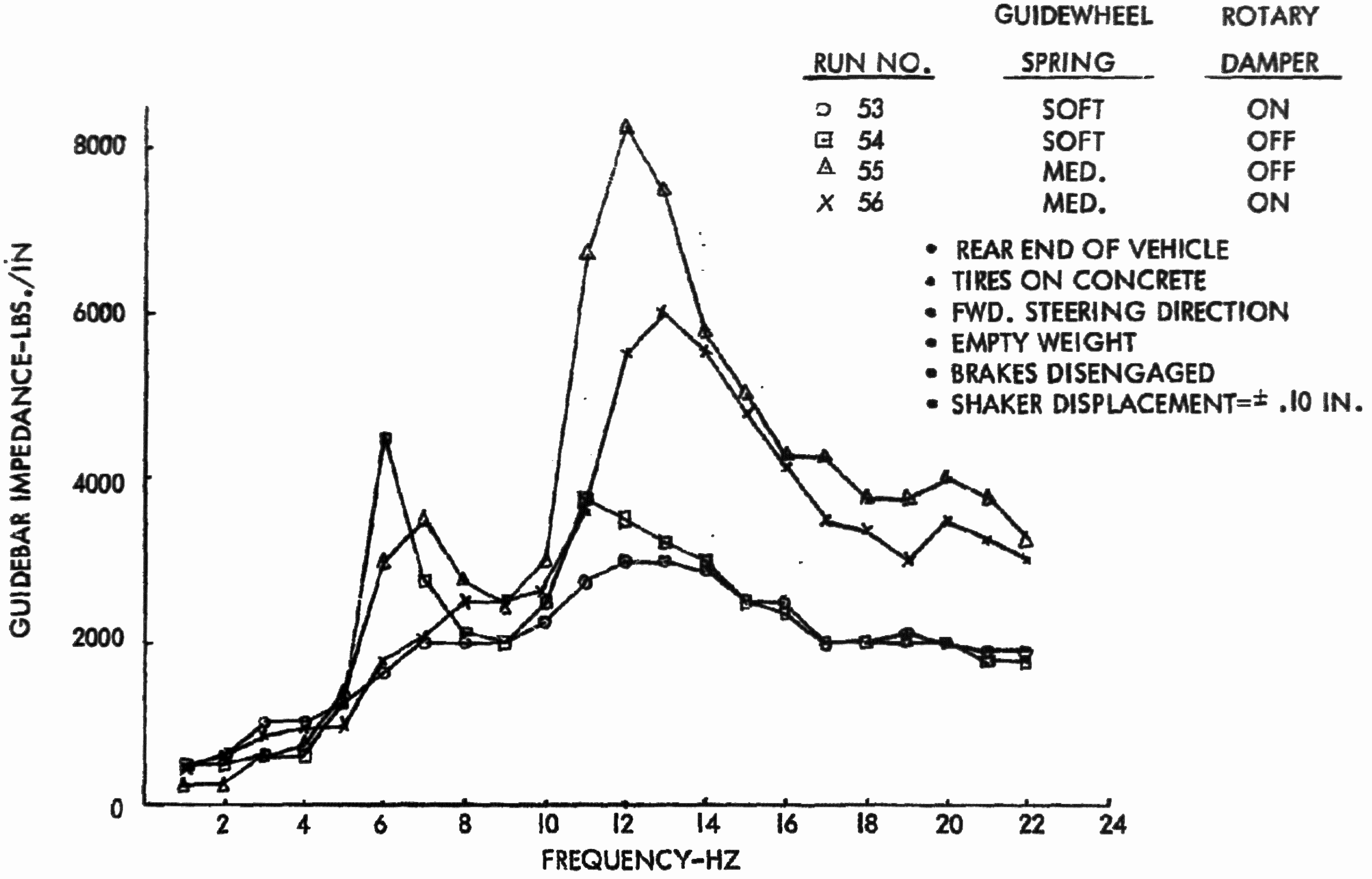


FIGURE 4-9 GUIDEBAR IMPEDANCE CURVES

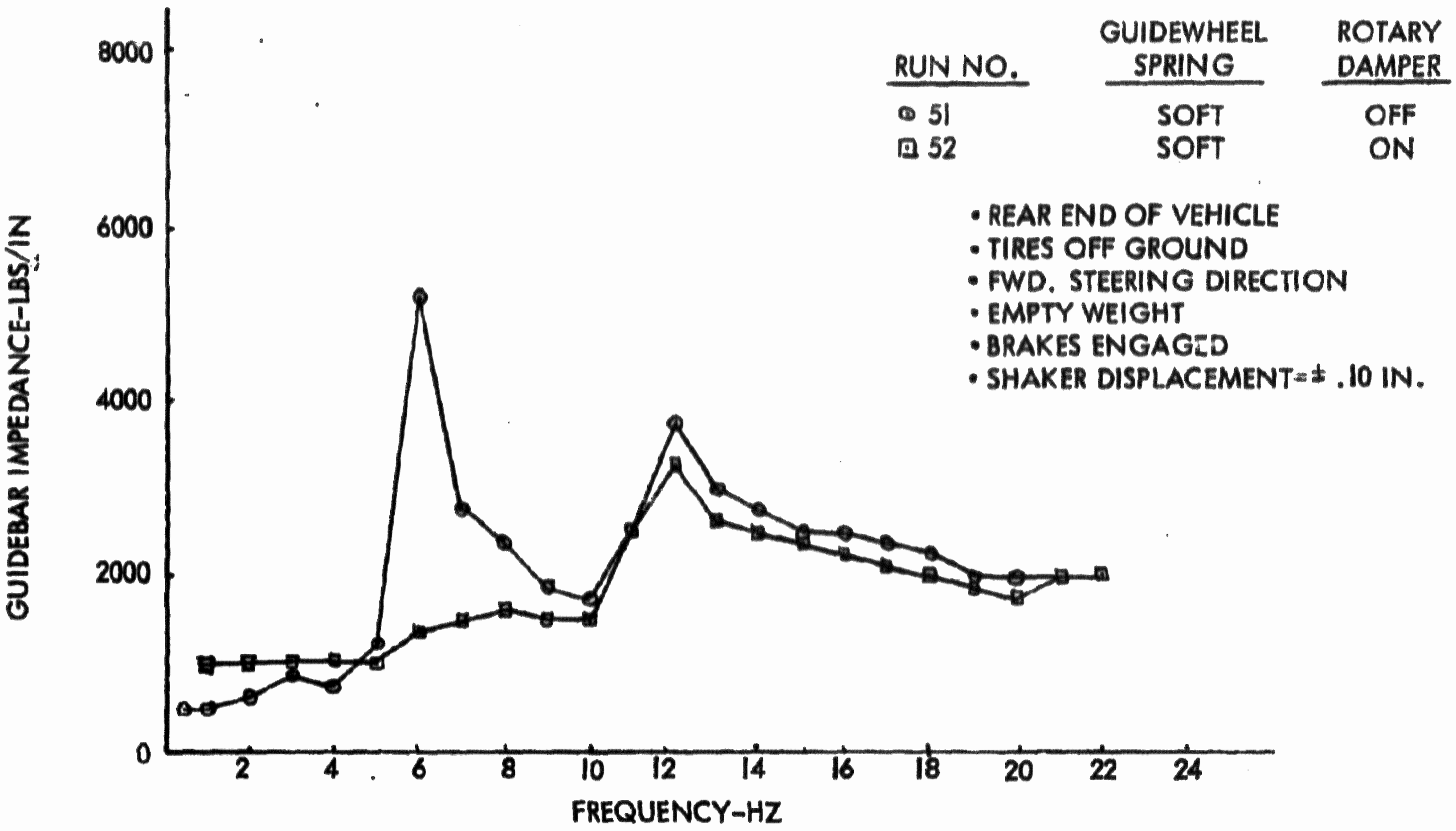


FIGURE 4-10 GUIDEBAR IMPEDANCE CURVES

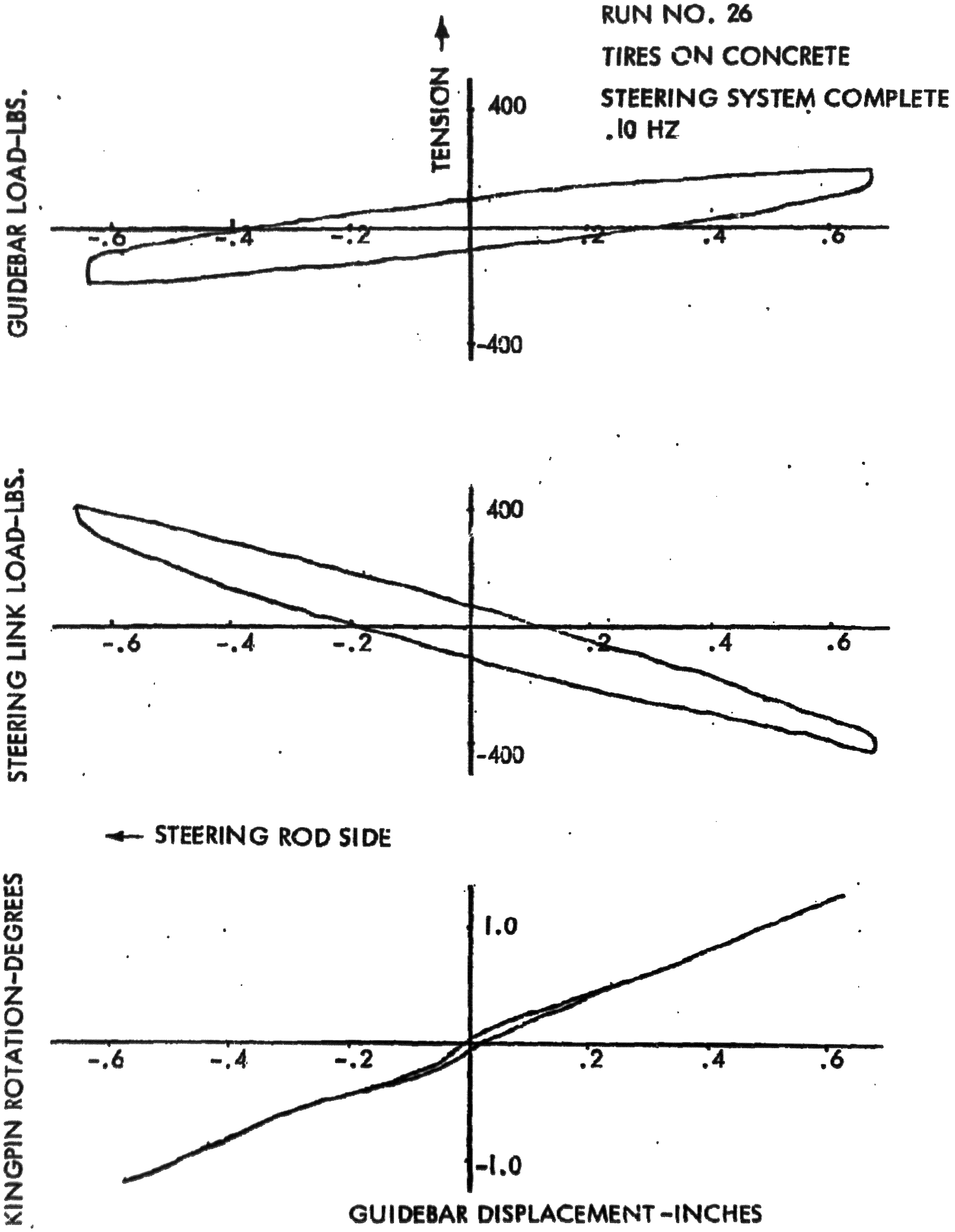


FIGURE 4-11 GUIDEBAR LOAD/STROKE CURVES, RUN NO. 26

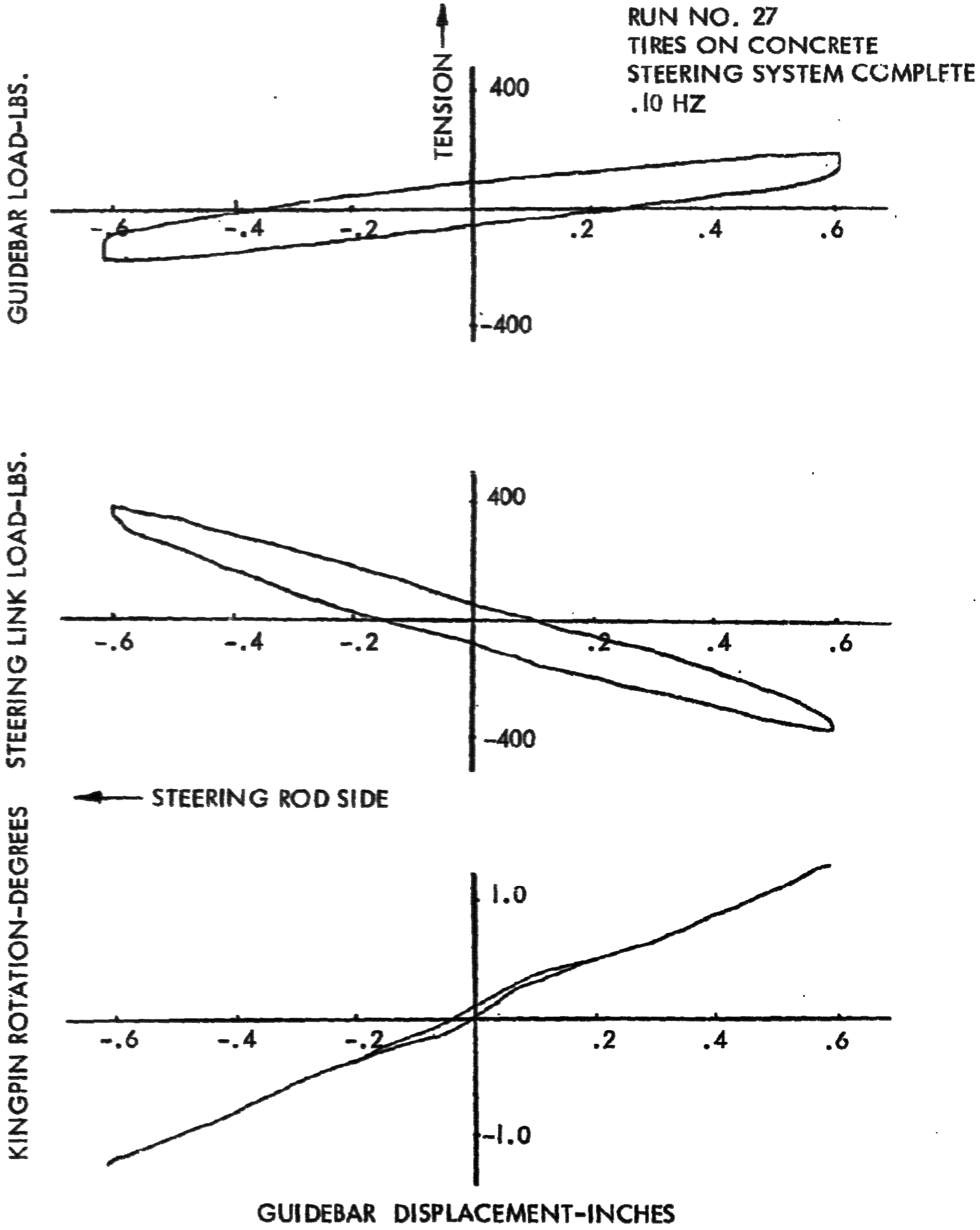


FIGURE 4-12 GUIDEBAR LOAD/STROKE CURVES, RUN NO. 27

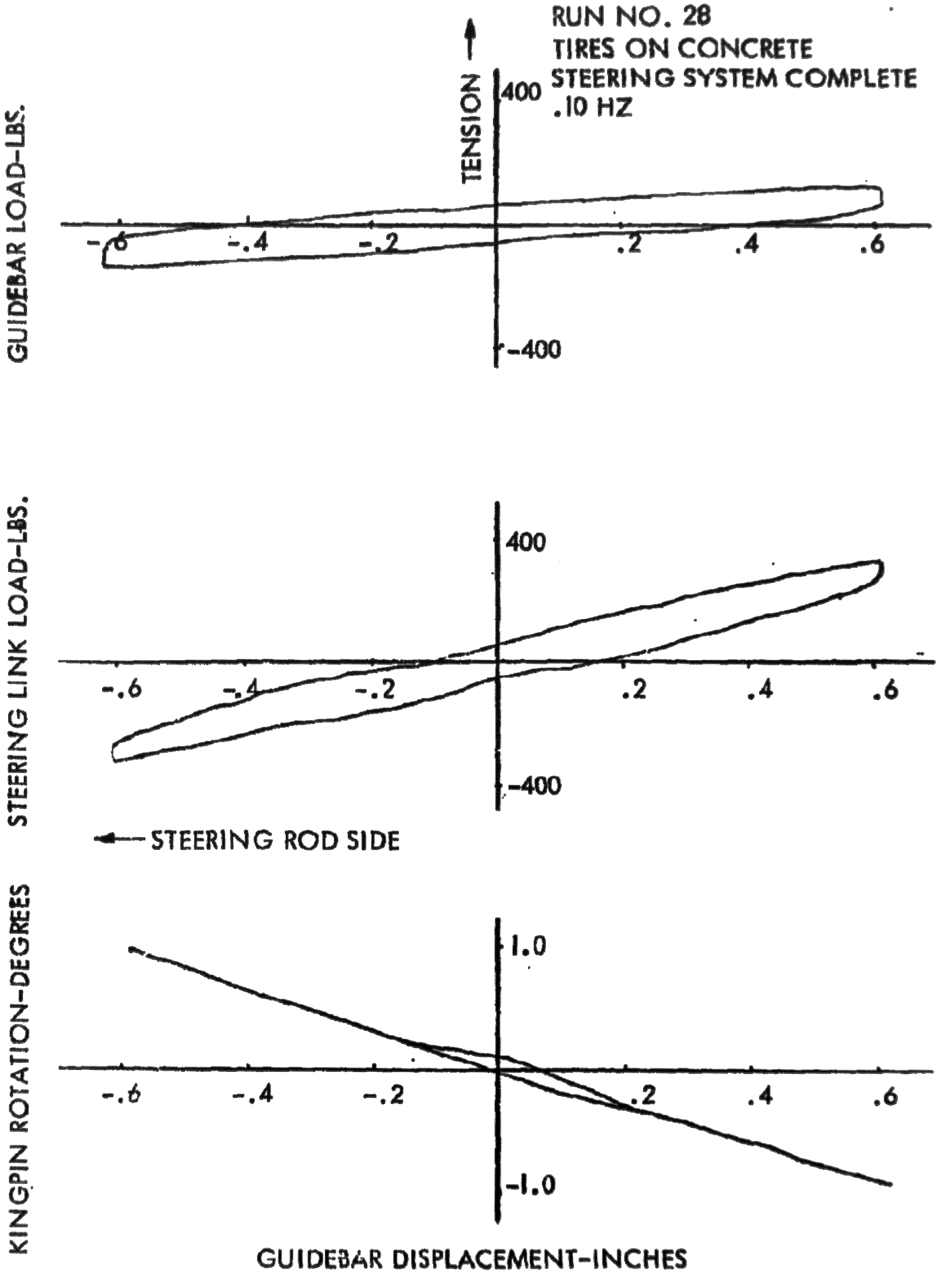


FIGURE 4-13 GUIDEBAR LOAD/STROKE CURVES, RUN NO. 28

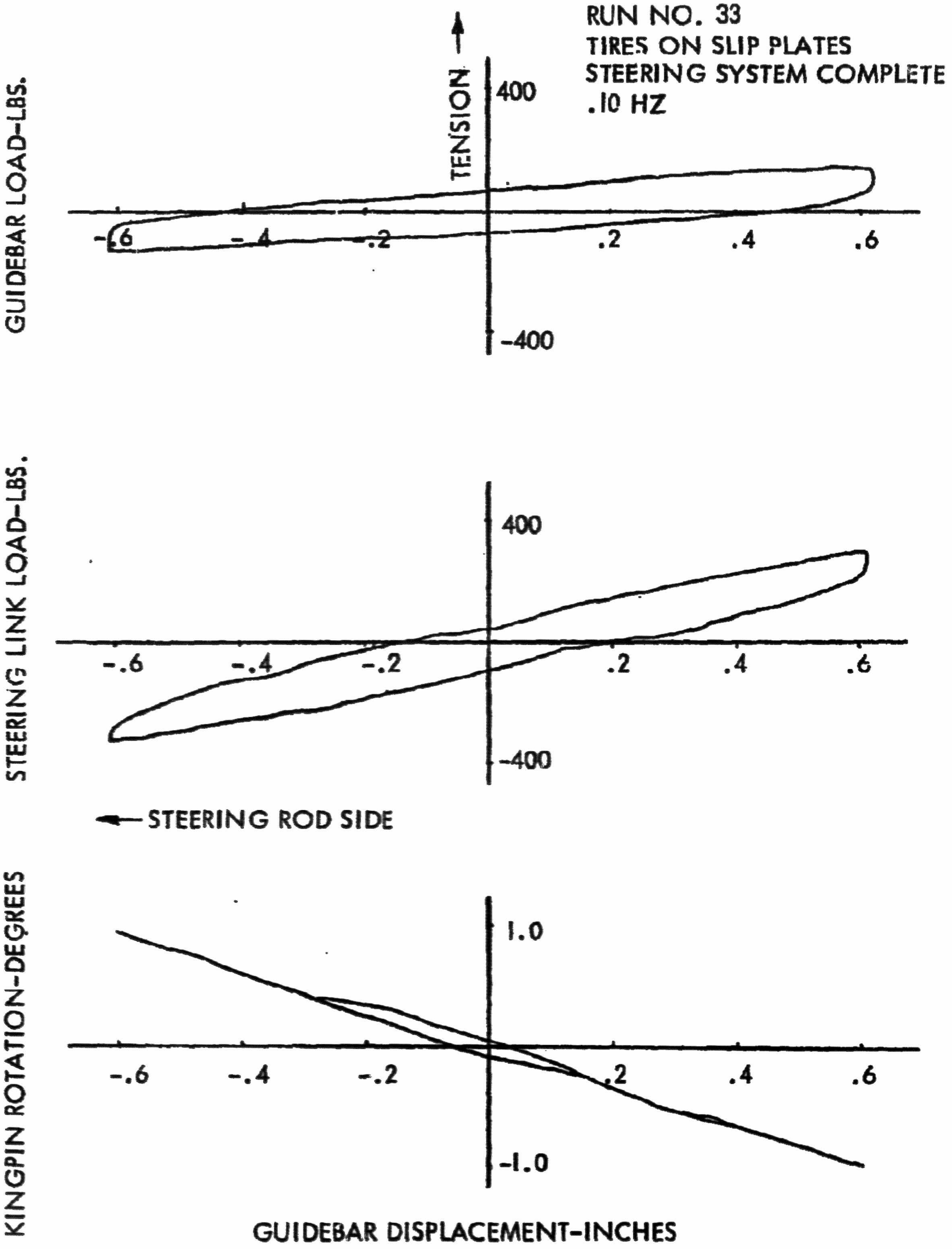


FIGURE 4-14 GUIDEBAR LOAD/STROKE CURVES, RUN NO. 33

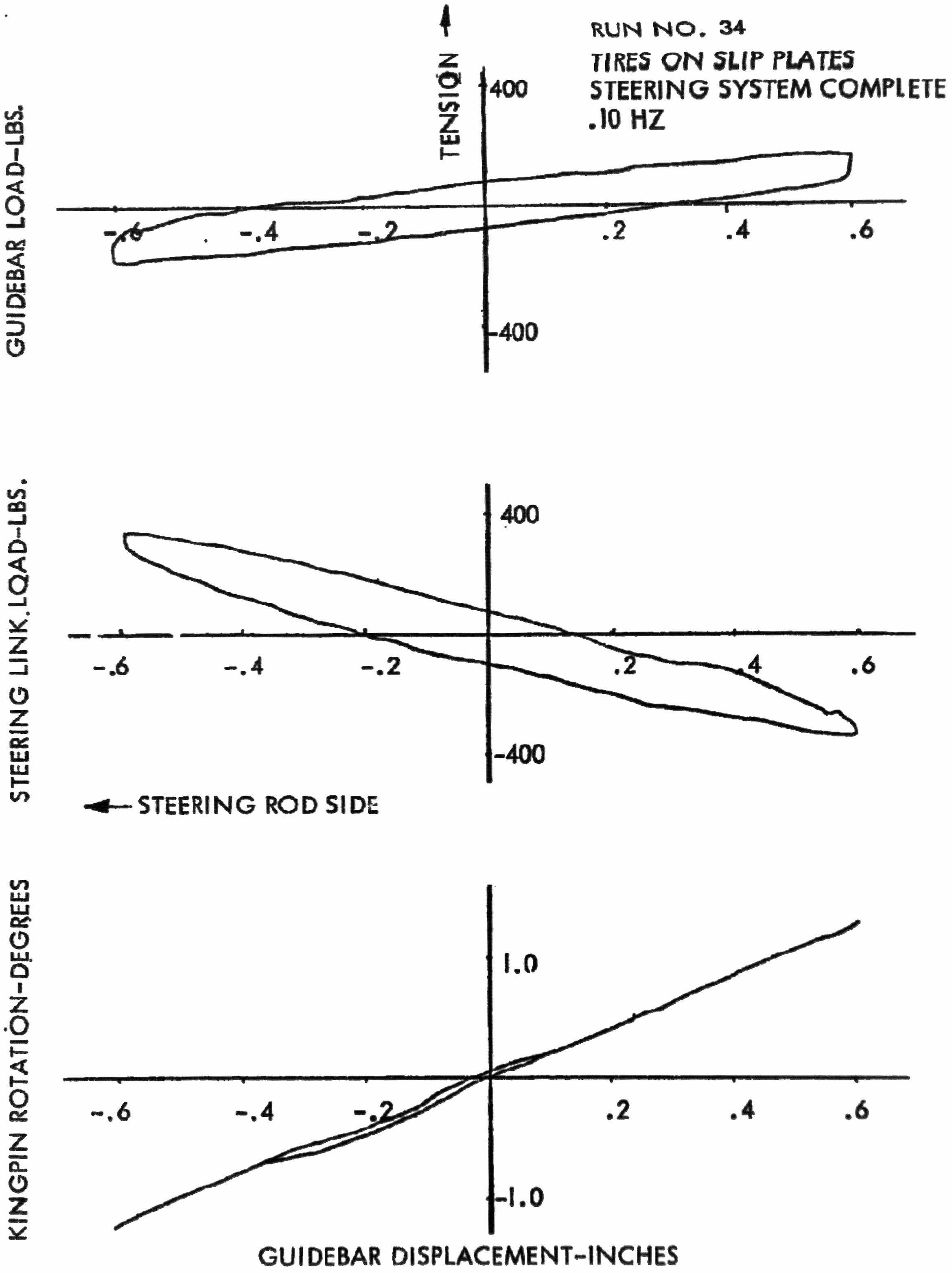


FIGURE 4-15 GUIDEBAR LOAD/STROKE CURVES, RUN NO. 34

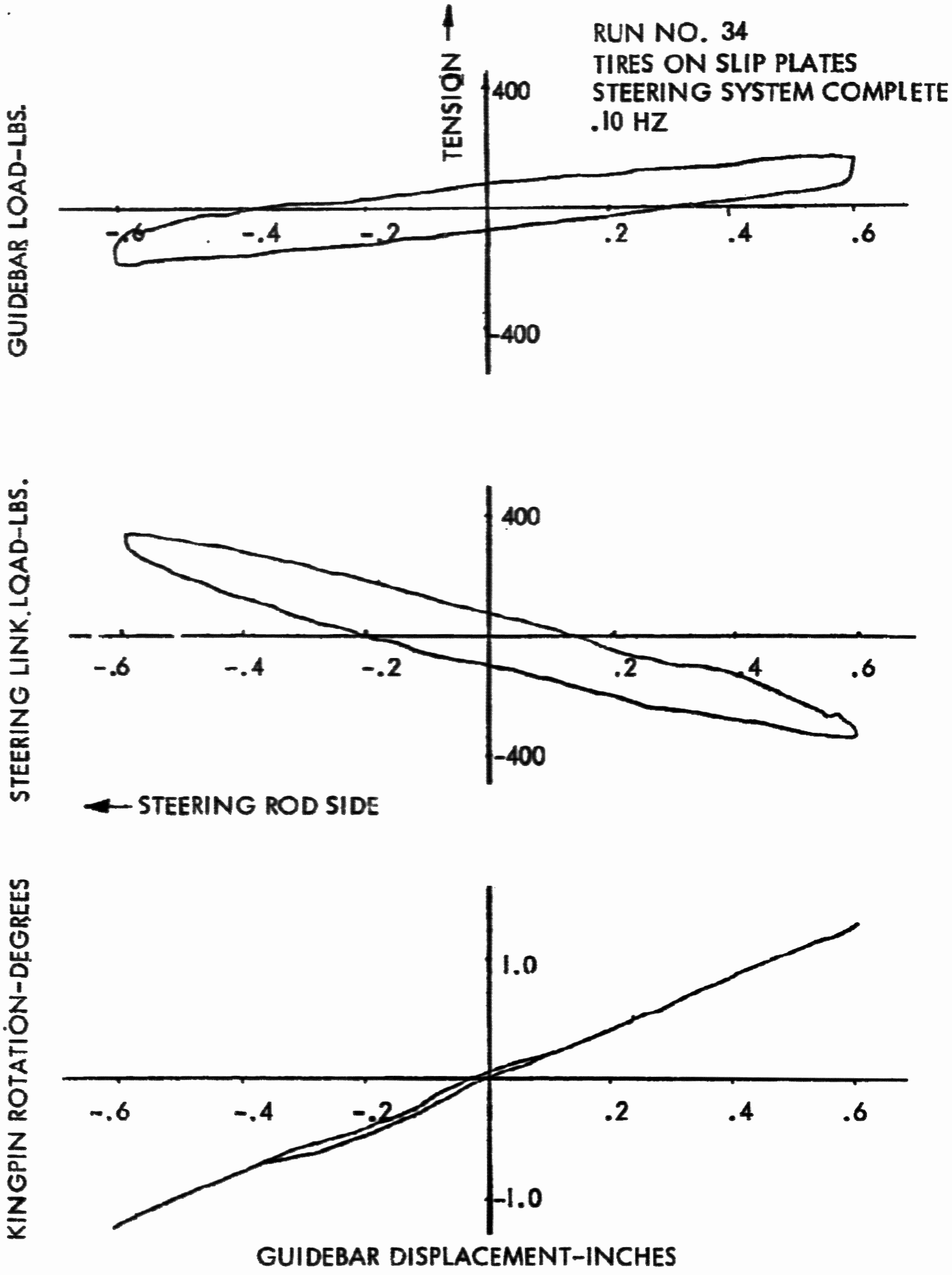


FIGURE 4-15 GUIDEBAR LOAD/STROKE CURVES, RUN NO. 34

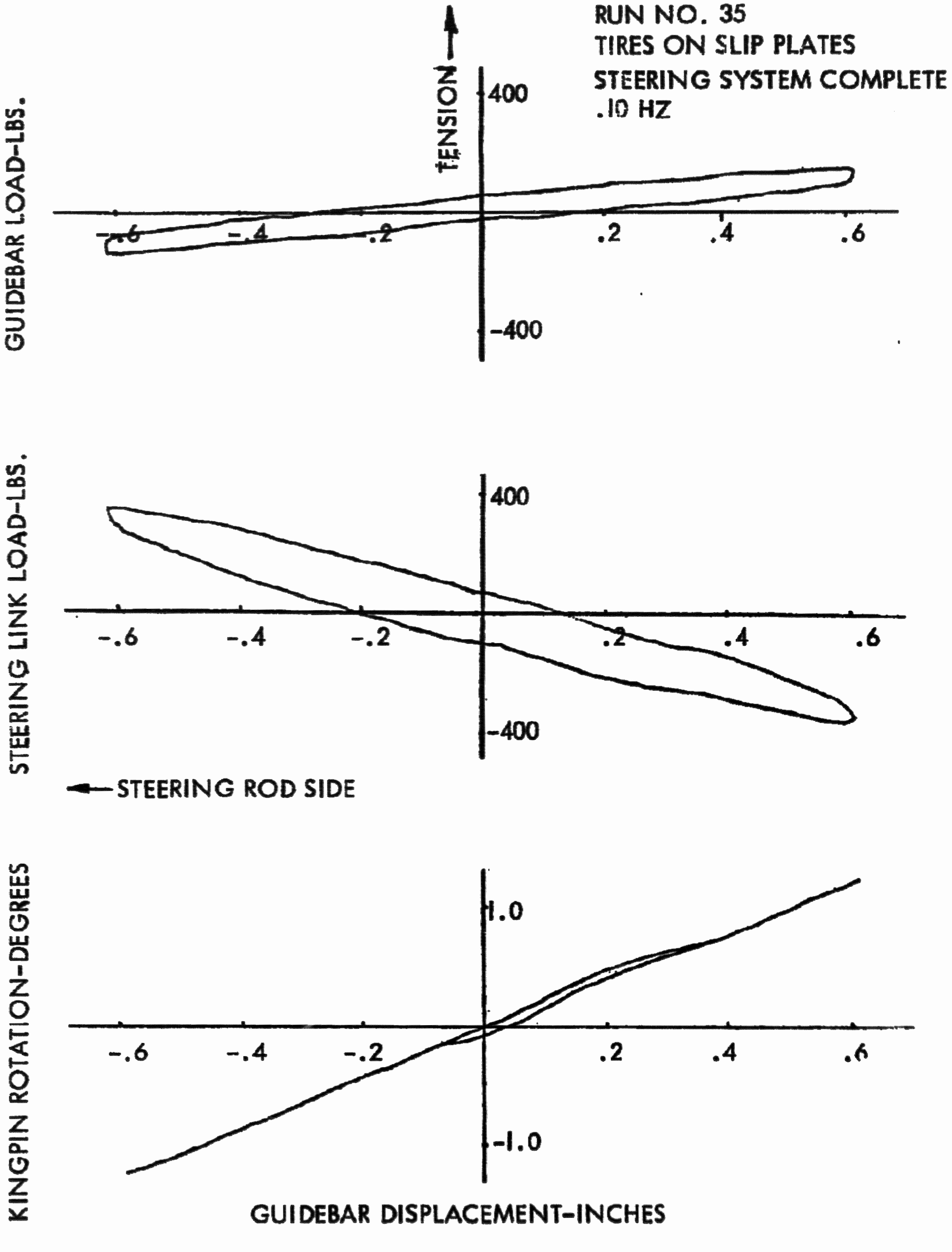


FIGURE 4-16 GUIDEBAR LOAD/STROKE CURVES, RUN NO. 35

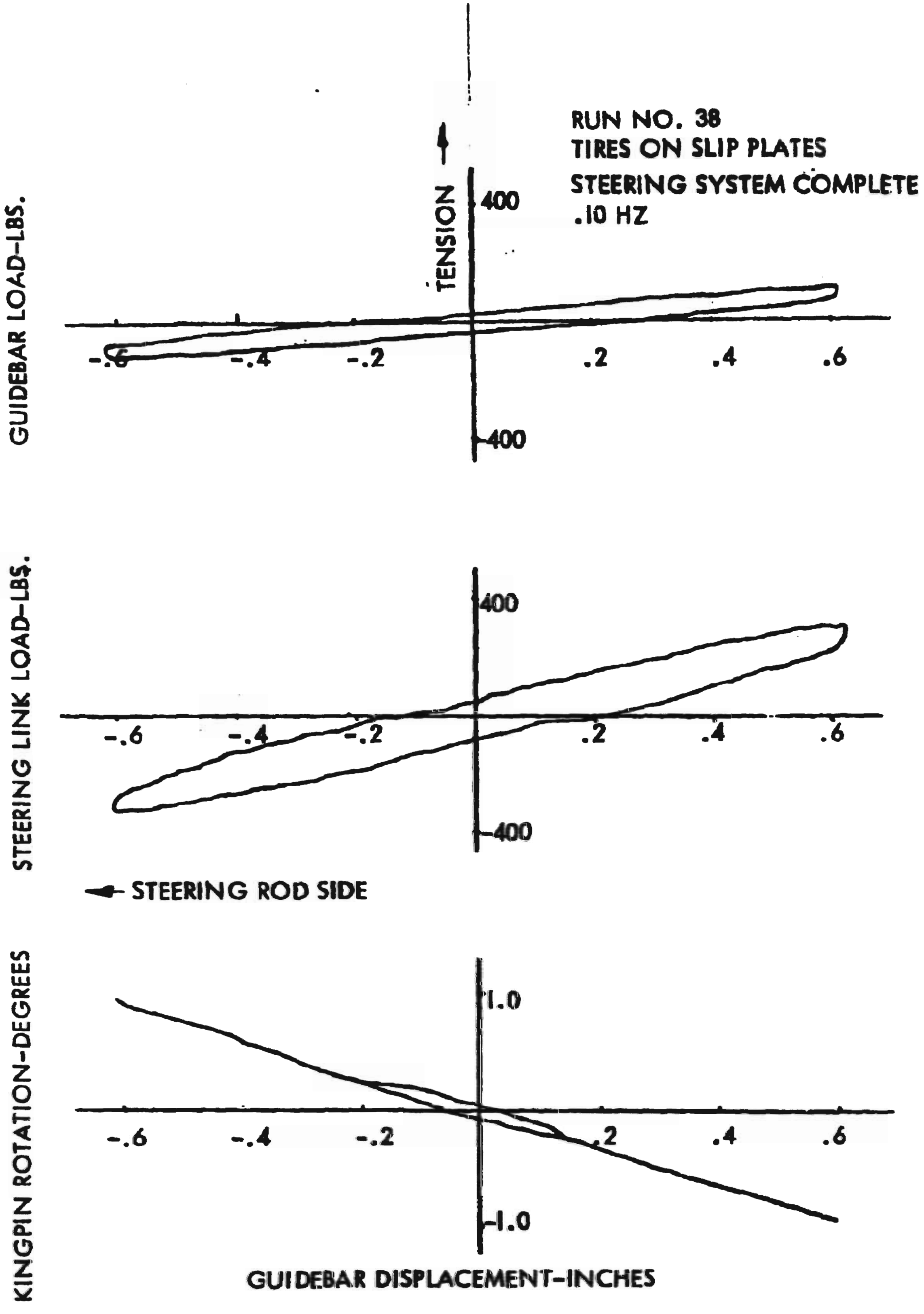


FIGURE 4-17 GUIDEBAR LOAD/STROKE CURVES, RUN NO. 38

in item (4), as expected, which is the result of the geometry difference of the reversing actuator in its retracted or extended position.

Guide/switchwheel support fitting stiffness characteristics are presented in Table 4-5. This table distinguishes the variation between the soft- and medium-hardness rubber springs supporting the guidewheels and switchwheels. Figure 4-18 presents the actual rubber stiffness measured during tests. Table 4-5 data were then calculated based on the geometry between wheel movement and rubber deflection.

The soft rubber springs have proven to be the best design for P40. The soft-spring design lessens guidebar loads and produces more desirable impedance characteristics, both improvements reduce maintenance requirements.

TABLE 4-5 GUIDE/SWITCHWHEEL SUPPORT FITTING STIFFNESS SUMMARY

	Stiffness* (Pounds/Inch)	
	Soft-Hardness Rubber	Medium-Hardness Rubber
Switchwheel	2,616	4,132
Guidewheel	1,953	3,086

* Represents stiffness from guide/switchwheel to guidebar

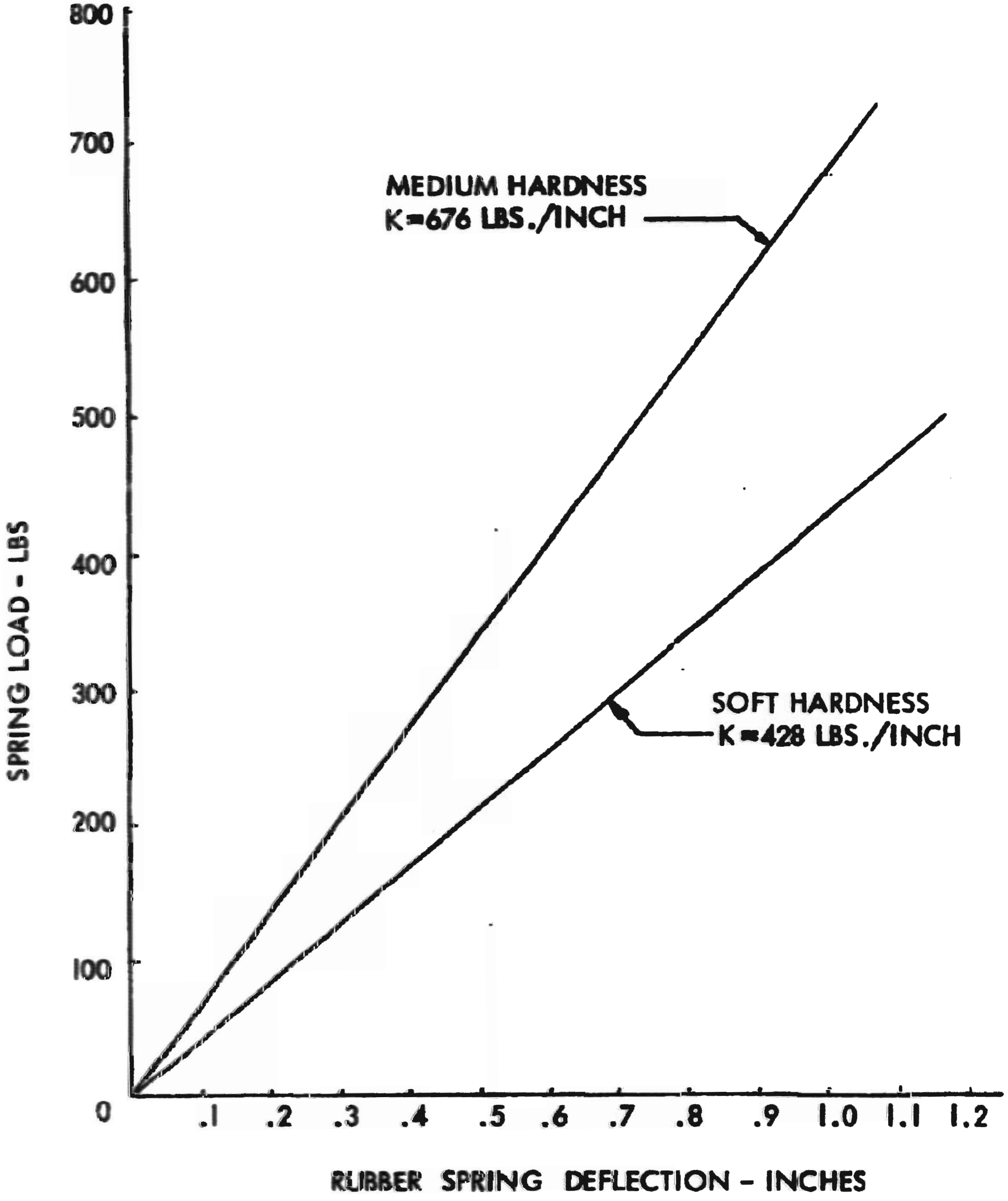


FIGURE 4-18 RUBBER SPRING STIFFNESS CHARACTERISTICS

4.3.4.2 Steering Reversal - One of the most advantageous design features incorporated on P40 is its automatic reversing capability.

Changing the direction of vehicle travel on P40 is accomplished in the steering reversal mechanisms by pneumatic actuators which reposition the steering rods. Reversing as implemented on P40 is initiated by a manual switch on the system control panel in the passenger compartment forward electronic cabinet. On a shuttle system requiring automatic reversing, the control system would perform the reversing function automatically from a wayside signal. Reversal mechanism position switches determine when reversal is complete and the vehicle can proceed.

A guideway demonstration test and a component fatigue test were conducted to verify the steering reversal design. The demonstration test at D/FW Airport was conducted in the 6W guideway as follows:

(1) Clear the test operation with Central Control.

(2) Manually drive the vehicle into a straight section of guideway and stop.

(3) Throw the direction-of-travel switch in the opposite position.

(4) Manually drive the vehicle to verify steering is functioning normally and stop.

(5) Throw the direction-of-travel switch in the opposite direction and proceed.

(6) Repeat the same test in a superelevated, 150-foot radius curve.

A cyclic load test was conducted to demonstrate the reversal actuator preloading the roller into the wedge area of the Cam. A cycle of this operation takes place every time the vehicle reverses. A considerable number of cycles will be accumulated during 20 years of service in a shuttle application.

The cyclic load test used the forward end wedge area of a cam and one steering link roller which is currently used on the AIRTRANS steering link. A reversal actuator load of 1,500 pounds, achieved by a 125-psi actuator pressure, was used to verify the design. The reversal actuator furnishes enough force to move the roller out of the cam in the actual installation. Since only one roller and one side of the cam surface were used, a test load of 750 pounds was required. The cyclic rate of the test was normally held to 20-30 cycles/minute. A photograph of the test setup is shown in Figure 4-19.

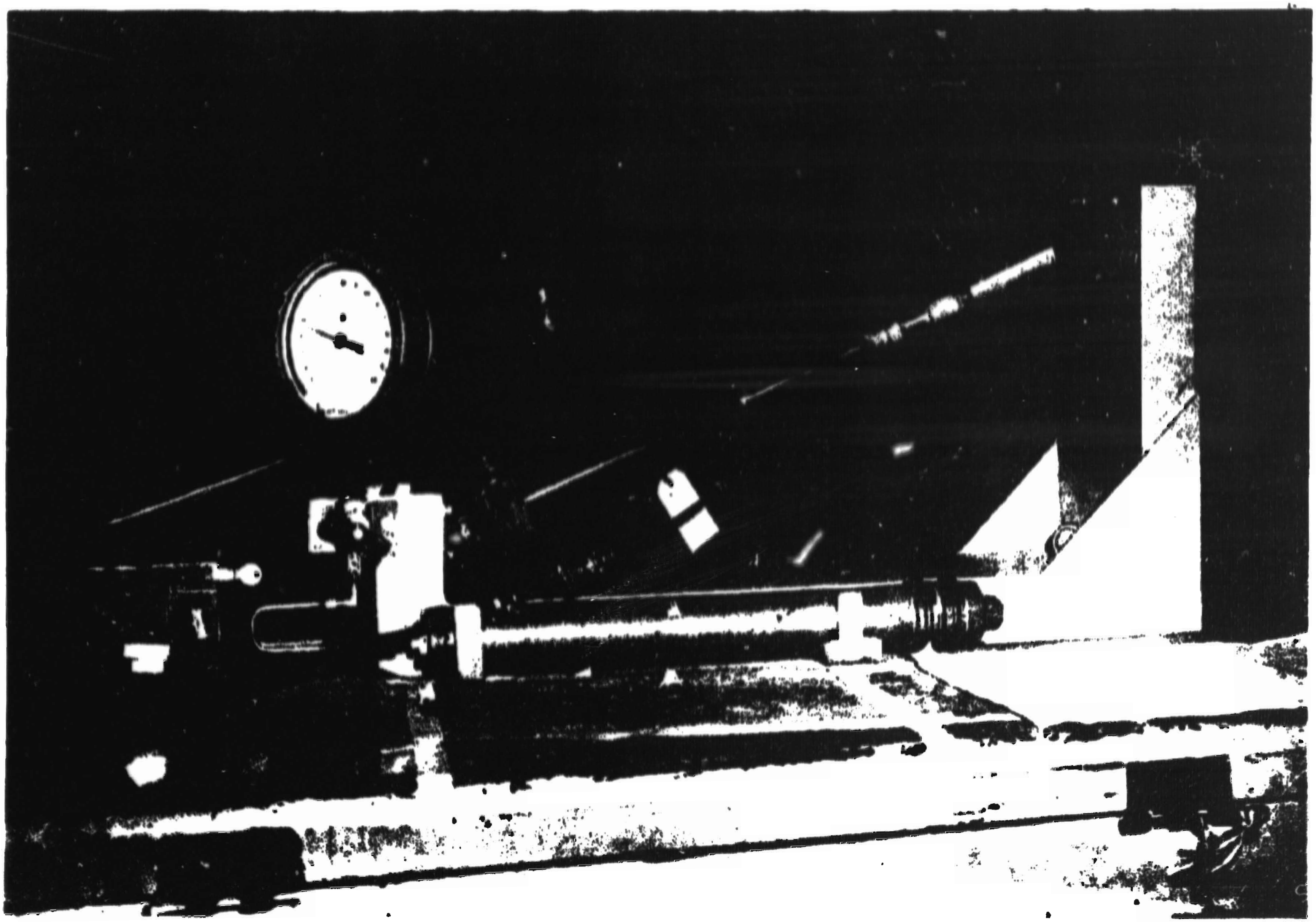


FIGURE 4-19 PHOTOGRAPH OF STEERING REVERSAL CAM TEST SETUP

An inspection of the wear interface between the cam and roller was taken daily and recorded in the test log presented in Table 4-6. The X-dimension as recorded in Table 4-6 and defined in Figure 4-20 represents a wear rate of the cam and becomes critical as the stroke limits of the actuator are approached.

The cam and roller test operated satisfactorily until 179,585 cycles. At that time, the roller which had seen service on AIRTRANS began wedging in the cam, restricting motion. The spring load pressure which withdraws the roller from the wedge was increased to 60 psi. After this problem was encountered two more times, the used roller was replaced with a new roller and the spring-back pressure was increased to 150 psi and then 300 psi. The wear on the cam was calculated to be 0.0417 inch at that time. This is the difference of the X-dimension taken at 405,650 cycles and at the start of testing. The new roller finished the test with no problems and showed no excessive wear. The cam wear associated with the new roller was calculated to be 0.0609 inch. The total cam wear for a million cycles is 0.1026 inch. The wear depth as shown in Figure 4-21 was measured 0.025 inch (A) and 0.03 inch (B).

Test results show a cam wear of 0.1026 inch. The reversing actuator has 0.125-inch excess stroke at each end of operation, resulting in a useful cam wear life of approximately one million cycles. This test gives a good indication there should be no wear problems in driving the rollers into the wedge.

After the original AIRTRANS roller was replaced, the new roller operated for approximately 600,000 cycles with no problems. The races were in good condition, with the only sign of wear being on the outside diameter which showed a slight surface roughness. In general, the bearings were in good condition for a part that has been tested to 10 years of simulated service life.

The vehicle reversing tests at D/FW Airport were successfully demonstrated in a straight and 150-foot section of the guideway. The entire operation to reverse the direction of the vehicle was conducted in less than 5 seconds. The success of these tests enhances the deployment of P40 into an urban application with no system limitations.

TABLE 4-6 TEST LOG OF STEERING REVERSAL CAM TEST (PAGE 1 OF 2)

Date	Cycles	X-Dimension	Remarks
1-5-79	0	0.960	Test started
1-8-79	11,000	0.960	1500 hours
1-9-79	53,000	0.980	1500 hours
1-10-79	90,393	0.980	1130 hours
1-10-79	97,000	0.980	1500 hours
1-11-79	147,777	0.9805	1500 hours
1-12-79	179,585	0.9805	0830 hours - bearing wedged in track (no travel). Bearing removed and rotated. Test started again at 1010 hours
1-12-79	188,591	0.982	1515 hours
1-15-79	215,950	Not Recorded	0945 hours - spring backpressure upped from 50 psi to 60 psi
1-16-79	246,400	0.9805	Spring pressure upped to 150 psi
1-17-79	270,584	0.985	Groove in cam and roller surface wearing more on one side. Metal particles (powder) being deposited on cam. Roller cleaned and reversed
1-19-79	315,381	0.9875	Still wearing on one side more. Roller not reversed. Cleaned and turned fixture on side. Greater wear on one side of each surface of cam
1-22-79	340,995	Not Recorded	Roller froze up in cam on 1-20-79. 150-psi pressure required to unlock roller. Spring backpressure upped to 280-300 psi
1-23-79	378,300	0.9974	
1-24-79	405,650	1.0017	Just prior to changing roller

TABLE 4-6 TEST LOG OF STEERING REVERSAL CAM TEST (PAGE 2 OF 2)

Date	Cycles	X-Dimension	Remarks
1-26-79	405,650	1.0006	Test setup transferred to 3rd floor. New ABT 14 roller installed (Ref Page)
1-31-79	425,067	1.0002	
2-5-79	452,608	1.0075	
2-8-79	479,244	1.0152	
2-12-79	520,114	1.025	
2-14-79	565,000	1.030	
2-18-79	614,025	1.033	
2-20-79	648,740	1.034	
2-28-79	775,775	1.036	
3-4-79	831,888	1.041	
3-8-79	900,659	1.033	Small metal hair sliver removed from bearing
3-9-79	919,482	1.041	
3-13-79	936,316	1.041	
3-15-79	964,049	Not Recorded	Spring-back pressure 325 psi, source pressure to 1,360 psi
3-20-79	1,000,000	1.0615	

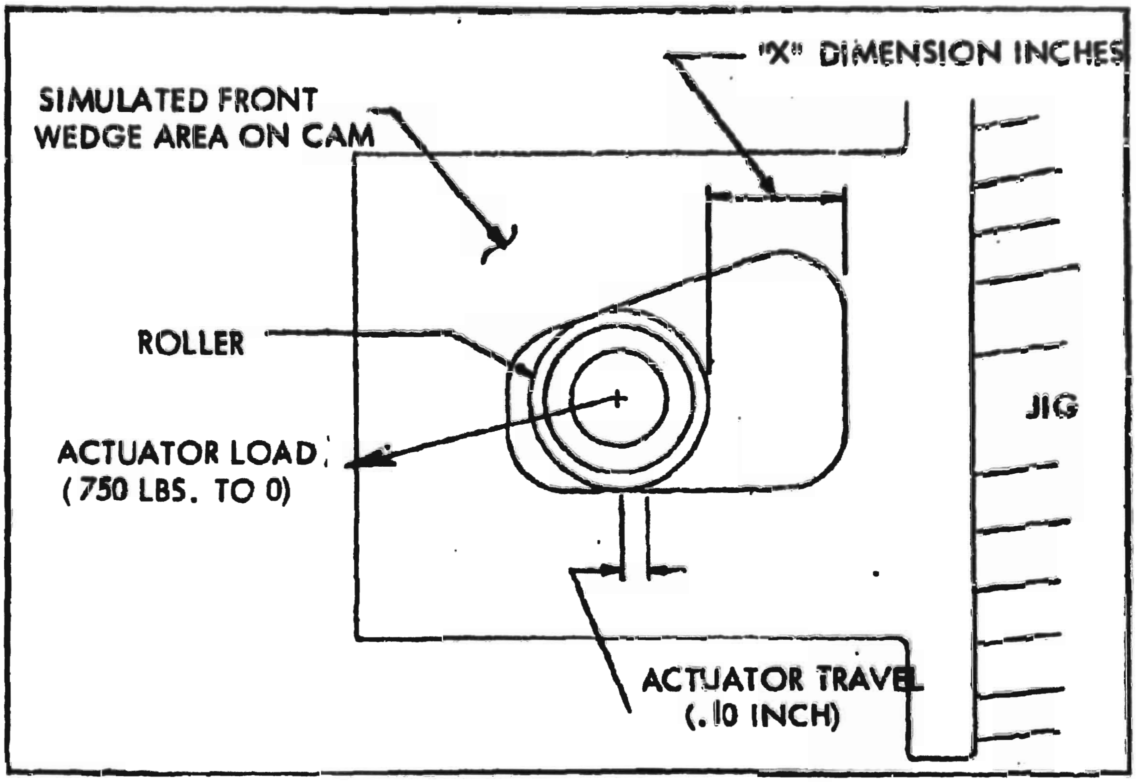


FIGURE 4-20 SIMULATED CAM/ROLLER TEST SETUP

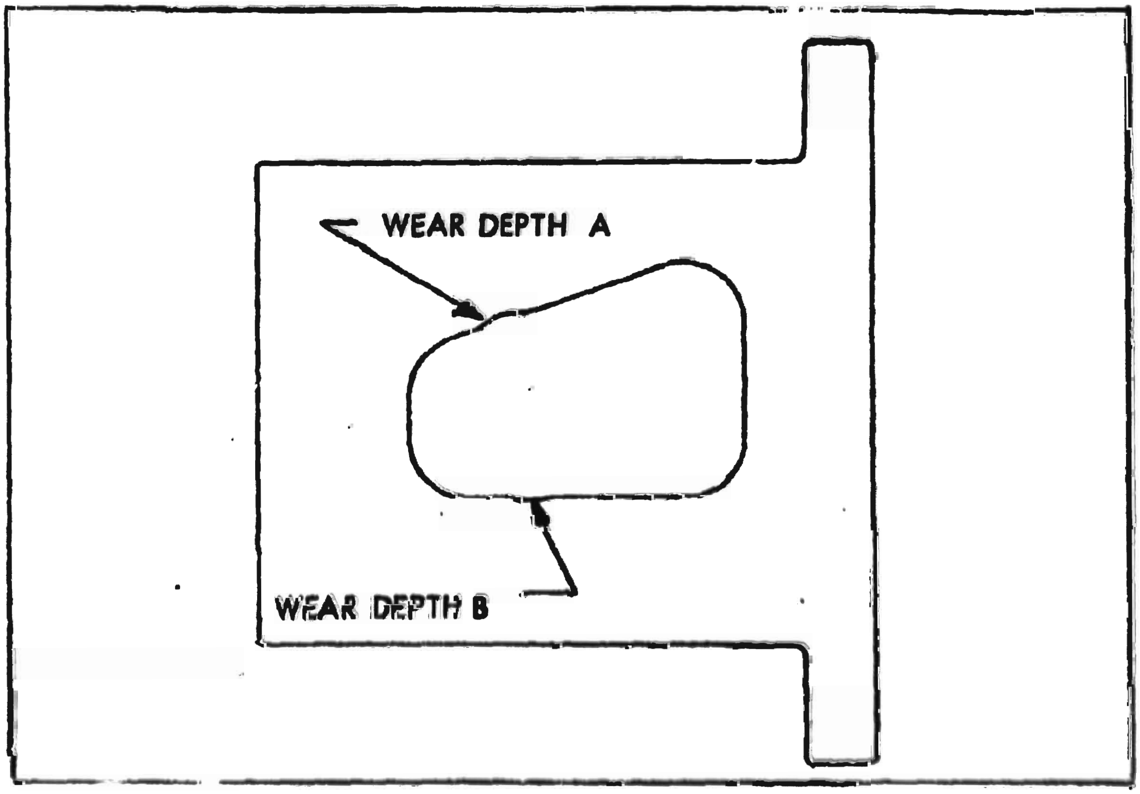


FIGURE 4-21 CAM WEAR DEPTH

4.3.4.3 Towing - The P40 vehicle is capable of being towed either on- or off-guideway with a special tow bar attached to a suitable tug. For on-guideway towing, steering forces are applied by the guideway walls through the guidewheels. The tow bar provides only a towing force. For off-guideway, steering forces are applied by the tug through the tow bar. A removable nylon pin in the tow bar provides for the two towing modes. This pin also serves as a shearpin to prevent excessive steering loads on the vehicle. Before towing P40, the powered reversal mechanisms must be in their appropriate positions for the direction to be towed. In the event of air pressure loss, manually installed stops are available for blocking the reversing mechanisms as required. An off-guideway steering bar designed for better maneuverability can be used to steer the rear of the vehicle, if desired.

The purpose of the towing tests was to:

(1) Demonstrate both towing modes of the P40 vehicle with and without air pressure to the reversal actuator

(2) Demonstrate use of the tow bar, removable stops for the reversal mechanism and the off-guideway rear steering bar

(3) Verify the towing procedures established for P40

The following procedures were prepared for use by D/FW airport personnel when P40 is placed in operation and were used in conducting the towing demonstration.

(1) On-guideway towing procedure (normal)

 (a) Attach tow bar to vehicle (2 pins).

 (b) Attach tow bar to tug.

 (c) Turn on circuit breaker for battery.

 (d) Place system control panel mode selector in "TOW."

 (e) Connect air.

 (f) Tow.

(2) On-guideway towing procedure (actuator does not hold pressure)

 (a) Same as (1a) above

 (b) Same as (1b) above

(c) Shut off air supply to reversing valve with manual valve at side of vehicle above air compressor and open pneumatic lines to the actuators to release any trapped pressure.

(d) Install mechanical stops in bellcrank with a quick-release pin at each end. If the mechanism is out of position, the steering rod may be manually moved to the correct position and the locks installed.

(e), (f), (g) Same as (1c), (1d), (1e) above.

(h) If the steering rod cannot be manually positioned, the brakes should be manually or pneumatically caged and the vehicle moved forward or aft by the tug to achieve alignment and the stops installed.

(i) Tow.

(3) Off-guideway towing procedure (normal)

(a) Install off-guideway shearpin in tow bar.

(b) Attach tow bar to vehicle.

(c) Attach tow bar to tug.

(d) Turn on circuit breaker for battery.

(e) Place system control panel mode selector in "TOW."

(f) Connect air.

(g) Throw vehicle direction manual switch on the system control panel opposite to the direction to be towed.

CAUTION

Anytime the manual switch is used, operators must stand clear of the guidebars and steering linkages.

(h) Insert rear off-guideway steering rod stop.

(i) Throw vehicle direction switch for the direction to be towed.

(j) Remove D/FW on-guideway guidebar removable stops (if used).

(k) Tow.

(4) Off-guideway towing procedure (smaller turning radius)

(a), (b), (c), (d), (e), (f) Same as for (3) above

(g) Throw vehicle direction switch for the direction to be towed.

(h) Install rear manual off-guideway steering bar at rear of vehicle.

(i) Remove D/FW on-guideway guidebar removable stops (if used).

(j) Tow with tug and manually steer rear of vehicle with care.

CAUTION

Rear operator (on foot) must limit his steering input so that the tire does not contact and damage the collectors. A rear guidebar stroke of ±3 inches is adequate for steering and clearance. Rear operator should turn rear wheels for same turn direction as front wheels.

(5) Off-guideway towing procedure (actuator does not hold pressure)

(a) Repair air system.

(b) Follow off-guideway towing procedures above.

OR

(a) Install mechanical stop in front and rear bellcranks with quick-release pin.

(b) Insert rear manual off-guideway steering bar at rear of vehicle.

(c) Remove D/FW on-guideway removable stops (if used).

(d) Attach tow bar to vehicle and tug.

(e) Tow with tug and manually steer rear of vehicle with bar.

(6) Inserting vehicle in guideway

(a) Pull vehicle to guideway insertion point.

(b) Remove tow bar.

(c) Remove rear off-guideway steering rod stop.

(d) Install D/FW on-guideway removable stops (if used).

(e) Push vehicle into guideway.

All towing procedures were successfully demonstrated. The reversal mechanism stops were modified slightly to permit easier insertion. The towing procedures were acceptable with minor changes which have been incorporated. Shearing the nylon pin was also demonstrated successfully. The measured minimum vehicle turning radius was 94 feet without the rear steering bar and 45 feet with the rear steering bar.

The vehicle steering system, tow bar, reversal mechanism stops, off-guideway steering bar and towing procedures adequately fulfill all towing requirements for the urban prototype vehicle P40.

4.3.5 SUSPENSION SYSTEMS - The urban prototype vehicle (P40) was designed to provide a simplified suspension system that would give the vehicle antidive capabilities to reduce guidebar/brush travel, a softer lateral stiffness, and increased roll damping. The incorporation of these design improvements would also provide a softer vertical system stiffness that would enhance the already adequate vehicle ride. Static and dynamic tests were performed on a complete vehicle and on individual components to determine suspension system characteristics that are associated with ride quality improvements.

The lateral and vertical suspension system consists of primary and secondary stiffness components. The foam-filled tires provide primary stiffness both laterally and vertically. A pneumatic airbag and spherilastik bearings mounted in the upper and lower suspension links provide secondary suspension system stiffness both laterally and vertically. The vehicle suspension system is shown in Figure 4-22. For a detailed description of the vehicle suspension system, refer to Volume 3.

4.3.5.1 Lateral Suspension System Tests - The lateral suspension system was modified considerably from the T365 configuration. Airbags placed directly over the axle, and the addition of spherilastik bearings to replace the stiffer A-frame design required testing to verify the lateral stiffness of the vehicle. This was accomplished by testing the tires and airbag/spherilastik bearing combination to obtain their lateral stiffness characteristics.

The test was conducted on the completed P40 vehicle. The stiffness of each component was obtained by applying a lateral load to the car body directly over one axle and measuring the relative deflection between components. The relative motion between car body and axle determines the secondary (airbag/spherilastik) stiffness, and the relative motion between axle and ground provides the primary (tire) stiffness. A lateral load of approximately 1,300 pounds was applied in both directions over the rear axle of the vehicle. A schematic of the test setup is shown in Figure 4-23.

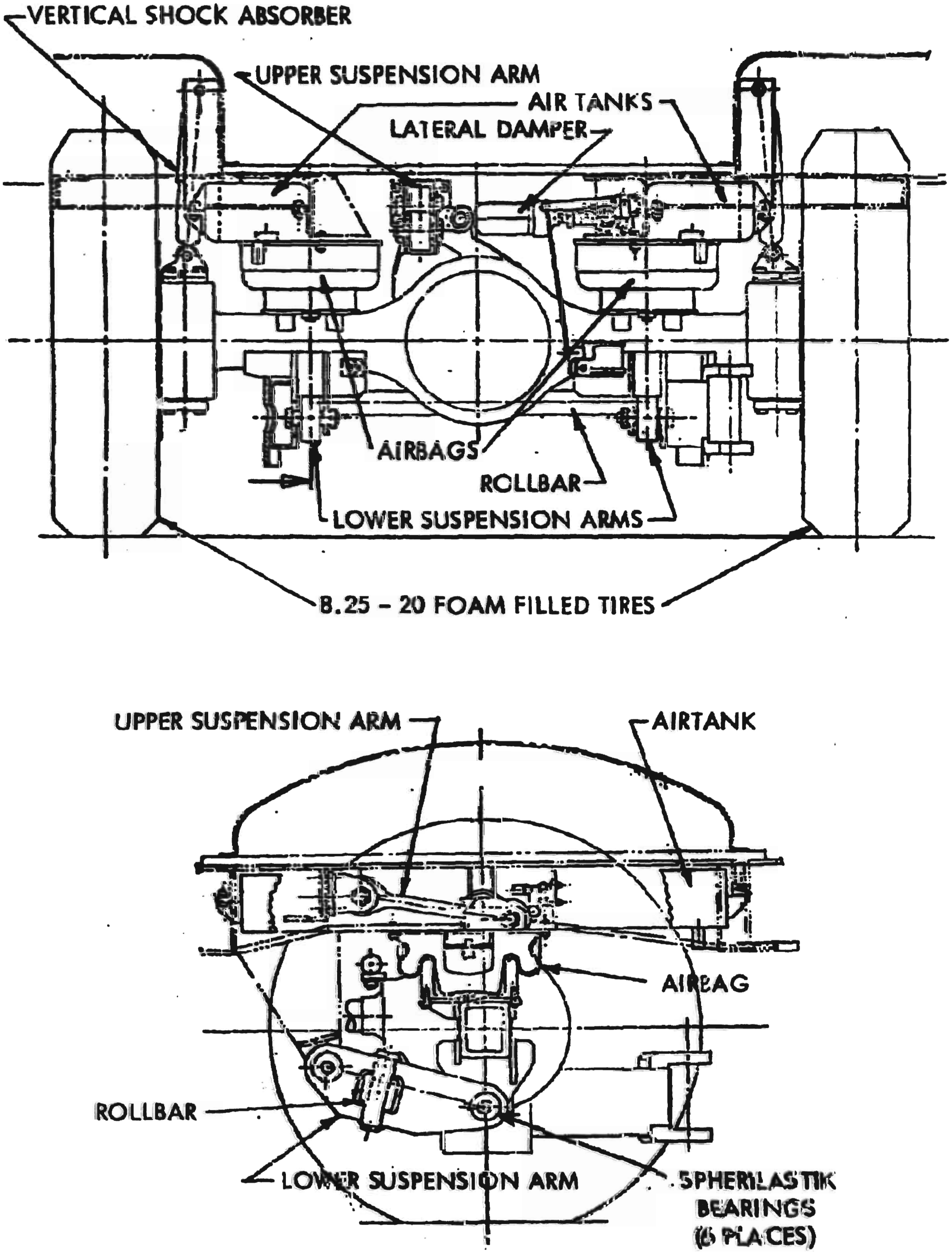


FIGURE 4-22 AUTP PHASE II SUSPENSION SYSTEM

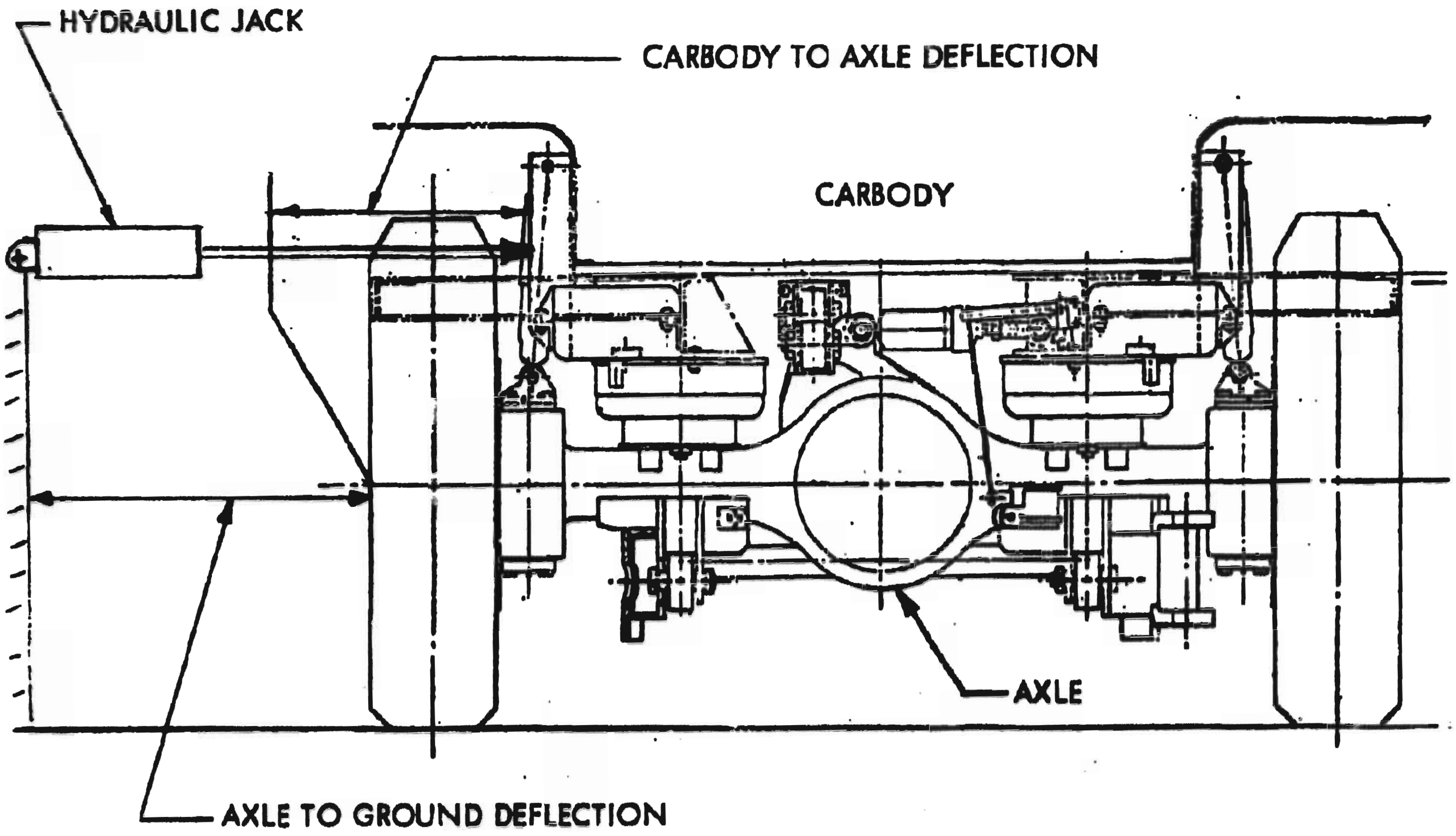


FIGURE 4-23 LATERAL SUSPENSION SYSTEM TEST SETUP

Test results are presented in Figure 4-24 through 4-26. The primary (tire) lateral stiffness exhibits a value of 3,886 pounds/inch per axle, as shown in Figure 4-24. The secondary (airbag/spherilastik) lateral stiffness exhibits a value of 2,946 pounds/inch per axle, as shown in Figure 4-25. The addition of these curves represents a lateral stiffness of 1,667 pounds/inch per axle and is presented in Figure 4-26. The above lateral stiffness includes the roll effects from the tires and roll bar.

The tire stiffness, of 3,886 pounds/inch, which includes a small influence from roll, compares favorably with the Firestone data for foam-filled tires that are shown in Figure 4-27. The Firestone data indicate a stiffness of 2,200 pounds/inch per tire for an average test load of 1,400 pounds (700 pounds/tire), which

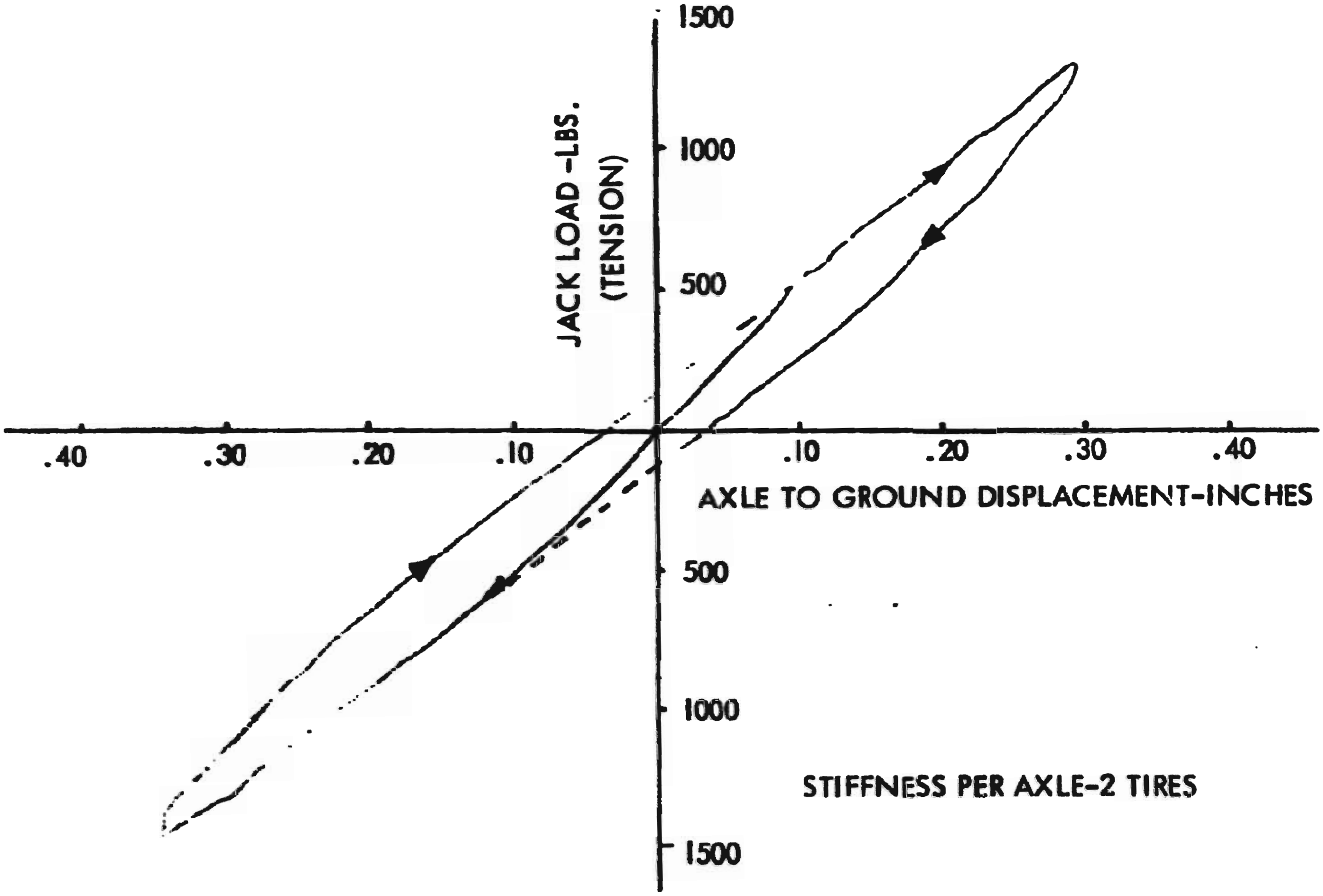


FIGURE 4-24 PRIMARY LATERAL STIFFNESS

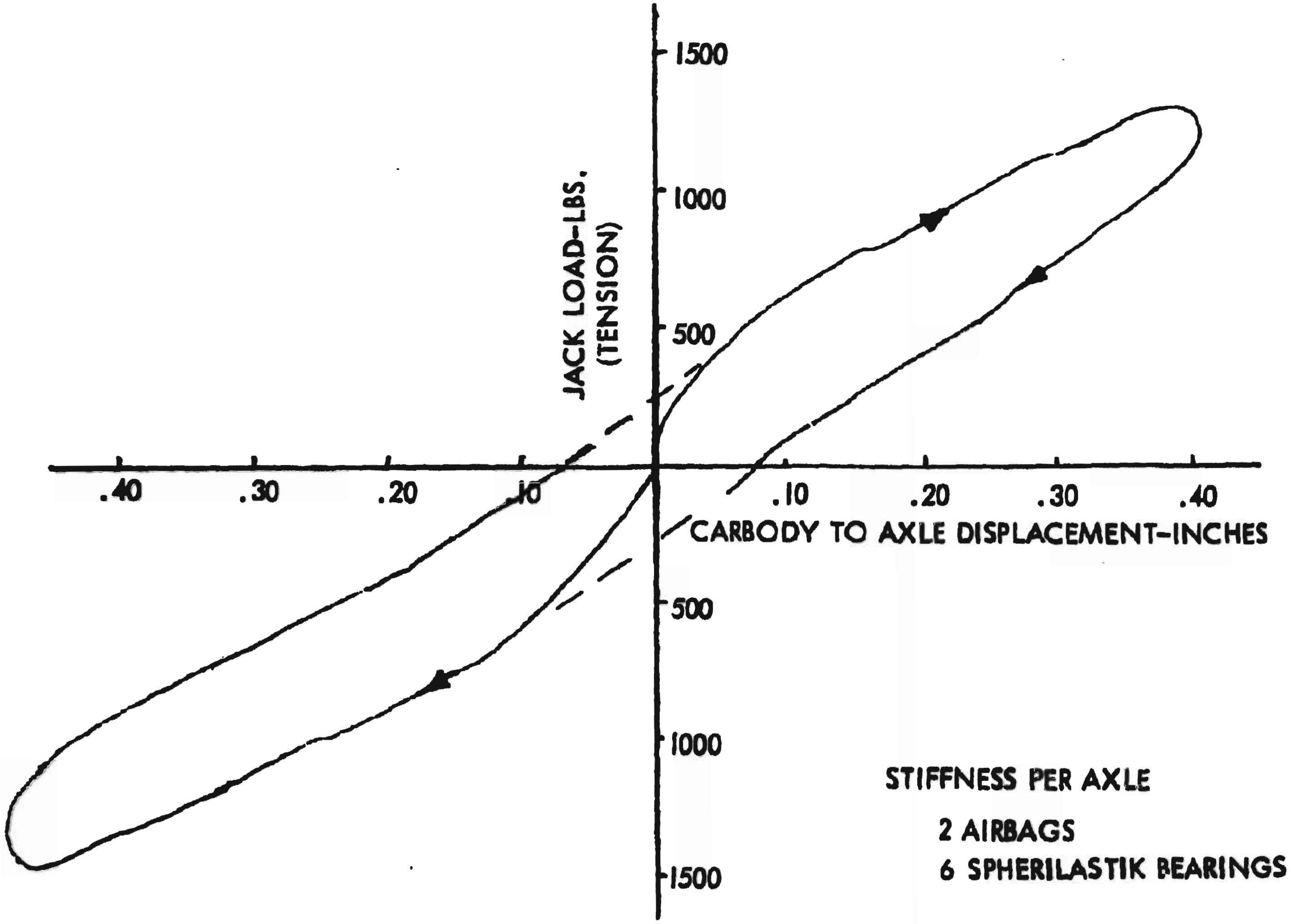


FIGURE 4-25 SECONDARY LATERAL STIFFNESS

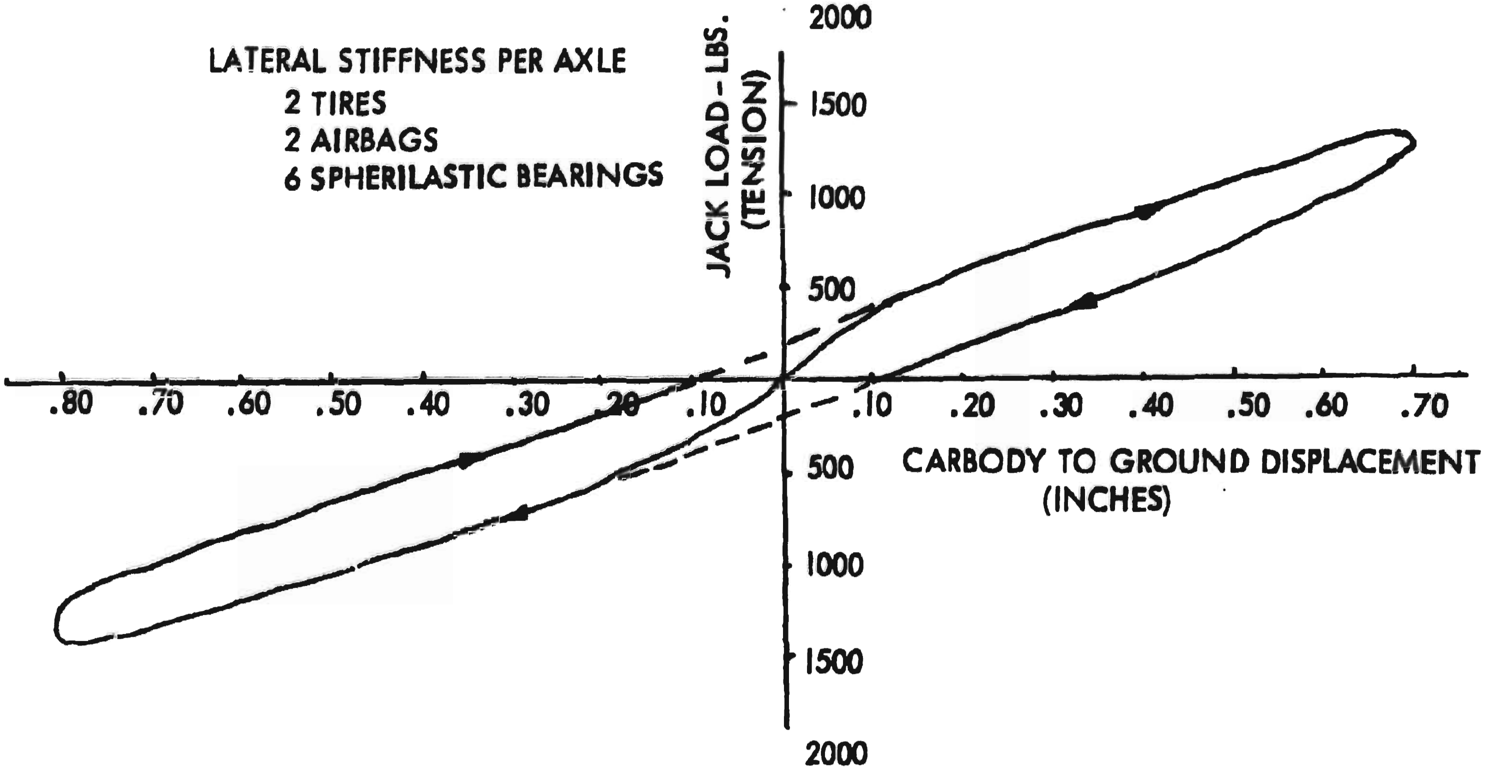


FIGURE 4-26 LATERAL SUSPENSION SYSTEM STIFFNESS

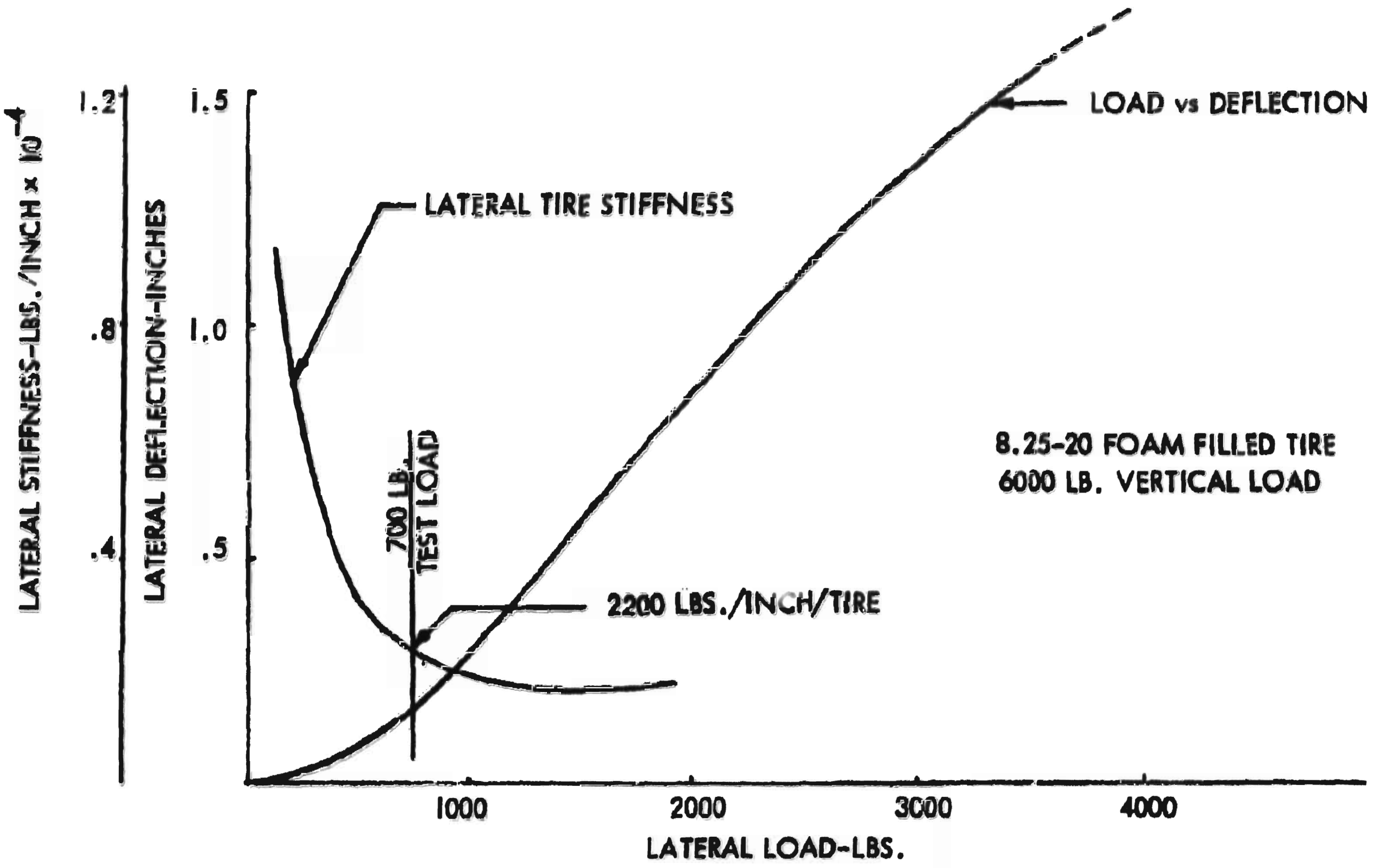


FIGURE 4-27 LATERAL TIRE STIFFNESS

is equivalent to 4,400 pounds/inch per axle. The airbag lateral stiffness test results from Firestone are presented in Figure 4-28. This curve shows the bag stiffness characteristics for various airbag pressures and frequencies for the nominal ride height of P40. The bag stiffness vs bag pressure at nominal ride height was plotted for the 0.1 hertz frequency, which is very nearly a static condition. Figure 4-29 presents this plot and indicates a bag stiffness of 1,175 pounds/inch or 2,350 pounds/inch per axle. Combining the theoretical spherilastik stiffness and roll stiffness to the bag and tire stiffness produces a lateral stiffness at each axle of 1,362 pounds/inch. This produces a 18% variation with the test results. This variation can be attributed to possible friction in the lateral damper and a small variation in the rating of the spherilastik bearings, since only 200 pounds/inch in parallel with the airbags is needed to produce an 18% difference. This slight variation will not effect vehicle response.

4.3.5.2 Vertical Suspension System Tests - The vertical suspension system was modified considerably compared to the AIRTRANS and T365 vehicles. The vertical suspension system characteristics were needed to verify the P40 design. This was accomplished by testing the tires and airbag/spherilastik bearing combination.

This test was accomplished in two phases. First, the tire stiffness and, second, the airbag/spherilastik combination were tested.

The tire stiffness, which is termed the primary vehicle stiffness, was obtained by jacking the vehicle slightly off the concrete to measure the uncompressed wheel radius. The vehicle was removed from jacks onto calibrated load cells at each wheel, and the compressed wheel radius and wheel load were measured. The resulting individual tire stiffness is presented in Table 4-7. The Firestone curves for the SUP-R-FIL tires are presented in Figure 4-30, with P40 tire data plotted. These results compare favorably with vendor data, except for the right front tire. This difference can only be attributed to inaccurate measurements during testing.

The secondary suspension system consists of airbags and spherilastik bearings mounted between the axle and car body frame. The secondary stiffness per axle was measured at the rear axle only by applying a vertical load to the vehicle coupler while measuring the relative deflection between the car body frame and axle. A schematic of the test setup is presented in Figure 4-31. The test results indicate a stiffness per axle of 876 pounds/inch with shocks installed. A plot of the test results is presented in Figure 4-32.

The airbag stiffness was individually tested by Firestone prior to installation on the vehicle. Figure 4-33 presents airbag stiffness as a function of load acting on the airbag at its nominal ride height of 6.3 inches. Additional Firestone test

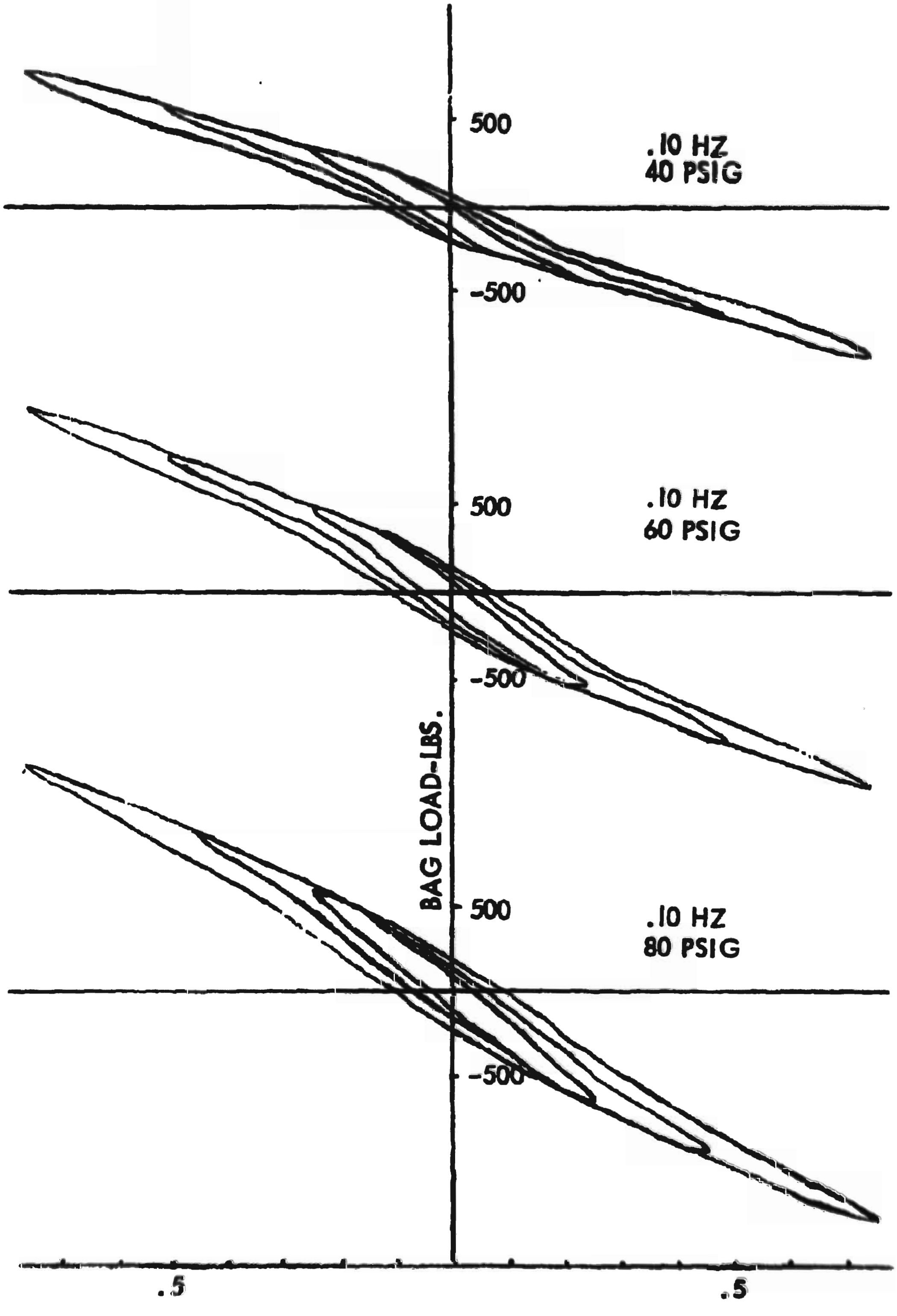


FIGURE 4-28 LATERAL AIRBAG STIFFNESS – NOMINAL RIDE HEIGHT

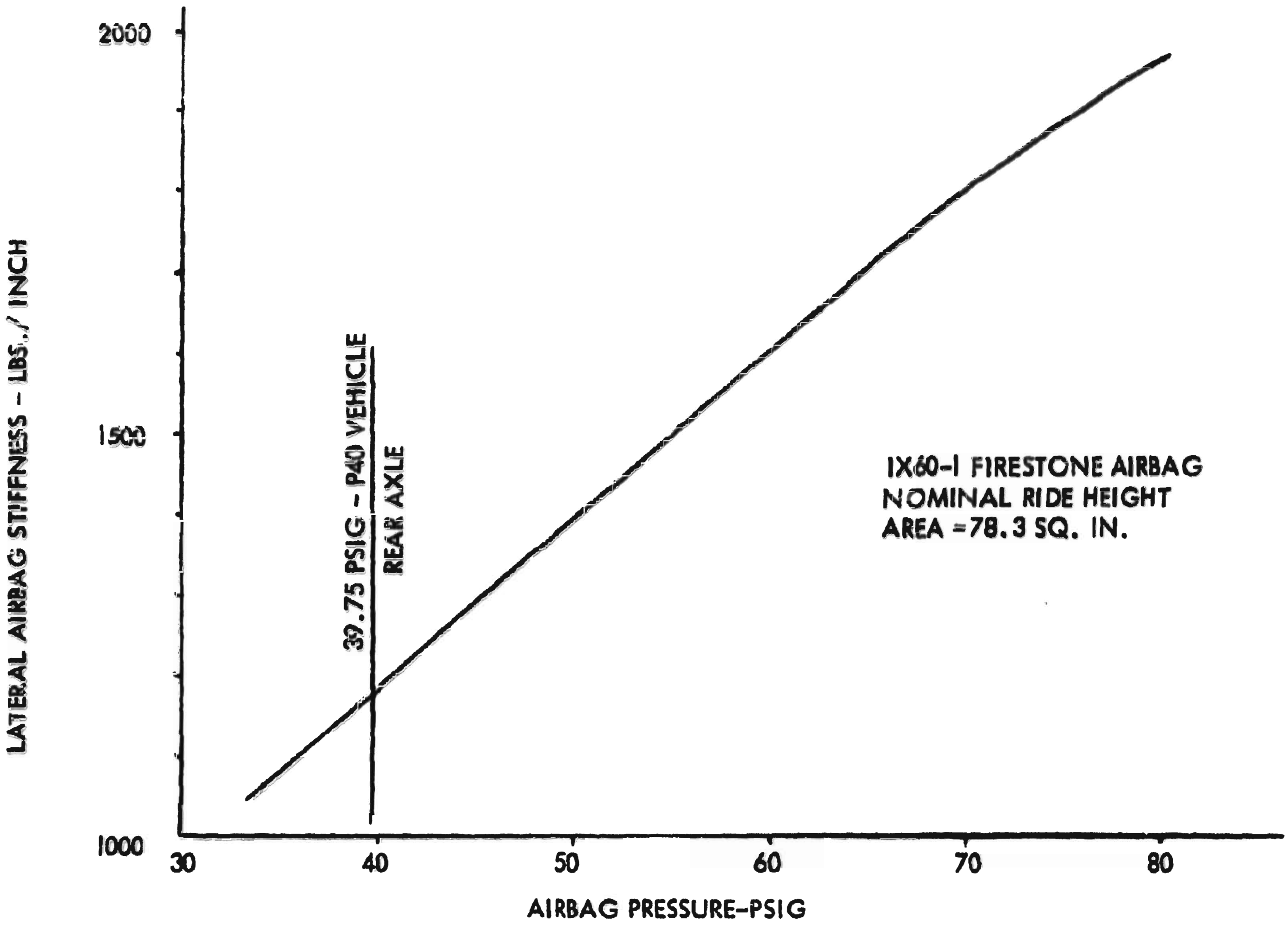


FIGURE 4-29 LATERAL AIRBAG STIFFNESS VERSUS AIRBAG PRESSURE

TABLE 4-7 P40 VEHICLE PRIMARY (TIRE) STIFFNESS CHARACTERISTICS

Tire	Weight on Tire (pounds)	Tire Deflection (Inches)	Tire Stiffness (Pounds/Inch)
Left rear	4,722	0.87	5,427
Right rear	4,208	0.76	5,536
Left front	4,539	0.72	6,304
Right front	4,635	0.95	4,878

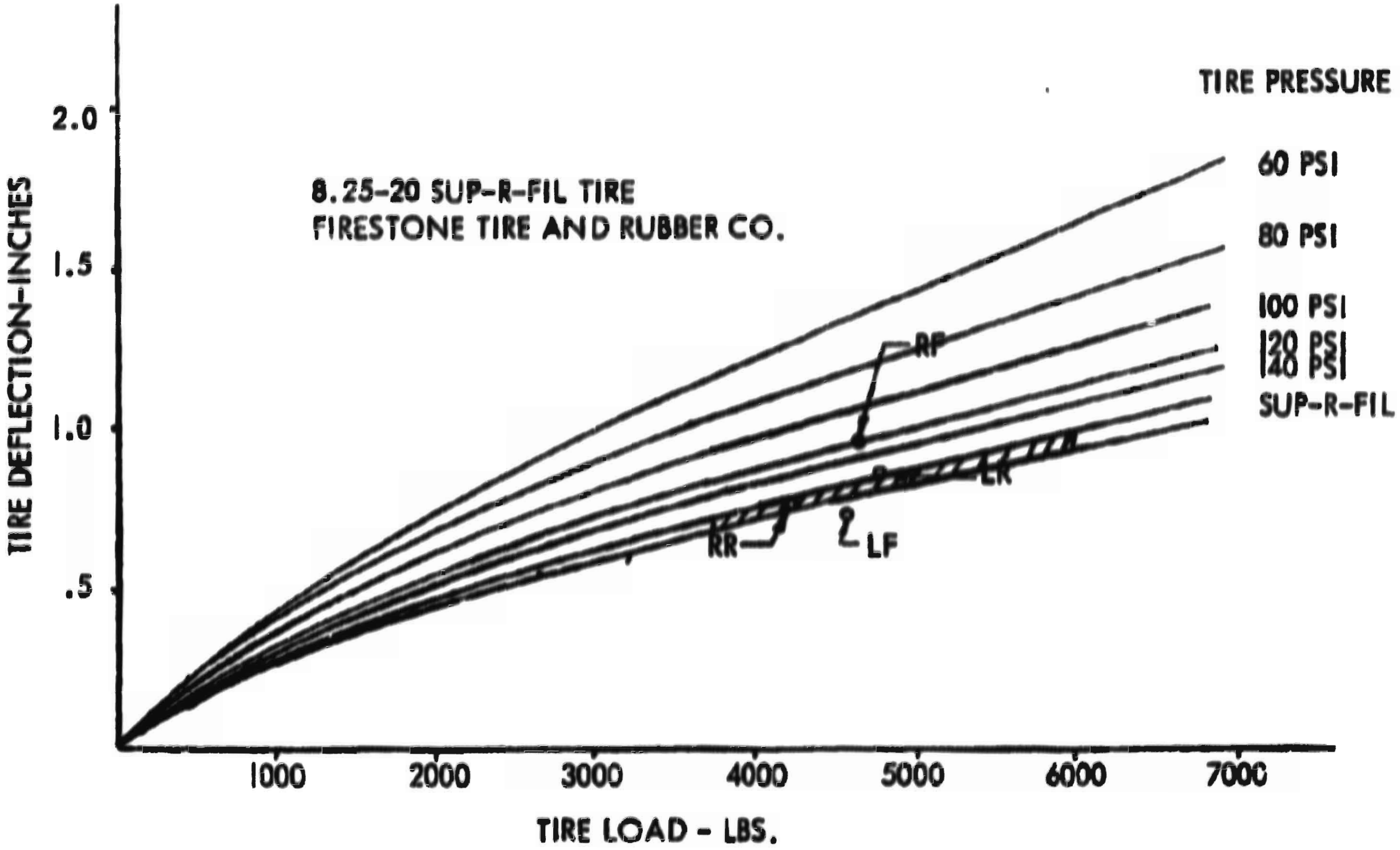


FIGURE 4-30 STIFFNESS CHARACTERISTICS OF FIRESTONE SUP-R-FIL TIRES

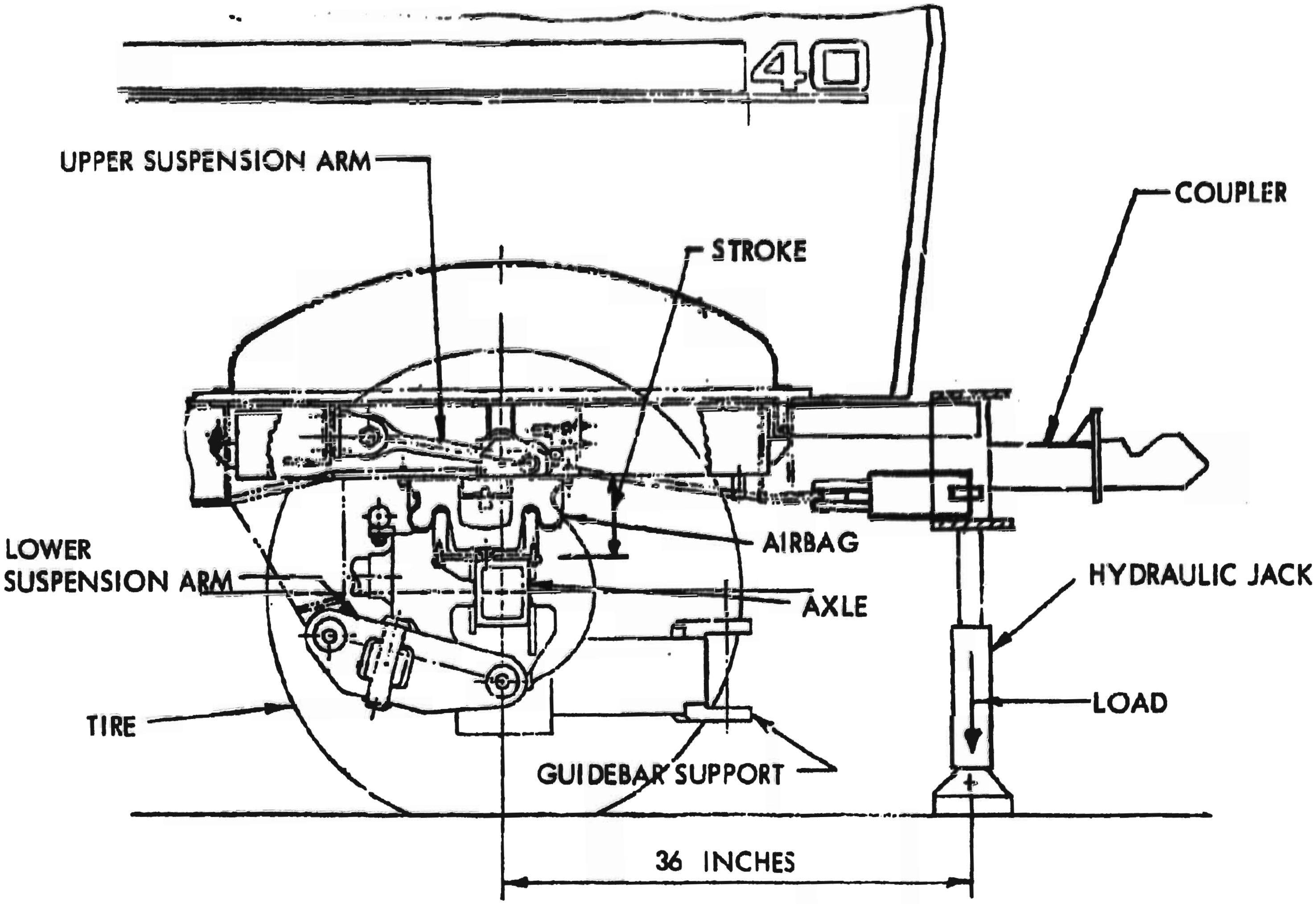


FIGURE 4-31 SCHEMATIC OF VERTICAL SUSPENSION SYSTEM TEST SETUP

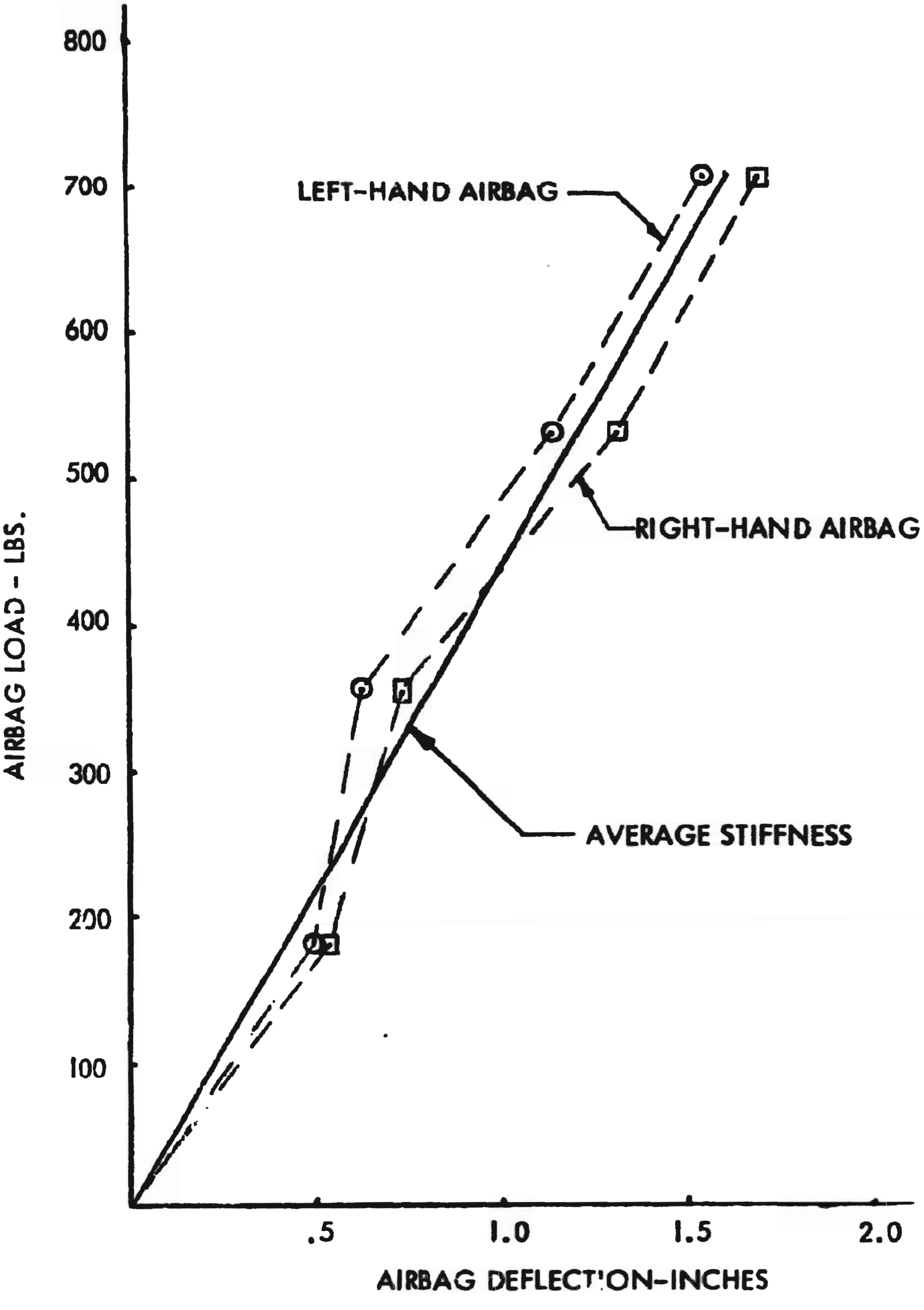


FIGURE 4-32 SUSPENSION SYSTEM VERTICAL STIFFNESS

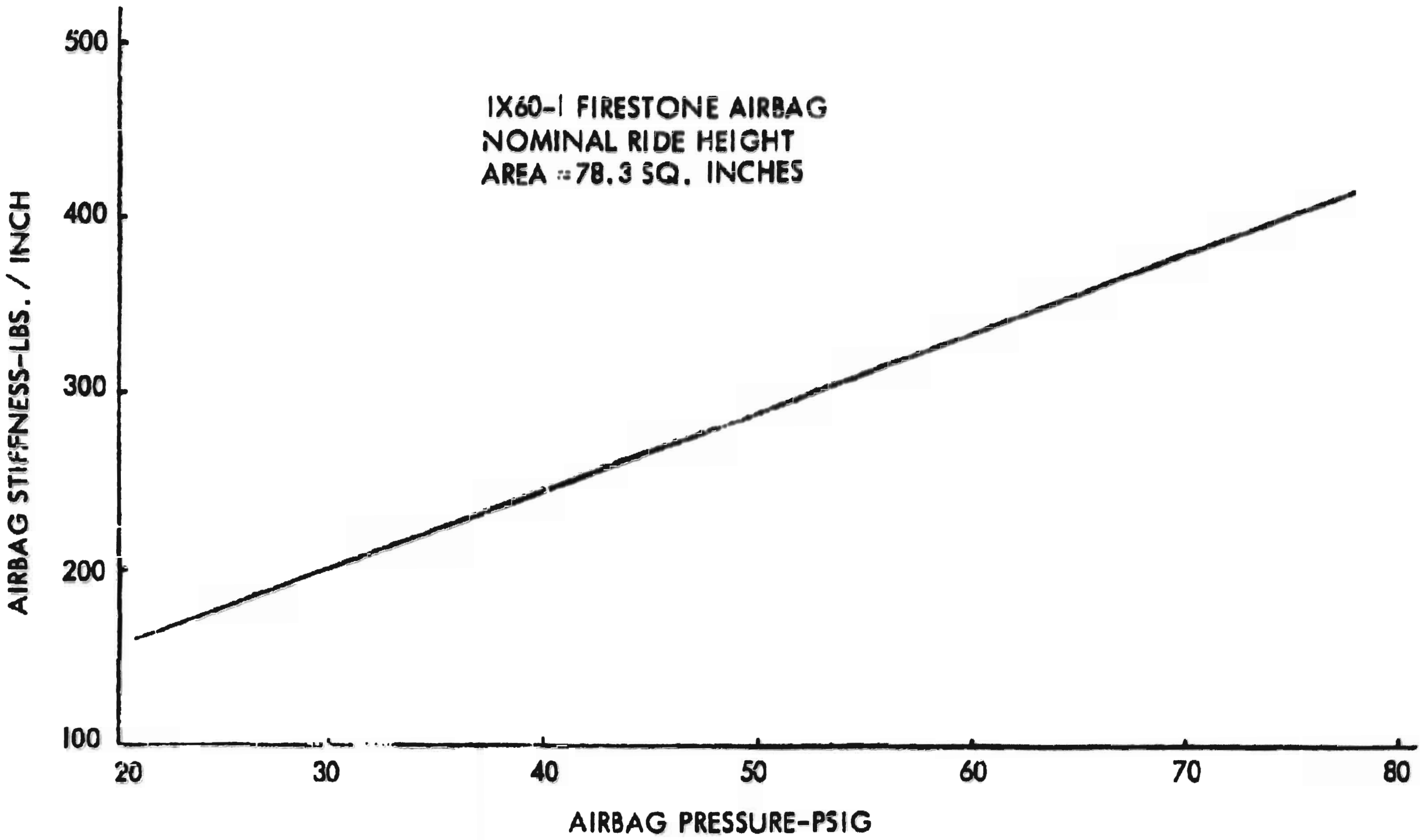


FIGURE 4-33 AIRBAG STIFFNESS VERSUS PRESSURE

results for various ride heights, airbag pressure and airbag load are presented in Tables 4-8 through 4-10. P40 vehicle empty has an average load of 3,114 pounds acting on each rear airbags, which produces a bag stiffness of 244 pounds/inch. Combining the spherilastik stiffness of 123 pounds/inch with the airbag produces a secondary suspension stiffness of 367 pounds/inch per wheel or 734 pounds/inch per axle. The difference between 876 pounds/inch and 734 pounds/inch represents a 16% difference which is considered good correlation since the shocks and spherilastik bearings can contribute to the above variation. These effects will decrease with vehicle usage, however.

4.3.5.3 Vehicle Dynamic Response Tests - Vibration tests were conducted on the P40 vehicle to determine the dynamic response characteristics of the vehicle. Vehicle characteristics are required for design verification and interpreting ride quality performance.

Tests were conducted on dry concrete with the empty vehicle weighing approximately 18,100 pounds. Electromagnetic shakers capable of surveying 0-100 hertz were mounted at each corner of the vehicle. An oscilloscope with a tangent scale was used to measure modal displacements. A viscorder was used to measure modal damping. System characteristics were obtained with and without shock absorbers. Data were taken with AIRTRANS-type shocks installed also. A photograph of the dynamic test setup is shown in Figure 4-34.

Test results obtained are presented in Table 4-11. The vehicle response characteristics exhibit a considerable reduction in modal frequencies as compared to AIRTRANS and test vehicle T365. This comparison is shown in Table 4-12. The P40 shock absorber influenced the vehicle response characteristics more than expected, as evidenced in Table 4-11. This effect prompted the testing of AIRTRANS shocks on P40 vehicle. These results are reported in Table 4-11 also.

The measured frequencies indicate a softer suspension system than AIRTRANS or test vehicle T365. The heave frequency of 1.30 hertz is higher, however, than the design target of 1.0 hertz. During testing, it was noted that the modal characteristics were a function of amplitude. The shakers were at their maximum stroke capability when the 1.30 hertz was obtained, and if larger shakers had been available, it is expected the design target would have been reached. The attaining of the target static stiffness for the airbags indicates the dynamic response should be approaching design target also. Ride quality measurements in the demonstration phase will be used to evaluate design changes to the suspension system.

4.3.6 COUPLER - Couplers were installed on both ends of the P40 vehicle. The couplers were mounted to the chassis structure. Each coupler represents a considerable mass hanging from a chassis that had not originally been designed for this type

TABLE 4-8 AIRBAG DESIGN CHARACTERISTICS

RIDE HEIGHT - 5.3 IN.

AIRBAG LOAD-LBS.	PRESSURE PSIG	AIRBAG STIFFNESS - #/"	DEFLECTION INCHES	FREQUENCY C.P.M.
2000	25.5	176.6	11.3	55.8
2500	31.9	204.3	12.3	53.6
3000	38.3	231.4	13.0	52.1
3500	44.6	253.8	13.5	51.0
4000	51.1	286.2	14.0	50.2
4500	57.4	313.6	14.3	49.5
5000	63.8	341.0	14.7	49.0
5500	70.2	363.4	14.9	48.6
6000	76.6	395.3	15.1	48.2
6500	83.0	423.2	15.4	47.9
7000	89.4	450.7	15.3	47.6

A = 78.33 SQ. IN. - AREA AT RIDE HEIGHT
A_c = 78.17 SQ. IN. - AREA AT -.5 IN. DEFLECTION
A_e = 78.44 SQ. IN. - AREA AT +.5 IN. DEFLECTION
V = 1923 CU. IN. - VOLUME AT NOMINAL DESIGN HEIGHT
V_c = 1883 CU. IN. - VOLUME AT -.5 IN. DEFLECTION
V_e = 1964 CU. IN. - VOLUME AT +.5 IN. DEFLECTION
1X60-1 FIRESTONE AIRBAG WITH 1700 CU. IN. RESERVOIR

TABLE 4-9 AIRBAG DESIGN CHARACTERISTICS

NOMINAL RIDE HEIGHT - 6.3 IN.

AIRBAG LOAD-LBS.	PRESSURE PSIG	AIRBAG STIFFNESS-#/"	DEFLECTION INCHES	FREQUENCY C.P.M.
2000	25.5	180.1	11.1	56.3
2500	31.9	208.7	12.0	54.2
3000	38.3	237.3	12.6	52.8
3500	44.6	265.8	13.2	51.7
4000	51.1	294.4	13.6	50.9
4500	57.5	323.0	13.9	50.3
5000	63.3	351.5	14.2	49.8
5500	70.2	380.2	14.5	49.3
6000	76.5	408.7	14.7	48.1
6500	83.0	437.3	14.9	48.7
7000	89.4	465.4	15.0	48.4

A = 78.33 SQ. IN. - AREA AT NOMINAL DESIGN RIDE HEIGHT
A_c = 78.33 SQ. IN. - AREA AT -.5 IN. DEFLECTION
A_e = 78.33 SQ. IN. - AREA AT +.5 IN. DEFLECTION
V = 2005 CU. IN. - VOLUME AT NOMINAL DESIGN HEIGHT
V_c = 1964 CU. IN. - VOLUME AT -.5 IN. DEFLECTION
V_e = 2047 CU. IN. -VOLUME AT +.5 IN. DEFLECTION
1X60-1 FIRESTONE AIRBAG WITH 1700 CU. IN. RESERVOIR

TABLE 4-10 AIRBAG DESIGN CHARACTERISTICS

RIDE HEIGHT - 7.3 IN.

AIRBAG LOAD-LBS.	PRESSURE PSIG	AIRBAG STIFFNESS - #/in	DEFLECTION INCHES	FREQUENCY C.P.M.
2000	26.1	299.0	6.6	72.5
2500	32.6	358.5	7.0	71.1
3000	39.2	418.1	7.2	70.0
3500	45.7	477.7	7.3	69.3
4000	52.2	537.2	7.4	68.8
4500	58.7	596.8	7.5	68.3
5000	65.2	656.3	7.6	68.0
5500	71.7	715.9	7.7	67.7
6000	78.3	775.5	7.7	67.5
6500	84.8	835.0	7.8	67.3
7000	91.3	894.6	7.8	67.1

A = 76.67 SQ. IN. - AREA AT RIDE HEIGHT
A_c = 78.33 SQ. IN. - AREA AT -.5 IN. DEFLECTION
A_e = 73.33 SQ. IN. - AREA AT +.5 IN. DEFLECTION
V = 2088 CU. IN. AT RIDE HEIGHT
V_c = 2047 CU. IN. AT -.5 IN. DEFLECTION
V_e = 2120 CU. IN. AT +.5 IN. DEFLECTION
1X60-1 FIRESTONE AIRBAG WITH 1700 CU. IN. RESERVOIR

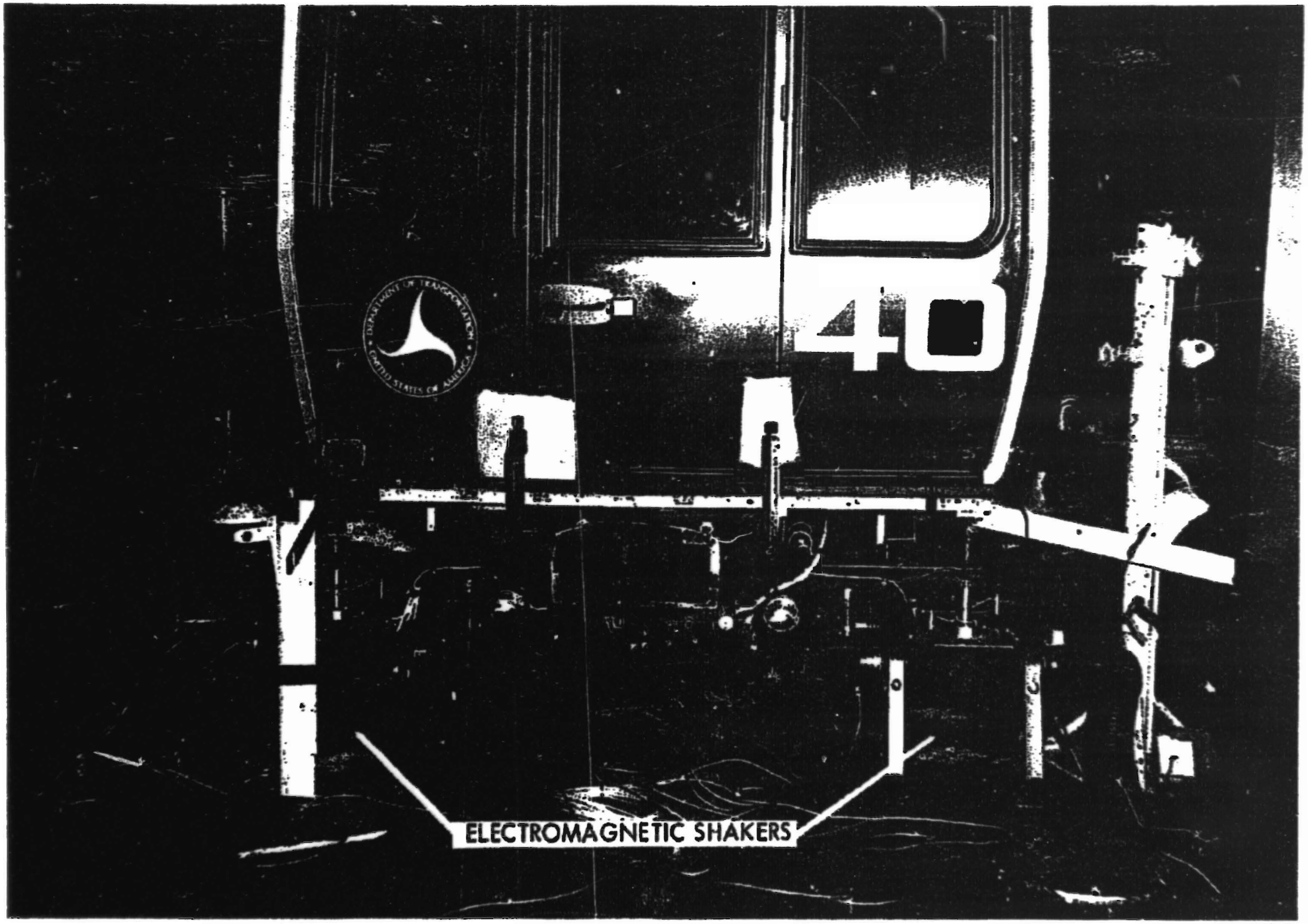


FIGURE 4-34 PHOTOGRAPH OF VEHICLE DYNAMIC RESPONSE TEST SETUP

TABLE 4-11 P40 VEHICLE DYNAMIC RESPONSE CHARACTERISTICS

Mode		Test Frequency - Hz			Remarks
		Without Vertical Shocks	With Vertical Shocks	With AIRTRANS Vertical Shocks	
	Heave	1.30	2.00	1.42	
	Pitch	1.40	1.67	1.50	
	Roll	1.25	1.55	1.32	
With Lateral Shocks	Side Translation	-	2.53	-	Same data as for initial test setup, lateral shaking not repeated
	Yaw	-	2.58	-	
Without lateral Shocks	Side Translation	2.44	2.48	-	
	Yaw	2.48	2.60	-	

NOTE: Modes were not probed in final test except for the 1.30 heave mode.

TABLE 4-12 P40 VEHICLE VERSUS AIRTRANS DYNAMIC RESPONSE CHARACTERISTICS

Mode		Test Frequency - Hz	
		P40 Without Vertical Shocks	AIRTRANS Without Vertical Shocks
	Heave	1.30	2.4
	Pitch	1.40	1.7
	Roll	1.25	1.9
without lateral shocks	Side Translation	2.44	3.2
	Yaw	2.48	3.3

loading. Dynamic response characteristics of the coupler were required to verify the coupler support structure.

An electromagnetic shaker was attached to the coupler approximately at the midpoint of the overhang. Accelerometers were mounted to the coupler and vehicle body to record response from the shaker. Figure 4-35 presents a schematic of the test setup.

Frequency sweeps both laterally and vertically up to 100 hertz were conducted with a 1 g input.

A frequency response at 14 hertz vertical and 11 hertz lateral was measured. The accelerometer readings associated with the above frequencies were 0.25 g and 0.10 g, respectively, measured on the coupler and less on the chassis. The decay rate of the above accelerations compared to the 1 g input substantiates the P40 vehicle coupler design, since it was designed to a constant level (no amplification) back to the chassis.

4.3.7 LIGHTING SYSTEM - Interior and exterior lighting for the vehicle is provided under normal operating conditions by guideway-distributed power and under emergency conditions by the vehicle battery. Internal rearrangement of equipment and changes in the vehicle power system resulted in changes to the lighting system from the AIRTRANS configuration. The changes are that the number of fluorescent fixtures has been reduced from six to four, interior emergency lighting is provided totally by incandescent fixtures, and the outside driving lights are more durable.

Testing was accomplished using the P40 prototype vehicle operating in the darkened Vought engineering test laboratories. Illumination level data were taken with a hand-held illumination meter calibrated in foot-candles. Readings were recorded at various locations in and around the vehicle while the vehicle was powered by 480-volt ac external power and later by the onboard 28-volt dc battery.

The data are presented in Figure 4-36 and Table 4-13. Normal interior lighting levels are adequate, though somewhat lower than AIRTRANS near the ends of the vehicle as would be expected due to the absence of two fluorescent fixtures. Emergency lighting levels also provide adequate illumination of all critical areas. Variations in readings between similar locations are attributed to differences in mounting the incandescent fixtures.

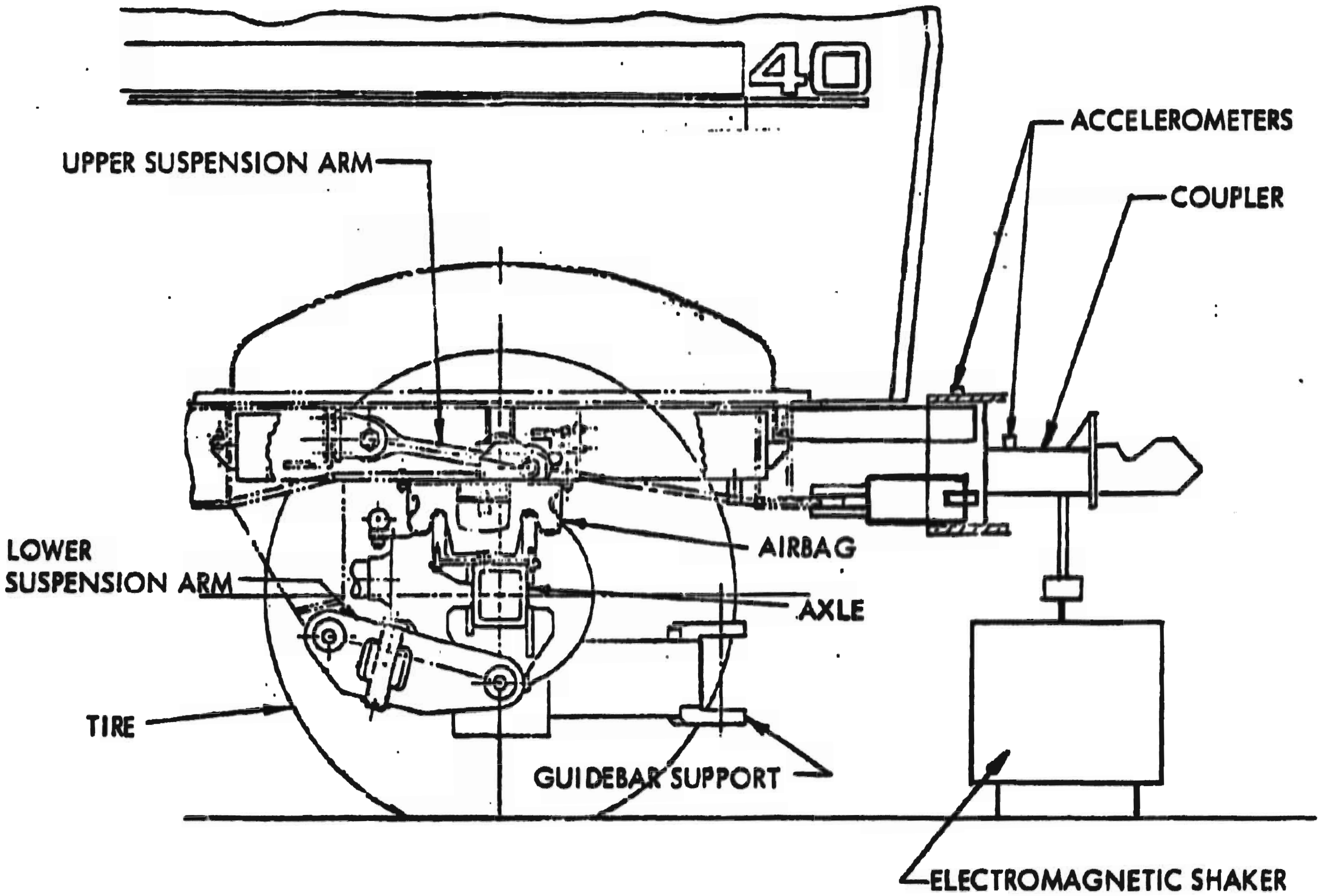
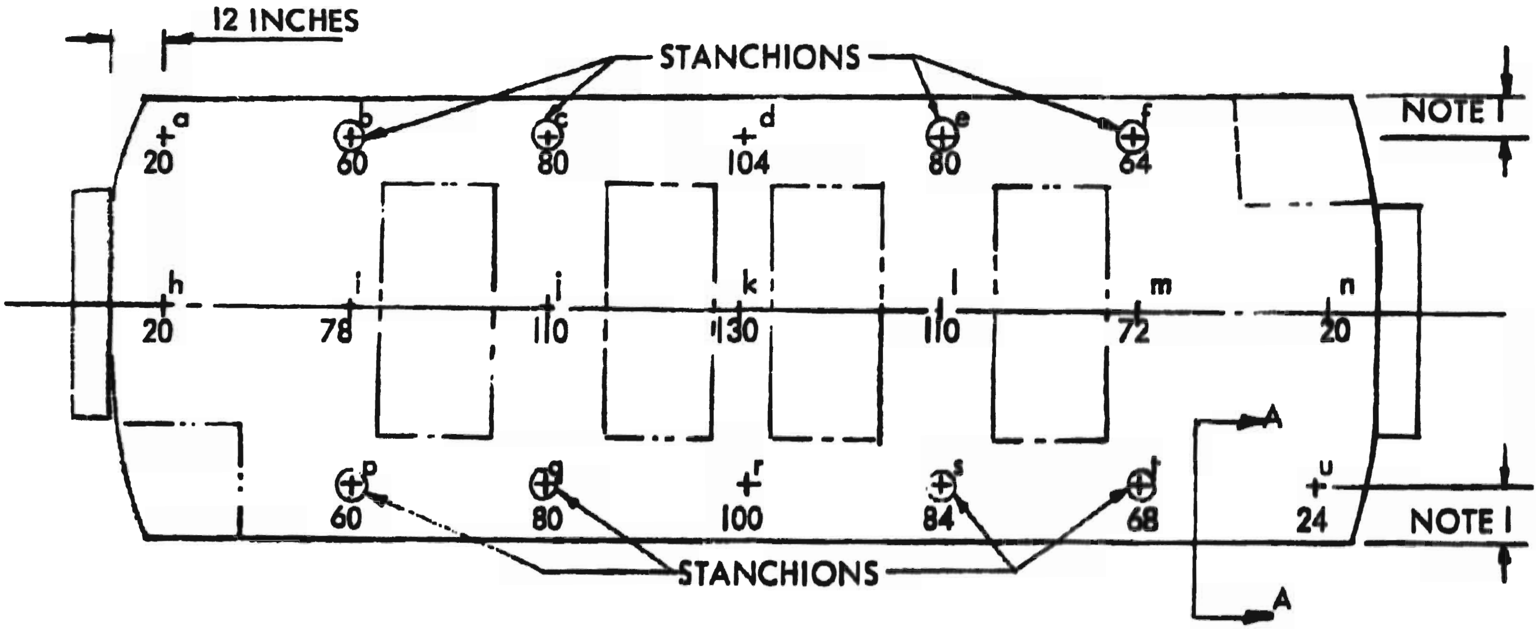


FIGURE 4-35 COUPLER VIBRATION TEST SETUP



INTERIOR LIGHTING LEVELS IN FOOT-CANDLES

NOTE I. APPROXIMATELY THREE INCHES OUTBOARD OF SEAT EDGE. (SEE SECTION A-A)

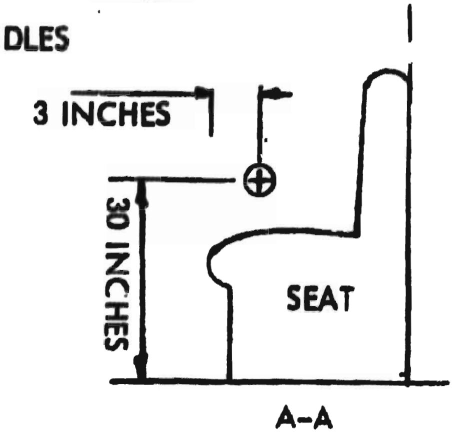


FIGURE 4-36 VEHICLE NORMAL INTERIOR LIGHTING LEVELS

TABLE 4-13 EMERGENCY LIGHTING LEVELS (PAGE 1 OF 2)

Location	Reading (foot-candles)
Bumper step at forward end of car with door open	3
Coupler at forward end of car with door open	2
Bumper step at rear end of car with door open	10
Coupler at rear end of car with door open	8
Forward door at ground level with doors open, 2 feet from car	11
Rear door at ground level with doors open, 2 feet from car	14
Right door at ground level with doors open, 2 feet from car	10
Left door at ground level with doors open, 2 feet from car	9
Threshold at forward end of car with end door open	4
Threshold at rear end of car with end door open	8
Threshold (centerline) at right side door with side door open	10
Threshold (centerline) at left side door with side door open	8
Right passenger-operated switches with side door closed	6
Left passenger-operated switches with side door closed	6
Right side door emergency release with doors closed	8
Left side door emergency release with doors closed	6
Forward end door emergency release with doors closed	2-4
Rear end emergency release with doors closed	2-4

TABLE 4-13 EMERGENCY LIGHTING LEVELS (PAGE 2 OF 2)

Location	Reading (foot-candles)
Fire extinguisher with doors closed	8
Center (fore and aft) at floor level at lateral centerline	6
Forward quarter point at floor level on lateral centerline	10 at light focus
Aft quarter point at floor level on lateral centerline	12 at light focus
Top of parapet at right side door centerline with doors open	12
Top of parapet at left side door centerline with door open	13

4.3.8 TRANSFORMER/RECTIFIER UNIT - The regulated transformer/rectifier (T-R) unit is used to convert an unregulated, nominal 480-volt ac, 3-phase, 60-hertz input voltage to a closely regulated (±1%) output voltage, the output voltage can be adjusted and set anywhere between +26 and +29.5 volts. The unit, with a continuous output rating of 100 amperes, is used for battery charging, trickle charging, selected vehicle lighting, controls, electronics, communications and other vehicle auxiliary functions.

The T-R is an integrally packaged unit, forced air cooled and mounted under the car. Major elements of the 148-pound unit consist of input and output power filters, a power transformer, phase-controlled power semiconverter (6-phase), blower, control board and outdoor enclosure. The unit can be rapidly installed and removed from the vehicle by means of special mounting provisions and connectors for all vehicle wiring interfaces.

The T-R unit was designed, developed and tested by Utah Research and Development Corporation (URDC) of Salt Lake City, Utah. A production prototype unit was subjected to a series of laboratory tests for purposes of design verification. These tests, in the sequence performed, are listed below:

(1) Room-temperature functional tests

(2) Low-temperature cold soak and functional tests at -30°F ambient

(3) High-temperature heat soak and functional tests at +120°F ambient

(4) Audible noise test

(5) Electromagnetic interference tests

(6) Vibration and shock tests

The T-R unit performed satisfactorily during these tests, except output voltage regulation with low input line voltage was outside of specification limits at both high- and low-temperature extremes.

The room-temperature functional tests were conducted at URDC's test facilities. All other tests were performed at Sperry Univac's laboratories in Salt Lake City, Utah.

No formal running tests were planned or performed on the T-R unit, however, its output voltage is measured periodically with a digital voltmeter. The output voltage has remained within tolerance.

4.3.8.1 Room-Temperature Tests -- The T-R unit was submitted to room-temperature functional tests at URDC's test facilities. Test procedures and a summary of results are presented below:

(1) The T-R unit was set up and connected as in Figure 4-37. Ambient room temperature was 75°F. Battery was allowed to discharge for 10 minutes at 20 amperes.

(2) Power was applied and line-to-line voltage set at 480 volts ac. Switch (SA) was closed.

(3) The output voltage rose to 29.5 volts dc, and the charger dropped out of current limit.

(4) Load regulation was checked by opening and closing switch (SA) three times. Output voltage did not vary beyond the specified 29.21 to 29.8 volts dc range.

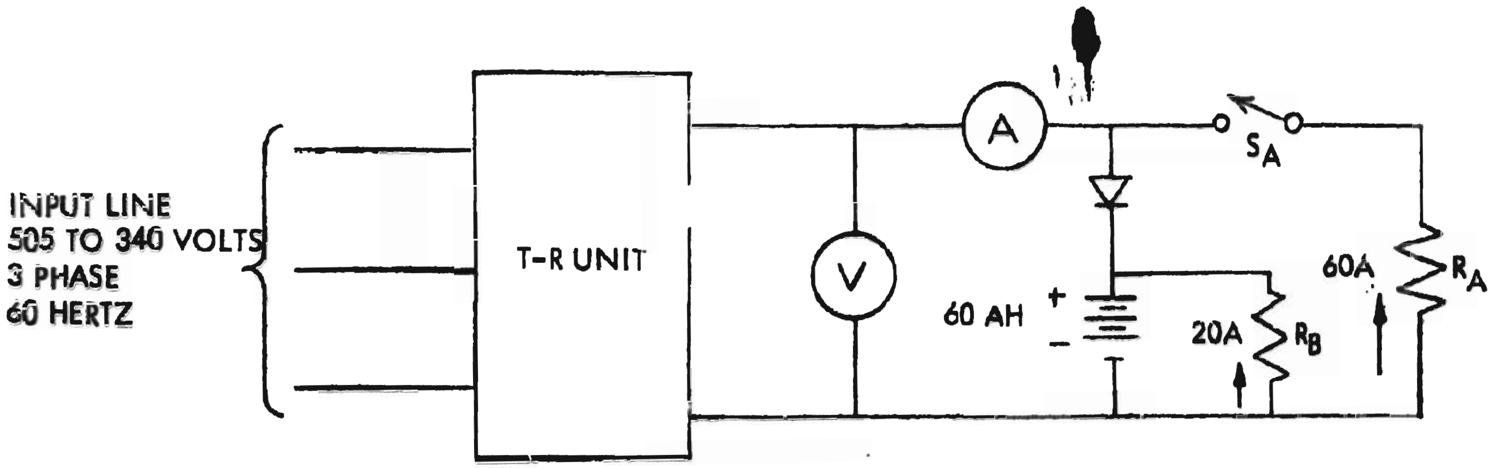
(5) With switch (SA) closed, line regula[illegible] checked as follows: Line-to-line input voltage [illegible] at 505 volts ac and output voltage recorded. Line voltage input was set at 432 volts ac and output voltage recorded. Input voltage was returned to 505 volts ac and the output voltage recorded. Output voltage did not vary outside the specified 29.21 to 29.8 volts dc range.

(6) Line-to-line input voltage was set at 480 volts ac. Output ripple voltage was checked with an oscilloscope. Switch (SA) was opened and closed three times and ripple voltage recorded in each switch position. Ripple voltage did not exceed the specified 1.0 volt peak-to-peak.

(7) With full load on the T-R unit as defined by Figure 4-37 and input voltage at 381 volts line-to-line, the output voltage measured was higher than the specified 25.7 volts.

(8) With full load on the T-R unit and input voltage at 340 volts line-to-line, the output voltage measured was higher than the specified 23.0 volts.

(9) Enclosure inlet air, fan inlet air and enclosure outlet air temperatures were measured and recorded for 505, 480 and 432 volts line-to-line. The unit was operated at each voltage level until thermal equilibrium was reached while delivering approximately full load as defined by Figure 4-37. The temperatures were well within design limits.



A = AMMETER
V = VOLTMETER
S_A = MANUALLY OPERATED SWITCH
R_A and R_B = LOAD BANKS
BATTERY = 60 AMPERE-HOUR (AH) , POCKET PLATE , NICKEL CADMIUM

FIGURE 4-37 TRANSFORMER/RECTIFIER (T-R) UNIT TEST CIRCUIT

4.3.8.2 Low-Temperature Tests - The T-R unit was subjected to tests while experiencing an ambient temperature of -30°F. Test procedures and a summary of results for these low-temperature tests are presented below:

(1) The T-R unit, in a nonoperating state, was placed in a low-temperature test chamber where it cold soaked for 24-hours at a regulated temperature of -30°F.

(2) The unit was operated in the Figure 4-37 test configuration, at full load, until thermal equilibrium was reached.

(3) The procedures of the room-temperature test were repeated with no deviation observed from specified performance except that, during the air temperature measurements with a line voltage setting of 432 volts, the output voltage was recorded as 28.3 volts instead of a minimum of 29.2 volts. This low voltage reading, as explained by URDC, is the result of needing one additional winding on the secondary of the main power transformer, a correction which could be verified by testing on additional units procured.

4.3.8.3 High-Temperature Tests - The T-R unit was subjected to tests at an ambient temperature of +120°F. Test procedures and a summary of results for these tests are presented below:

(1) The T-R unit, in a nonoperating state, was placed in a high-temperature chamber and heat soaked for 24-hours at a regulated temperatures of +120°F.

(2) The unit was operated in the Figure 4-37 test configuration, at full load, until thermal equilibrium was reached.

(3) The procedures of the room-temperature test were repeated with no deviations observed from specified performance except that, during the air temperature and line regulation measurements, with input line voltage of 432 volts, the output voltage was 28.5 and 28.7 volts, respectively, instead of the minimum of 29.2 volts.

4.3.8.4 Audible Noise Tests - The T-R unit, at room temperature in a shielded room, was operated at full load in the test circuit configuration of Figure 4-37. The audible noise level was checked by placing the unit 15 feet from the sound level meter with the measurements performed while the T-R unit was rotated 360°. The measured noise level perpendicular to each face of the T-R unit was significantly less than the specified limits of 68 dBa, being a maximum of 47. Audible noise is defined as "A" weighted sound pressure level and is in decibels referred to 0.0002 microbar as measured on the "A" scale of a standard sound level meter using the slow meter scale.

4.3.8.5 Electromagnetic Interference (EMI) Tests - The T-R unit was subjected to EMI tests at room temperature in a shielded room in accordance with test methods CE01, CE03, CE04 and CE05 of MIL-STD-461-4. Conducted emissions on the dc power leads, control and signal leads were measured from 30-hertz to 50 megahertz. Radiated emissions were measured from 14-kilohertz to 12.4 gigahertz. No deviations from specified performance were ovserved.

4.3.8.6 Vibration and Shock Tests - Extensive vibration and shock testing were performed on the T-R unit at room temperature in accordance with M[illegible]10C. The procedures and results of these tests are sum[illegible]ow:

(1) A six-hour vibration test was conducted in accordance with Method 514.2, Category F, Procedure VIII. A resonant search was conducted at 1/2 g level from 5 to 500 hertz in each of the three mutually perpendicular axes. The three worst conditions in each axis were determined and a 30-minute, 1 g dwell was performed at each of these frequencies as indicated:

   (a) Longitudinal Axis - 30, 68 and 85.4 hertz

   (b) Vertical Axis - 38.4, 114 and 155 hertz

   (c) Lateral Axis - 37.6, 58 and 117 hertz

   The balance of the time, 30 minutes in each axis, was consumed in performing two 15-minute sweeps from 0 to 500 to 0 hertz at 1 g input. The unit operated within tolerances with only a minor malfunction - a broken retaining clip on the end of the fan armature shaft. The broken clip presented no significant operating problem other than a rubbing noise when the fan was permitted to coast down upon being deenergized. The clip was replaced.

(2) Shock tests were conducted in accordance with Method 5.16.2, Procedure I and consisted of three shocks in each direction of the three mutually perpendicular axes. Each shock was at a 3 g level with a duration of 15 milliseconds. No malfunctions resulted from the shock tests.

(3) The room-temperature functional tests were repeated with all parameters in tolerance, except output voltage regulations was again outside of limits with low line voltage.

4.3.8.7 Evaluation - Based upon laboratory and running tests, the prototype T-R unit is considered acceptable for operation on prototype vehicle P40. However, further design study and possible testing are anticipated prior to production of the T-R unit for urban application. The additional effort would be primarily directed toward determining and correcting out-of-limit voltage regulation at low input line voltages at temperature extremes. Package design needs additional review.

4.3.9 REGENERATIVE BRAKING (T365) - The AUTP propulsion [redacted] was designed and developed during AUTP Phase I to meet t requirement of 30-mph operation with a severe duty cycle. system consists of two independent propulsion systems per vehicle each of which provides motoring and regenerative braking. Each system drives one [redacted] and has a 100-horsepower, shunt-wound dc motor and a motor controller. In motoring, the controller provides a variable, positive dc voltage to the motor armature. For regenerative braking, the direction of field current is reversed while maintaining the same armature current direction. In the braking mode, the controller rectifier circuit functions as a line-commutated inverter.

The system was evaluated during AUTP Phase I by both laboratory and on-guideway tests. Refer to Reference (2) for details. Laboratory tests included verification of electrical and control interfaces, duty cycle capabilities and system efficiency and torque. On-guideway tests included motoring and nonregenerative braking test runs under manual control in which system response and line voltage/current waveforms were studied.

Additional testing of the propulsion system was accomplisehd by on-guideway tests during AUTP Phase II. The objective was primarily to evaluate system performance with regenerative braking under automatic train control. Testing was accomplished using test vehicle T365 prior to its conversion to the P40 vehicle. Before testing, the propulsion system was modified to improve the low-voltage capability of the propulsion control to 340 volts. Phase I testing had disclosed a 380-volt limit instead of the specified 340 volts. Also, the vehicle control system modification for regenerative braking was installed.

Test runs were made in the high-speed test section in areas that were approximately level. A total of 12 acceleration-cruise-deceleration runs were made at speeds up to 30 mph. A summary of the test results in presented in Table 4-14.

Both propulsion systems performed well in all tests. The No. 1 system tripped out on undervoltage (327 volts) on run 6, but this was considered normal. The regenerative braking system provided very smooth stops with no detectable anomalies on the vehicle or the wayside power system. Although propulsion system real and reactive power data were recorded, correlation of the data with analytical results was not feasible because of large variations in the supply voltage.

TABLE 4-14 SUMMARY OF PHASE II PROPULSION TEST DATA (PAGE 1 OF 2)

Run Number	1	2	3	4	5	6	7	8	9	10	11	12
Systems tested	No. 1 and 2	No. 1 and 2	No. 1 and 2	No. 1 and 2	No. 1 and 2	No. 1 and 2	No. 1 Only	No. 2 Only	No. 1 Only	No. 2 Only	No. 1 Only	No. 2 Only
Braking mode (F=friction, R=regenerative)	F	R	F	R	F	R	R	R	R	R	R	R
Nominal cruise speed (mph)	10	10	17	17	30	30	10	10	17	17	30	30
Peak speed (mph)	10.7	10.4	16.0	16.0	27.3	24.3 (Note 3)	11.1	10.2	16.4	16.2	24.5	24.7
Acceleration rate (mph per second)	1.8	2.0	1.8	2.0	1.8	2.0	0.71	0.71	0.72	0.71	0.73	0.63
Deceleration rate (mph per second)	2.3	2.8	2.3	2.8	2.4	3.0	2.6	2.6	2.8	2.8	2.7	2.5
Minimum line voltage - accelerating (volts)	378	316	364	371	344	327	399	399	368	385	337	351
Minimum line voltage - decelerating (volts)	413	413	450	392	430	402	378	413	371	413	385	402

TABLE 4-14 SUMMARY OF PHASE II PROPULSION TEST DATA (PAGE 2 OF 2)

Run Number	1	2	3	4	5	6	7	8	9	10	11	12
Peak kW – accelerating	59.4	62.5	87.5	100	172	167	34.4	39.1	51.6	51.6	87.5	79.7
Peak kW – decelerating (Note 4)	-	-29.7	-	-48.4	-	-100	-20.3	-12.5	-40.6	-40.6	-65.6	-70.3
Peak KVAR – accelerating	240	229	229	219	219	229	125	120	125	125	115	125
Peak KVAR – decelerating	-	208	-	193	-	208	172	167	182	193	193	203
Cruise kW	15.6	15.6	26.0	26.6	No Data	No Data	12.5	15.6	23.4	No Data	No Data	No Data
Cruise KVAR	41.7	41.7	26.6	20.8	No Data	No Data	26.0	31.3	36.5	No Data	No Data	No Data

Notes:

1. All runs consisted of acceleration from 0 mph to cruise, cruise and deceleration to 0 mph.
2. All power quantities measured at input to propulsion system(s).
3. No. 1 system tripped on undervoltage (327 volts) while accelerating at 23.4 mph and picked up again in cruise.
4. Real power returned to source.

4.3.10 COMMAND CONTROL AND COMMUNICATIONS

4.3.10.1 Command Control - Control system performance tests were performed at the D/FW AIRTRANS facilities. The purpose of the tests was to verify that the operation of the command control functions of the vehicle control electronics (VCE) and associated hardware was within the design criteria. Refer to Volume 1 for design details of the control system. The tests were divided into two categories:

(1) On-jack tests in an AIRTRANS maintenance bay utilizing the AIRTRANS automatic train control (ATC) test set

(2) Guideway operational tests

For the duration of these tests, the portable test equipment (PTE) rack was located on the vehicle for data recording and problem diagnosis.

4.3.10.1.1 On-Jack Tests - Prior to the initial insertion of the vehicle in the guideway or following any required modifications affecting the command control system, the vehicle was placed on jacks and tested utilizing the D/FW AIRTRAINS ATC test set. These tests verified the functional response of the command control system to simulated wayside commands.

4.3.10.1.2 Guideway Operational Tests - The initial portion of the guideway tests was performed in the maintenance loop of the guideway system. Operation of the vehicle in the maintenance loop allowed the flexibility to tailor the wayside commands to the test requirements with minimal interference to AIRTRANS revenue operations. In addition to the maintenance testing, guideway tests to evaluate system components and designs were conducted to meet program test objectives. Demonstration and revenue operation complemented the above tests as system design and performance were further evaluated.

The vehicle was operated from a stop to the basic speed commands, profiled between basic speed commands and speed commands with speed overrides and stopped in the long and short profile and emergency stop modes. Table 4-15 lists the basic speed and stop commands, the speed override commands and the associated vehicle speeds and stop distances. During these tests, the following operational anomalies were encountered:

(1) Erratic operation of the Intel 8253 device when utilized in the timer application

(2) Marginal operation of the General Railway Signal rollback sensor assembly when operating at very low vehicle velocities

(3) Noise on the output signals from the Airpax 087-304-0040 magnetic field detector (used as a wheel tachometer)

TABLE 4-15 COMMAND SPEEDS AND STOPS – P40 GUIDEWAY TESTS

Signal Rail Speed Commands	Override Commands	Vehicle Speed
High Limit High Command (H/H)	None 82% 63%	24.4 ft/sec 20.0 15.4
High Limit Medium Command (H/M)	None 82% 63%	11.88 ft/sec 9.74 7.48
Medium Limit Low Command (M/L)	None 82% 63%	5.0 ft/sec 4.1 3.2
Medium Limit Long Profile Stop from H/M or M/L (M/P)	-	Existing speed to 0.0 ft/sec in 44 ft
Low Limit Short Profile Stop from M/L only (L/S)	-	Existing speed to 0.0 ft/sec in 25.7 feet
Zero Limit Zero Command (0/0)	-	Existing speed to 0.0 ft/sec emergency stop

The Intel 8253 device was used in the vehicle control electronics assembly as a gated timer to measure vehicle velocity (for use in the propulsion control system). The erratic operation of this device resulted in erroneous velocity measurements and in unsatisfactory, occasionally jerky, vehicle performance. The Intel device was replaced with the National Semiconductor 8253 and complemented with filters, a combination which eliminated the erratic characteristics.

The General Railway Signal (GRS) 30883 rollback sensor assembly, as used in this program, is a modified AIRTRANS rollback sensor. (Refer to Volume 1 for description.) At the very low velocities during startup, the rollback sensor would not reliably indicate forward motion before the safety system timed out and stopped the vehicle. The friction loading device between the pendulum and rotating shaft did not provide a uniform, consistent operation. The pendulum stop design also exhibited a relatively short service life.

The AUTP Phase II redesign by GRS addressed these shortcomings of the AIRTRANS unit and provided the additional centering feature. The single, leaf spring-loaded carbon brush was replaced with dual carbon brushes mounted in a coil spring-loaded assembly to provide a more uniform friction force over the life of the brush. The brushes now run on a replaceable stainless steel plate to help provide a constant and uniform retarding force and to provide simple replacement when the surface becomes worn. The AIRTRANS electromagnet was replaced by a permanent magnet for improved reliability. Testing to date has included laboratory and vehicle operations. Early vehicle operations indicated difficulties with stability of the pendulum at certain vehicle speeds, with pendulum bounce during startup and centering, with inconsistent centering of the pendulum and with simultaneous actuation of two of the magnet switches. These problems were all corrected and subsequent laboratory and vehicle operations have shown the current rollback sensor design to be satisfactory. Laboratory testing has included limited endurance running and operation in temperature extremes from -22°F (-30°C) to +158°F (+70°C). The overall reliability of the new unit will be determined through continued use on the prototype vehicle.

An Airpax 087-304-0040 magnetic field detector is used in conjunction with an exciter ring as a tachometer on each wheel of the vehicle to measure vehicle velocity and direction (Volume 1). The two detectors mounted on the rear wheels of the vehicle exhibited erratic outputs on the direction discrete signal. This resulted in the control system sensing a rollback condition which called for propulsion shutdown and stop. The two detectors were removed for test and repair, and the direction discretes were connected to indicate forward direction. On reinstallation of the sensors, a software modification was incorporated in the VCE to change from a unanimous direction signal concurrence to a majority concurrence. This enhances the noise immunity of the direction sensing. With the resolution of these problems, the vehicle was put into the AIRTRANS revenue guideway, carrying revenue passengers. Vought personnel were on the vehicle during revenue operation but not identified to passengers. Action by Vought personnel on the vehicle was taken only upon request by Central Control.

Revenue guideway testing consisted of:

(1) Operation on test routes for mainline, passenger station stops (left door) and employee station stops (right door)

(2) High-speed test runs

(3) Operation on revenue routes on a noninterferring basis for the audio announcement unit and the onboard graphics checkout (paragraphs 4.3.10.2.2 and 4.3.10.2.3)

The vehicle was operated in the AIRTRANS revenue guideway environment on test routes to avoid interference with the AIRTRANS revenue traffic control. During the initial test runs, three major problems were encountered:

(1) A 5-hertz drive train resonance

(2) Erratic performance at station stops

(3) Invalids on the data communication loop with the supervisory data system

The dynamic characteristics of the tires and mechanical system, when coupled with the electrical/electronic characteristics of the motor controller and control electronics in a closed loop control system, exhibited a 5-hertz resonance which produced an undesirable ride quality in cruise and an unacceptable stopping mode. At slow speeds during normal stops on level ground or on a downgrade, the system was excited at the resonant frequency causing an uncomfortable jerk and acceleration on the vehicle. At slow speeds during normal stops on an upgrade, the magnitudes of the jerk and acceleration required the stops to be aborted to preclude the possibility of damage to the guideway or the vehicle. The insertion of 1.5-hertz two-pole Chebyschev filters in series with each motor current command signal suppressed this phenomena to a negligible level.

Erratic performance at station stops manifested itself in short stops due to signal noise in the onboard velocity and distance measurements.

The control system utilizes onboard measurements of velocity and distance to compute motor current commands and to define the stop point for the end of profile (Volume i). Noise in the velocity measurement affects the velocity profile of the vehicle and hence the zero velocity distance. Noise in the distance affects the profile and has an accumulative effect on the final stopping point. To enhance the noise immunity of this circuit and the measured results in the VCE, hardware and software filtering and validity test modifications were implemented. A hardware low-pass r-c filter and a Schmitt trigger for shaping the pulse leading edge were implemented at the output of each wheel magnetic field detector. The software was modified to reject a measured velocity change of more than 1 foot/second per iteration cycle or a measured distance change in an iteration cycle that differs from the predicted distance change by more than 0.08 foot.

The wayside data communication transceiver for this P40 vehicle is a redesign of the AIRTRANS hardware physically incorporated in the vehicle control electronics assembly. The redesign was accomplished for operation in accordance with the AIRTRANS VWC (vehicle-to-wayside communications) transmitter and WVC (wayside-to-vehicle communications) receiver specifications. During initial operation in the AIRTRANS guideway system, the communications exhibited the following discrepancies:

(1) Asynchronous operation - loss of carrier detect

(2) Dropping pseudos - loss of first-word communication with wayside

(3) Invalid operation - loss of second-word communication with wayside

Discrepancies (1) and (2) were due to receiver problems isolated and design corrected during testing at D/FW. The asynchronous operation was corrected by a "three times" increase in receiver sensitivity. The problem of dropping pseudos was corrected by:

(1) Lowering the discriminator output level detect bias, eliminating random loss of data bits

(2) Replacement of the TTL (transistor-transistor logic) hardware in the digital section of the receiver with CMOS (complementary metal oxide semiconductor) hardware, improving the receiver noise immunity and eliminating truncation of received data

Testing revealed the invalid second-word message discrepancy to be a compatibility problem between the vehicle transmitter and the AIRTRANS wayside. As a result of onboard testing, the transmitter output was increased to approximately 2 times specification level and the data rate was decreased to 85% of specification rate. Operation was greatly improved (better than 99% success), but the problem was not completely eliminated. In conjunction with the D/FW AIRTRANS engineering and technician personnel, the data rate was returned to 100%, the carrier frequency shift was decreased to 90% of specification valve and the transmitter output was decreased to approximately 1.2 times specification level. In this configuration, the vehicle communication success rate was deemed acceptable and currently defines the P40 deliverable tranceiver setup criteria. The difficulties associated with the P40 data communications were unanticipated, as the tranceiver design involved standard FSK (frequency shift keying) signalling on low (1 kilohertz) data rates involving the same intercoupling components as AIRTRANS. While the pure identification of this problem is unresolved at program completion, it is not considered to be significant.

Vehicle automatic response to wayside commanded speed changes is shown in Figures 4-38 through 4-46. Figures 4-38 through 4-40 show vehicle startup from stop to 5 feet/second (M/L), 11.88 feet/second (H/M) and 24.4 feet/second (H/H), respectively. Figures 4-41 through 4-44 shown vehicle speed transitions from 5 feet/second (M/L) to 11.88 feet/second (H/M), from 11.88 (H/M) feet/second to 24.4 feet/second (H/H), from 24.4 feet/second (H/H) to 11.88 feet/second (H/M) and from 11.88 feet/second (H/M) to 5 feet/second (M/L), respectively. Figures 4-45 and 4-46 show long profile stops (522.5 inches) from 11.88 feet/second (H/M) and 5 feet/second (M/L), respectively. Figure 4-47 shows a short profile stop (302.5 inches). The following is the definition of the trace identification abbreviations used in Figure 4-38 through 4-47:

(1) X (feet) - Distance traveled after entering stop block and after a reset liftoff cue approximately 10 feet from stopping position

(2) V (feet/second) - vehicle velocity

(3) I (amperes) - motor armature current command per motor

(4) V (feet/second^2) - longitudinal acceleration measured at floor level at the forward end, left side of the vehicle

(5) PSI (pounds/inch^2) - vehicle service brake air pressure. Brakes are released when pressure is 0

(6) DIR (discrete) - Forward/reverse torque direction command to the propulsion motors

High-speed test runs were made in a designated area of the revenue system to demonstrate the capability to run 30 mph and to obtain acoustic and ride quality data. The data are discussed in paragraphs 4.11 and 4.12.

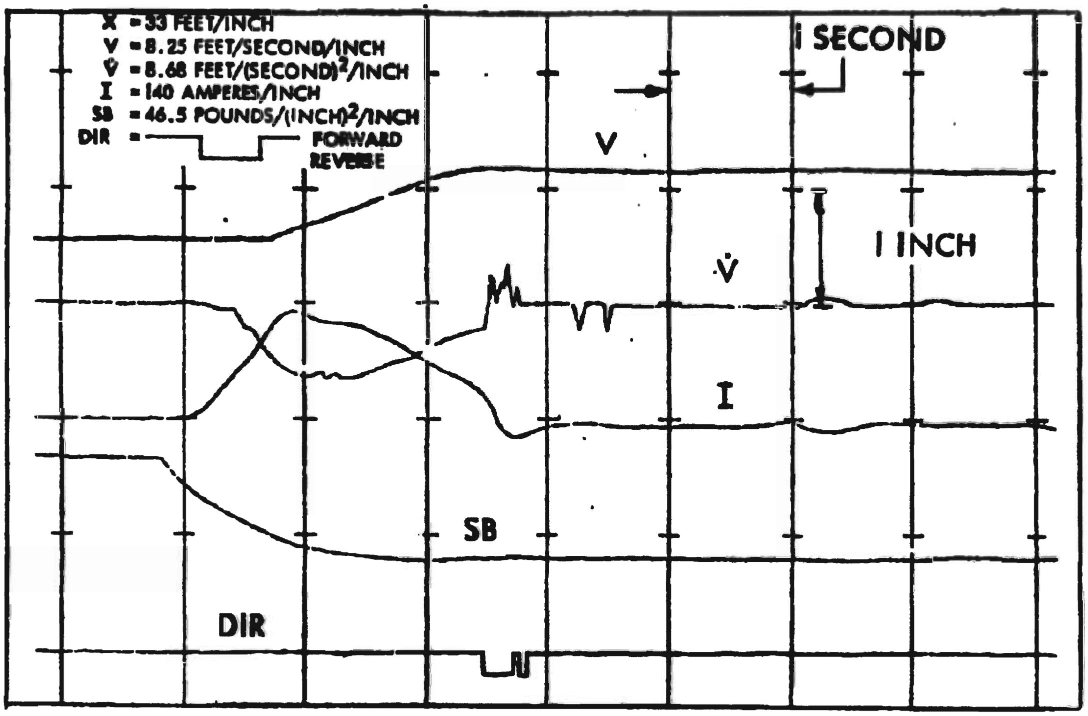


FIGURE 4-38 P40 STARTUP, 0 FEET/SECOND TO 5 FEET/SECOND

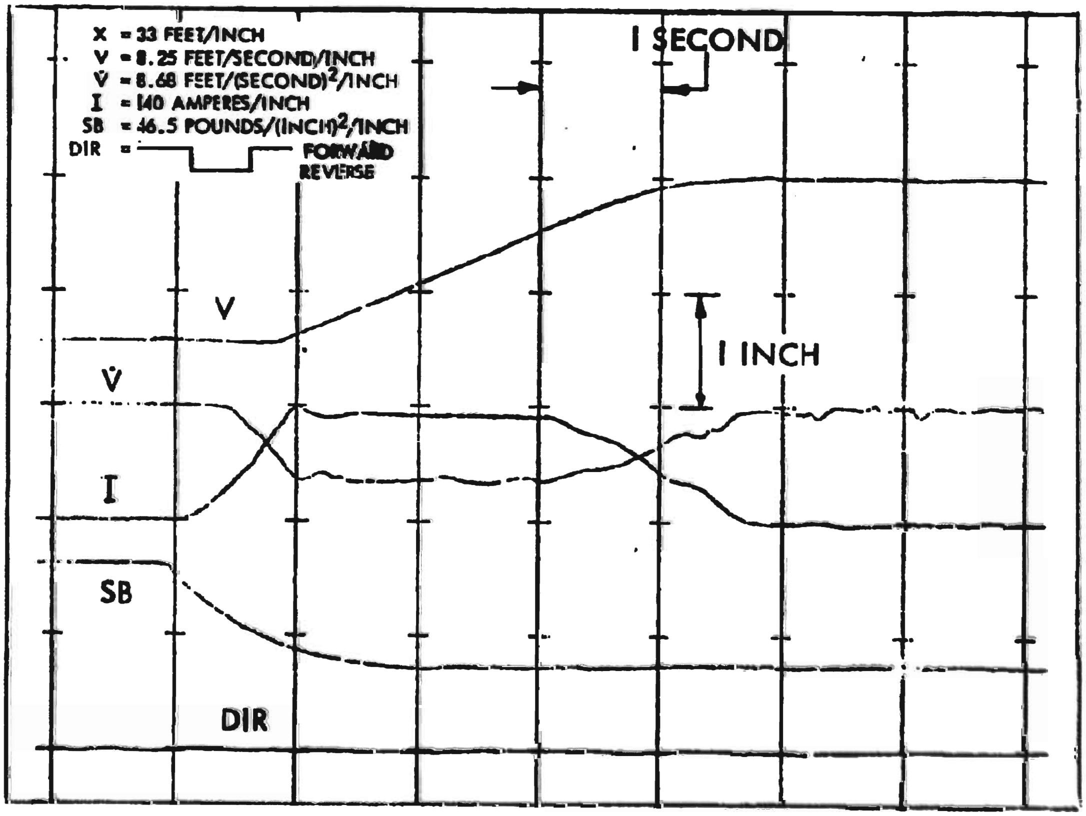


FIGURE 4-39 P40 STARTUP, 0 FEET/SECOND TO 11.88 FEET/SECOND

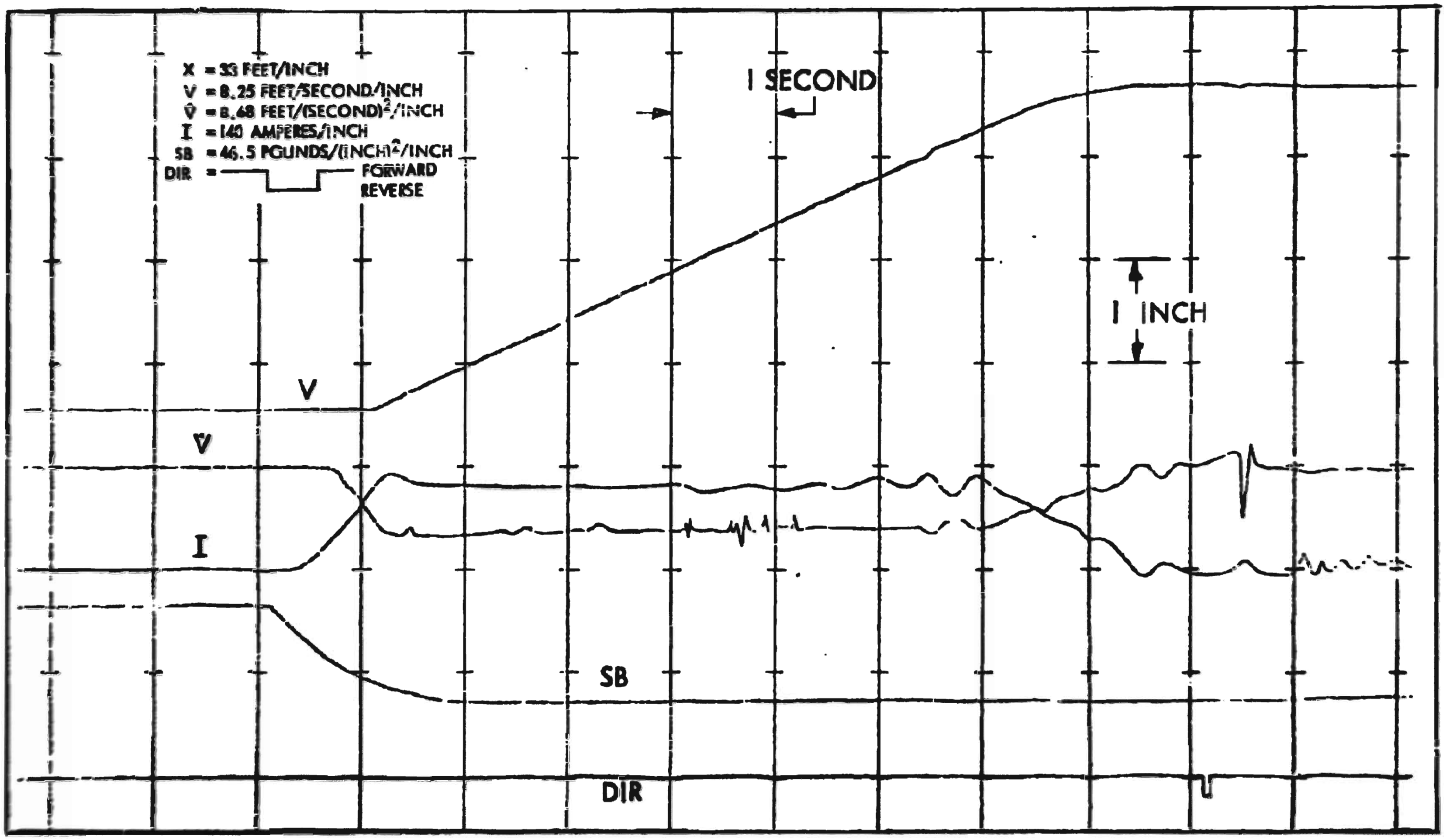


FIGURE 4-40 P40 STARTUP, 0 FEET/SECOND TO 24.4 FEET/SECOND

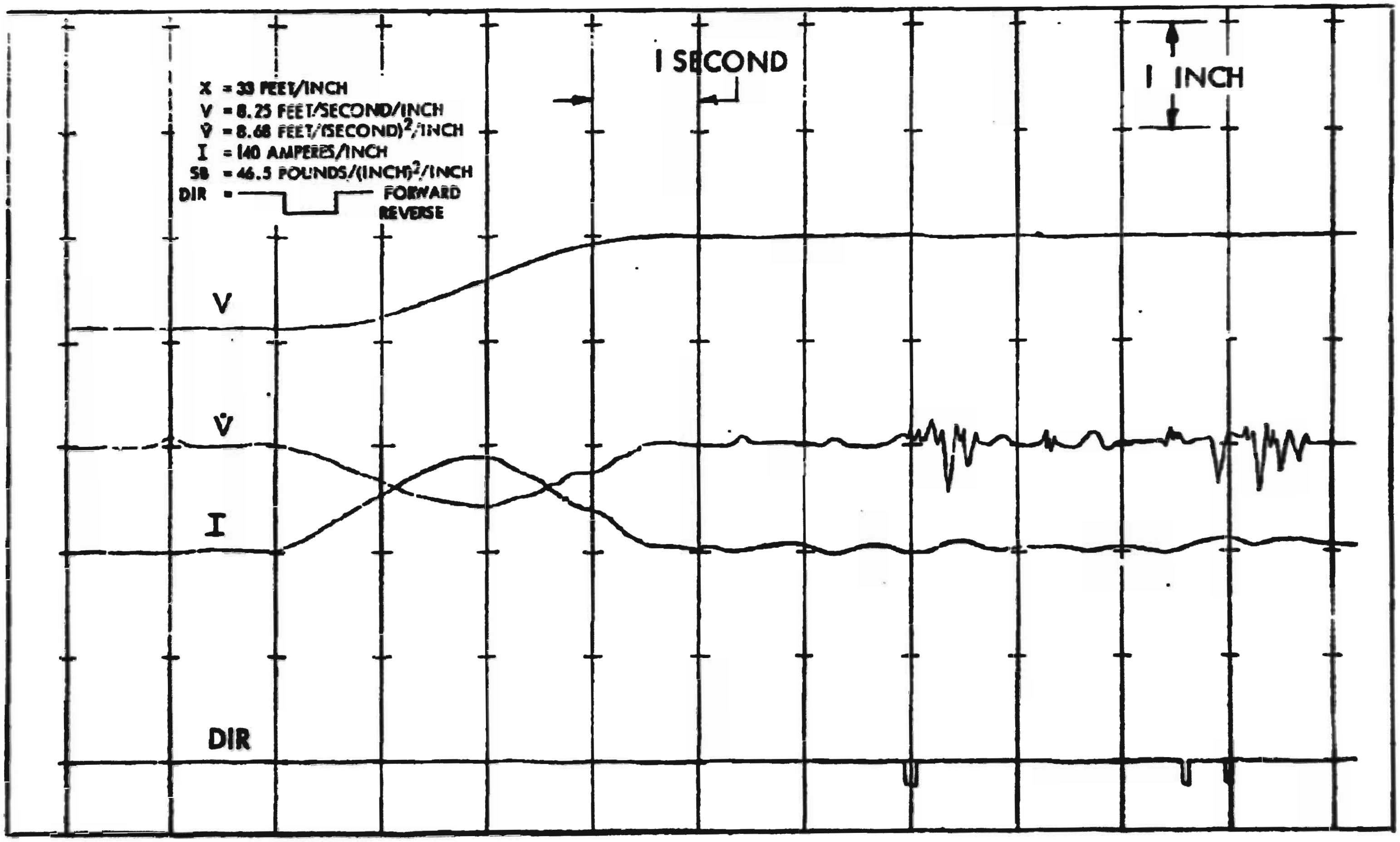


FIGURE 4-11 P40 SPEED TRANSITION, 5 FEET/SECOND TO 11.88 FEET/SECOND

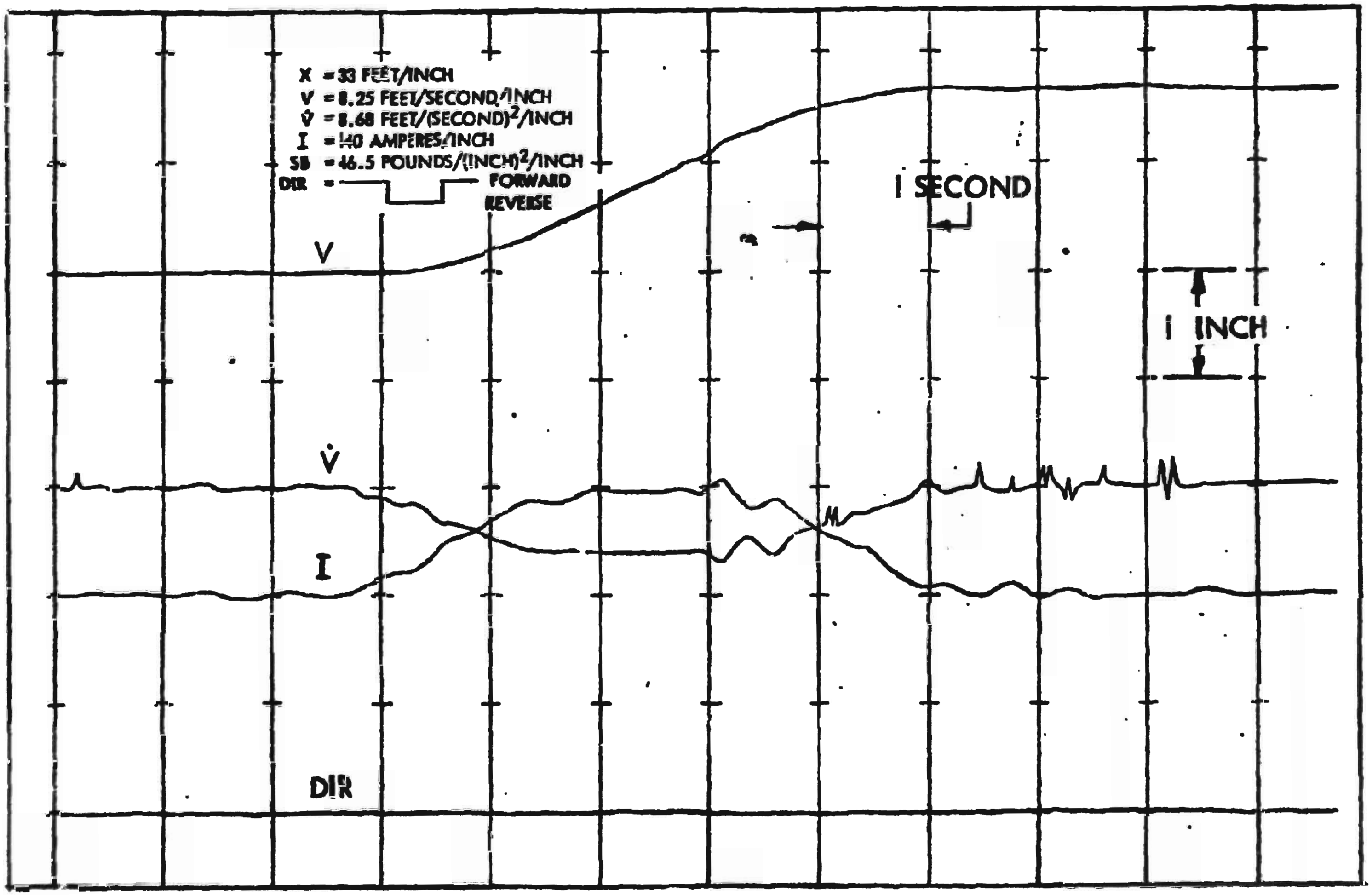


FIGURE 4-42 P40 SPEED TRANSITION, 11.88 FEET/SECOND TO 24.4 FEET/SECOND

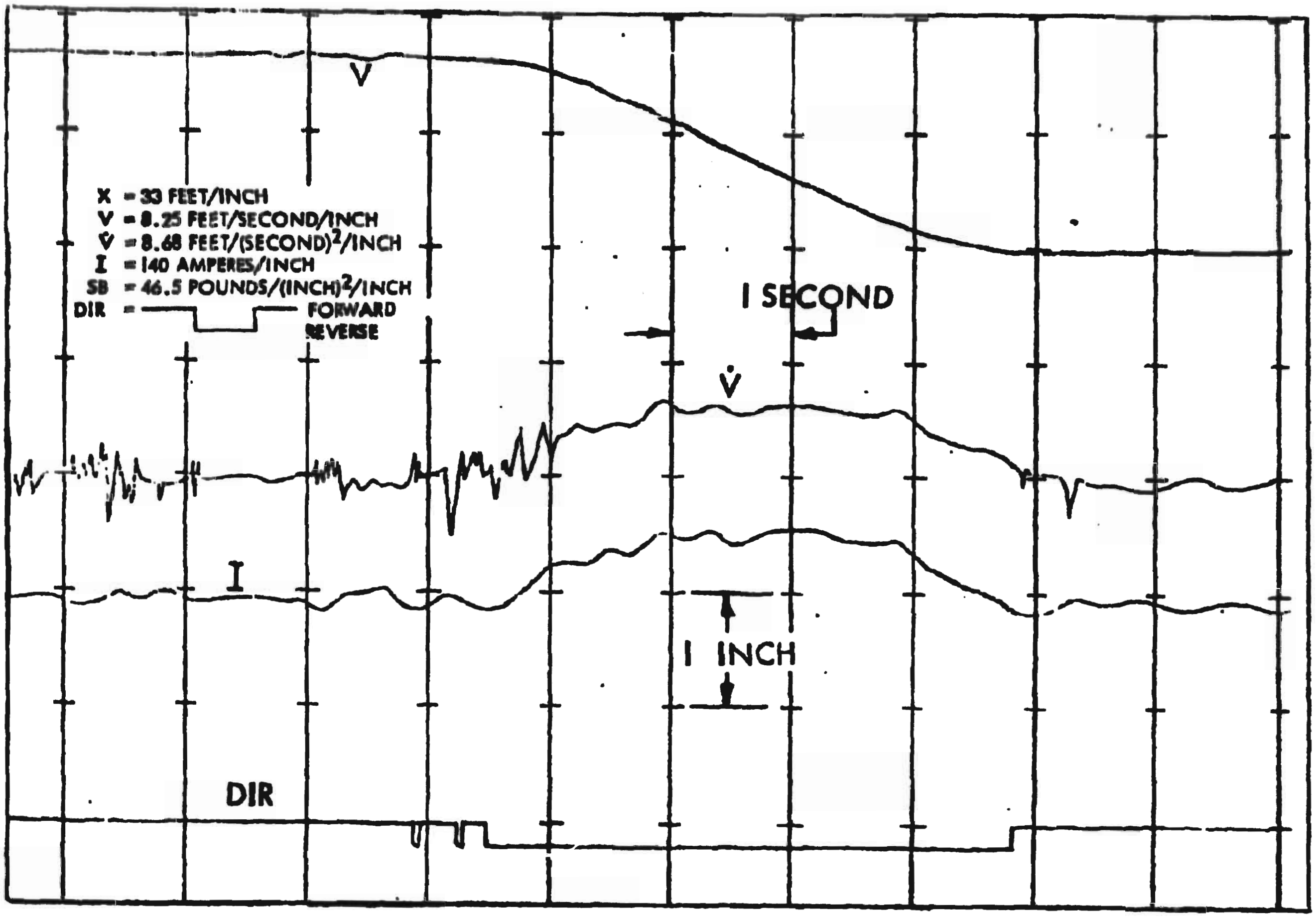


FIGURE 4-43 P40 SPEED TRANSITION, 24.4 FEET/SECOND TO 11.88 FEET/SECOND

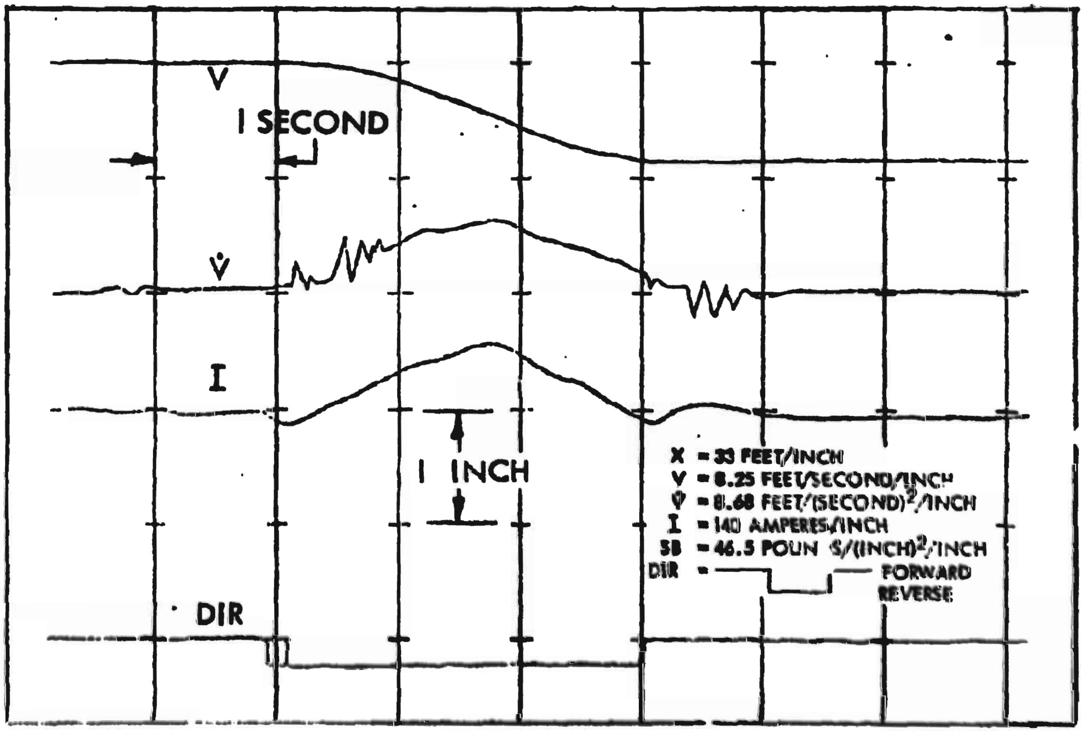


FIGURE 4-44 P40 SPEED TRANSITION, 11.88 FEET/SECOND TO 5 FEET/SECOND

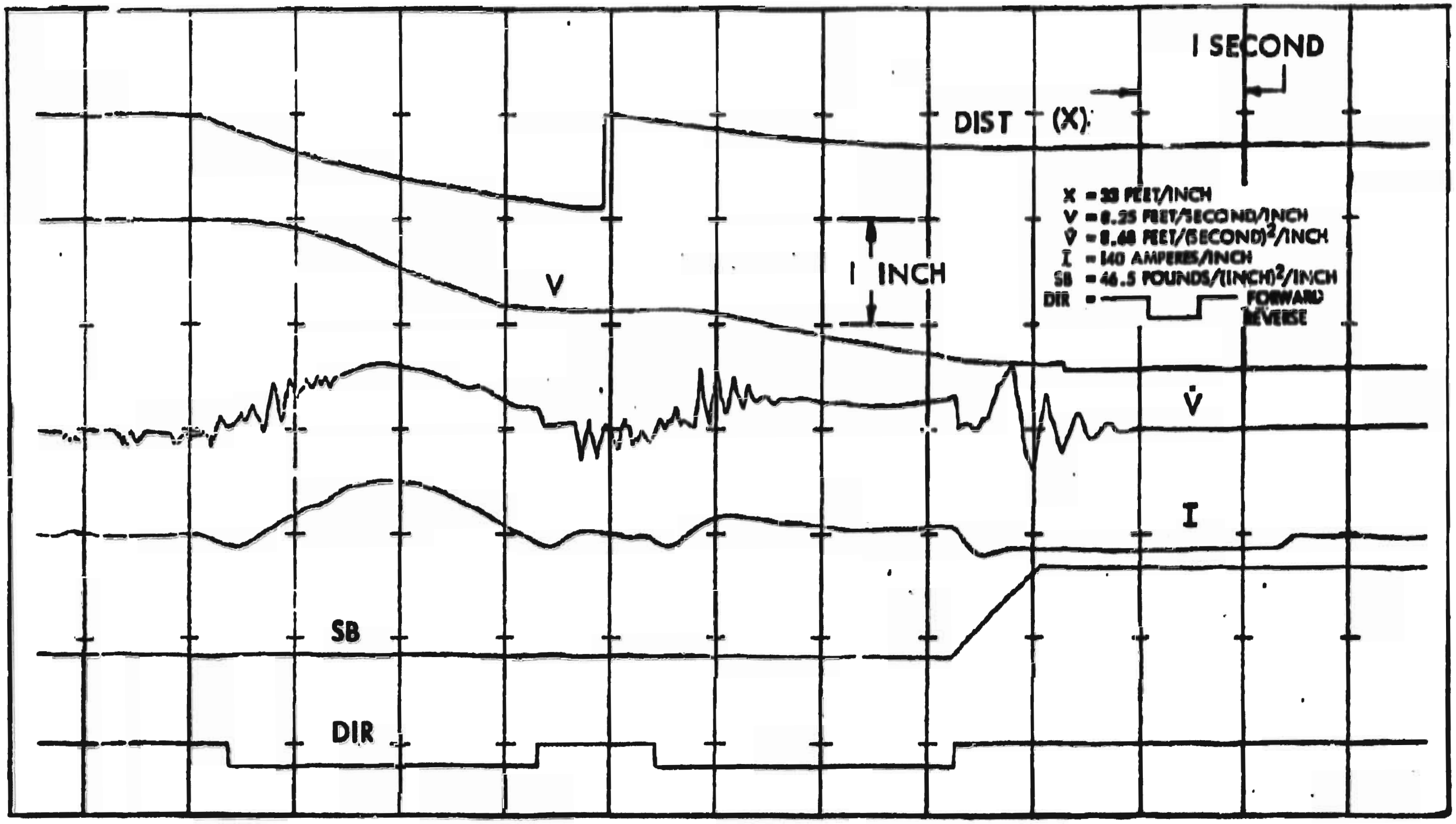


FIGURE 4-45 P40 LONG PROFILE STOP, 11.88 FEET/SECOND TO 0 FEET/SECOND

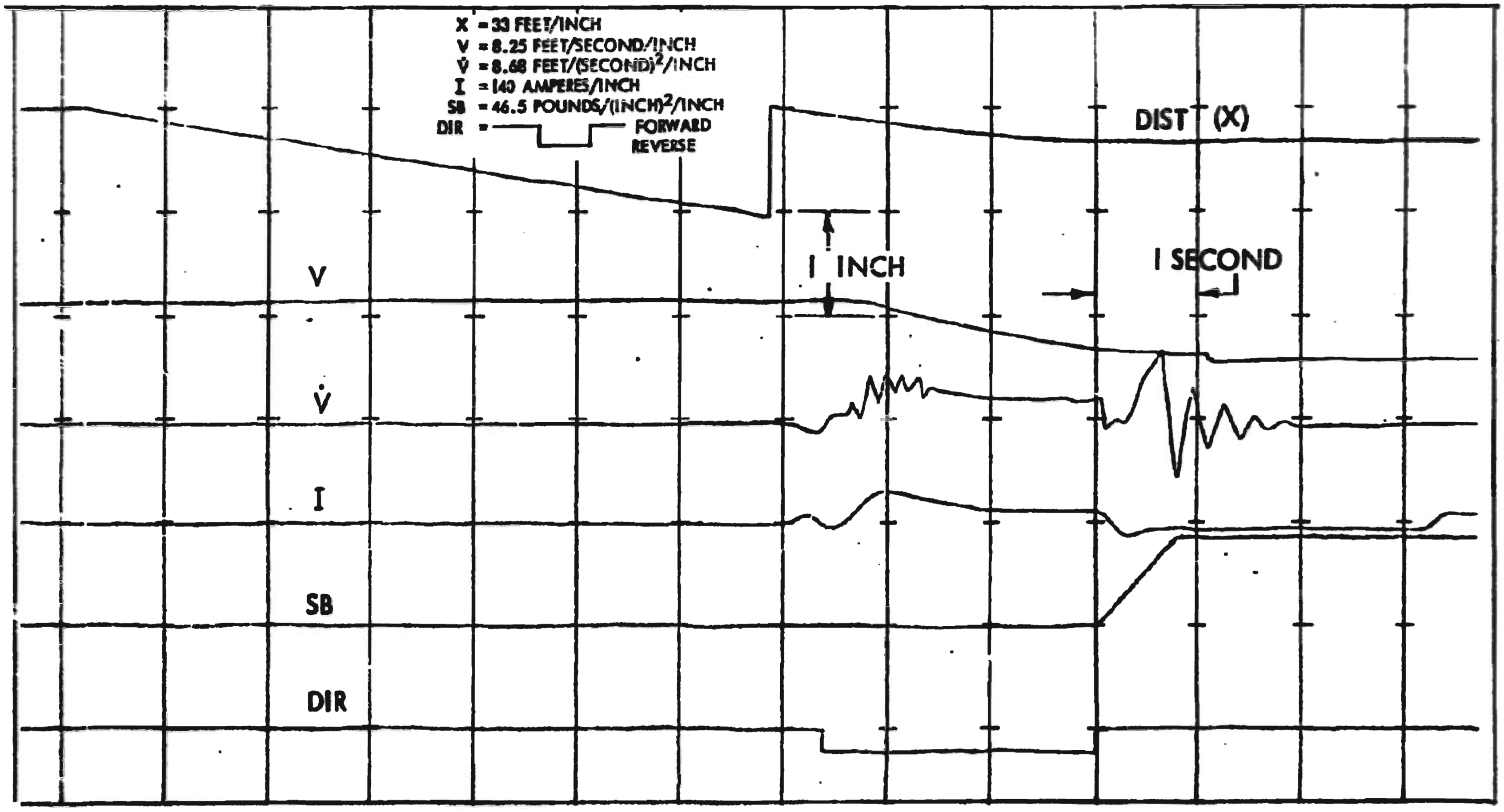


FIGURE 4-48 P40 LONG PROFILE STOP, 5 FEET/SECOND TO 0 FEET/SECOND

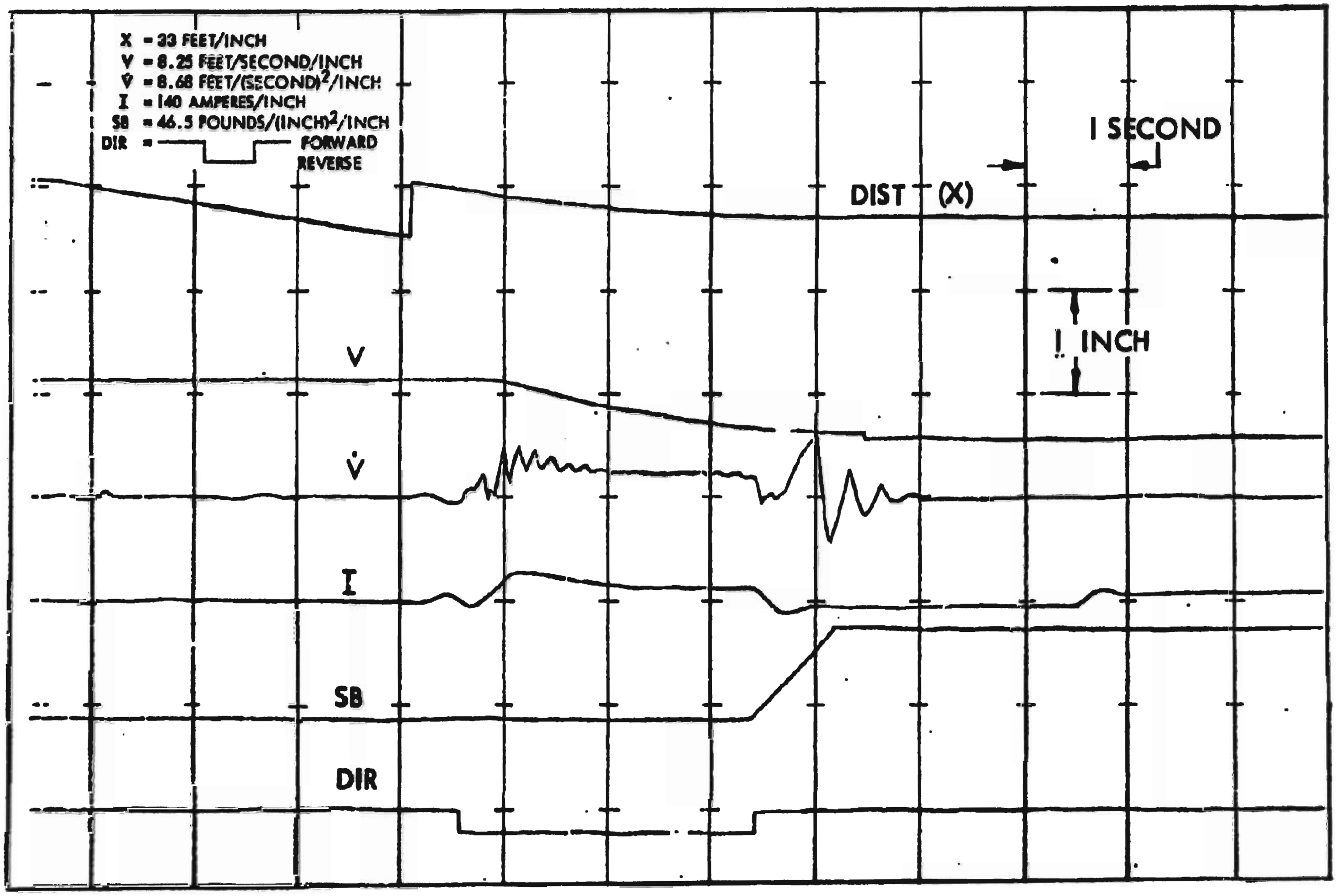


FIGURE 4-47 P40 SHORT PROFILE STOP, 5 FEET/SECOND TO 0 FEET/SECOND

4.3.10.2 Communications - The communication system design described in Volume 2 comprises four systems:

(1) TV surveillance

(2) Audio announcement unit (AAU)

(3) Dynamic graphics

(4) Time-to-arrival display

These systems were performance tested in the laboratory before installation in the AIRTRANS system at D/FW Airport. Further testing was done at the Airport to verify the performance in an operational environment.

4.3.10.2.1 TV Surveillance Test - Breadboard testing of the TV surveillance system showed that picture quality was essentially constant with signal levels of 1 to 100 microvolts. Usable pictures could be received at levels down to 0.5 microvolt.

The prototype was tested using a van to demonstrate performance of the system under mobile conditions. Satisfactory picture quality was demonstrated at distances up to 2.5 miles from the base station.

The prototype system was installed in the AUTP P40 vehicle, and the base station equipment was installed in the electronics room of the AIRTRANS South Parking Lot B station. The system was tested with the P40 vehicle operating throughout the Airport. Coverage was shown to be satisfactory throughout the Airport except from within the Braniff subterminal. The unit operated satisfactorily at a greater range than the 2 miles anticipated. Approximately 2.7 miles are being covered, which includes the far north end of the Airport.

4.3.10.2.2 Audio Announcement Unit (AAU) Test - The AAU was tested in the laboratory before installation in the AUTP P40 vehicle. These tests consisted of:

(1) Addressing each of the 14 stations and verifying that the proper announcements were made

(2) Selecting all available passenger station routes and verifying that only the proper station announcements for the selected route were made

(3) Strobing the AAU with invalid announcements and route codes and verifying that the AAU did not respond to invalid codes

(4) Measuring the duration of all the announcements and the time between announcements. This data was used to verify that enough travel time exists between stations

to allow the AAU to search for and find the appropriate station announcement prior to arrival at the station.

(5) Repeatedly strobing all routes and stations to verify that the AAU would consistently respond

Initial tests onboard P40 revealed some EMI problems in the form of aborted announcements. The unit was modified to increase the EMI immunity, and subsequent testing in the guideway has demonstrated satisfactory and reliable performance.

4.3.10.2.3 Dynamic Graphic Tests - Liquid crystal display (LCD) elements were selected for the onboard dynamic graphics because of their many advantages for this particular application. Because of the relatively recent emergence of large LCD elements, several sample elements were obtained and installed in a test setup to evaluate the three element types available: reflective, transmissive and transflective. The reflective types were selected because of their wide viewing angle and readability over a wide range of ambient light conditions. Tests over approximately 500 hours showed no discernible degradation in performance in any of the sample units. The tests did reveal that the LCD elements are sensitive to pressure applied to the face of the unit. This dictated that the assembly be designed to protect the individual LCD segments.

The final assemblies were tested in the laboratory with the AAU, which provided the display information. The units were installed in the P40 vehicle and tested in an operational environment. The initial performance was unsatisfactory due to the EMI problems associated with the AAU. Design changes were made to the AAU to improve EMI compatibility. Subsequent testing in the guideway at the D/FW Airport has demonstrated reliable and satisfactory performance of the system.

4.3.10.2.4 Time-to-Arrival Display Test - The time-to-arrival display was tested in the electronic laboratory prior to temporary installation in the D/FW South Parking Lot A station. The unit and software were designed with the flexibility to serve multiple routes. For demonstration purposes, however, the unit was operated servicing only the route from the above station. The time-to-arrival display operated satisfactorily in the installation in conjunction with the demonstration of P40.

4.3.11 ACOUSTICS - Operation of the P40 vehicle in an urban environment will generate noise levels that will affect, to some degree, passengers in the vehicle and the public adjacent to the wayside. Noise levels associated with the P40 vehicle were measured as the vehicle operated at D/FW Airport to permit comparison to noise levels that are considered annoying and have been documented by numerous agencies and individuals.

Interior and exterior noise levels of the vehicle were measured as the vehicle operated in the guideway. Interior measurements were made in the center of the vehicle 4 feet above the floor. Exterior measurements were made 25 feet from the guideway centerline and approximately 4 feet above the guideway. Measurements were taken with a Bruel and Kjaer Model 2203 sound level meter, A-weighted scale with slow meter response.

Measurements were taken at various combinations of the following parameters:

(1) Vehicle speed

(2) Acceleration/deceleration

(3) Vehicle auxiliaries

(4) Local environment

(5) Guideway geometry

With the vehicle stationary in the guideway, vehicle accessory noise level contributions in the interior of the vehicle were measured and are summarized in Table 4-16. Vehicle interior and exterior noise measurements are summarized in Table 4-17.

The results presented in Table 4-17 show vehicle interior noise levels adequate for passenger comfort at 10- and 17-mph operation. The vehicle also demonstrates acceptable levels in straight sections of the guideway at speeds up to 30 mph. There is a noticeable hum associated with the motor controller during the initial 3 seconds of acceleration and deceleration maneuvers inside the terminal areas, as shown by the 78 dBA readings in Table 4-17. Outside the terminals, however, the hum is not as noticeable, as indicated by the 76 dBA level outside terminals. While accelerating to 30 mph, the motor controller hum was the primary contributing factor to the 78-dBA reading shown in Table 4-17. This level was produced during manual operation, which gives a higher acceleration rate than automatic operation, and the level should decrease to approximately 76 dBA during automatic operation (as during the 10- and 17-mph operation outside of terminals). Even with the 78-dBA levels associated with accelerations and decelerations, the motor controller noise level is not significantly different from the specification level of 75

TABLE 4-16 P40 INTERIOR NOISE MEASURMENTS, VEHICLE STATIONARY

Accessories Operating	Noise Level* (dBA)
Transformer/rectifier - On 28-volt dc - On Motor controller fans - On	55
Transformer/rectifier - On 28-volt dc - On Motor controller fans - On Air compressor - On, unloaded	62
Transformer/rectifier - On 28-volt dc - On Motor controller fans - On Air compressor - On, loaded	64
Transformer/rectifier - On 28-volt dc - On Motor controller fans - On Air conditioner - On, loaded	74
Transformer/rectifier - On 28-volt dc - On Motor controller fans - On Air compressor - On, loaded Air conditioner - On, loaded	75

*Center of vehicle, 4 to 5 feet above floor, slow scale, A-weighted

TABLE 4-17 P40 VEHICLE INTERIOR AND EXTERIOR NOISE MEASUREMENTS

Speed (mph)	Noise Level* (dBA)			
	Interior			Exterior
	Accel/Decel	Straight	Curve	Accel/Decel
10	76 to 78**			67
17		75	75	70
30	78+	75	78++	75

*Center of vehicle 4 to 5 feet above floor, slow scale, A-weighted
**In terminals (tunnel type area)
+Manual acceleration rather than automatic
++S-turn designed for 17 mph

dBA. The hum is sufficiently low to be masked by normal conversation inside the vehicle, and should be no problem on future vehicle modifications to reach an acceptable noise level.

The noise level during vehicle operation at maximum speeds compares favorably to UMTA's preliminary DPM guidelines. At maximum speed with auxiliaries on, a maximum interior noise level of 75 dBA is allowed. P40 at 30 mph in a straight section of the guideway produces a level of 75 dBA.

Exterior noise levels measured adjacent to the guideway also are presented in Table 4-17. The recorded exterior noise level of the vehicle meets the DPM guidelines of 70 dBA and 75 dBA for 10-mph and 30-mph operation, respectively. The results presented in Table 4-16 show the air conditioner creates a 10-dBA level increase inside the vehicle. This increase is attributed to forced air passing through the ducts and not to compressor noise. This noise level associated with the ducts is not considered objectionable and does meet DPM guidelines. However, with baffling modifications inside the ducts of future vehicles, interior noise levels can be lowered.

The vehicle has accumulated hundreds of miles in revenue operations, recording no objections to the vehicle interior noise levels. However, the acceptability of vehicle noise levels is largely subjective, influenced by individual preference and requiring ridership of the vehicle to determine its acceptance.

4.3.12 RIDE QUALITY - The P40 vehicle, with a newly designed suspension system incorporating antidive capabilities was evaluated for ride quality characteristics of the new system. The vehicle was subjected to various test conditions throughout the D/FW guideway. Vehicle speed, guideway geometry and interior vehicle noise level were parameters considered during acquisition of the ride quality data. Vehicle accelerations were recorded and reduced for comparison with the current DPM guidelines for ride quality.

P40 was instrumented with two three-axis accelerometers located on the floor of the vehicle, first at each end door and then at the center of each side door.

Acceleration measurements were recorded as the vehicle traveled through designated test encounters. A description of guideway encounters, vehicle speed and accelerometer locations is presented in Table 4-18. Accelerometers located at the end doors yielded x, y and z linear accelerations with pitch and yaw rates. Accelerometers located at the side doors also produced x, y and z linear accelerations in addition to roll rate. The linear accelerometer measurements were reduced to 1/3-octave band data, with overall g-rms levels calculated for the 0.1 to 20 hertz and 0.1 to 80 hertz frequency ranges. The g-rms roll, pitch and yaw rates were calculated from the accelerometer measurements.

Curves representing an envelope of peak octave band accelerations for all vehicle encounters are presented in Figure 4-48 (longitudinal), Figure 4-49 (lateral) and Figure 4-50 (vertical). In each figure, the preliminary DPM guideline limitations for linear accelerations are shown. Maximum overall g-rms values are given on each figure for 17- and 30-mph operation and the encounter at which the maximum level was measured. In all comparisons, the P40 vehicle levels are below the guideline limits for both the 1/3-octave band and overall levels.

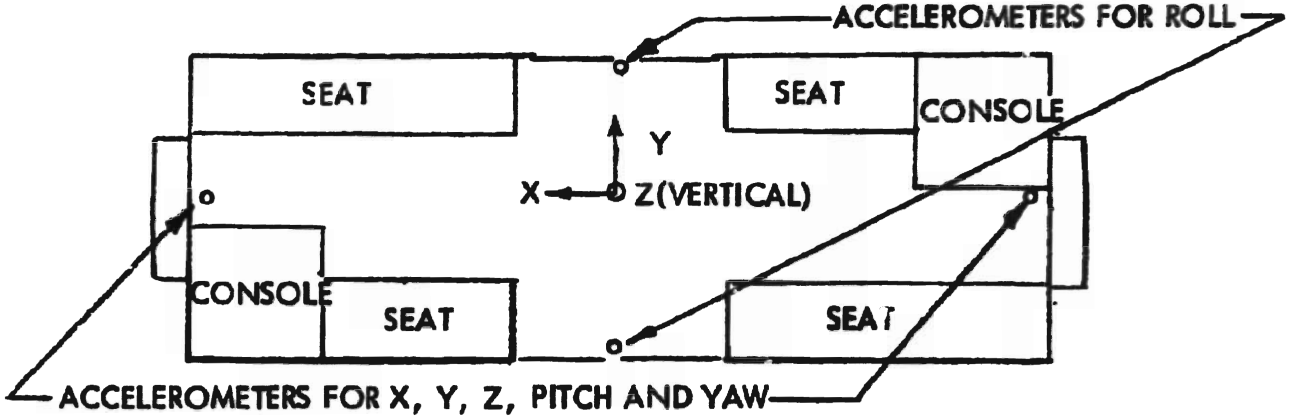
Vehicle angular rates compared to the DPM guidelines are presented in Table 4-19. These levels are also better than the guideline, representing another facet of the vehicle's capability to furnish passengers a high degree of ride comfort. In addition to meeting the preceding guidelines, the vehicle is below the ride comfort level under C of 3.0 (which satisfied 90% of the users), where:

$C = 1.40 + 7.7\ m_T + 8.25\ a_T$

m_T = sustained lateral acceleration

a_T = rms lateral acceleration

TABLE 4-18 P40 RIDE QUALITY INSTRUMENTATION AND TEST LOCATIONS



TYPE OF ENCOUNTER	DATA POINT	D/FW BLOCK NUMBER	TIME SECONDS	SPEED MILES/HOUR
4EBU - MERGE SWITCH	2	4ECU12.5 TO 4ECP15.1	10	9.6
4ENP - 150 FOOT RIGHT TURN	6	4ENP15.6 TO 3ESL01.5	10	14.4
3ESL - 800 FOOT LEFT TURN	8-9	3ESL12.2 TO 3ESL16.9	20	14.7
3ENB - DIVERGE SWITCH	15	3ENP17.5 TO 3ENL01.9	10	17
3NB - 150 FOOT LEFT TURN	15+	3ENB02.5 TO 3ENB04.5	10	17
3NB - 150 FOOT LEFT TURN	16+	3ENB06.7 TO 3ENB09.4	10	17
4WCL - STRAIGHT	20+	3WSL02.8 TO 4WCL01.5	20	17
4WCL - "S" TURN	21+	4WSL10.07 TO 4WSL12.9	20	17,30
4WSL - 5WSL STRAIGHT	21+	4WSL12.9 TO 5WCL01.5	20	17,30
5WSB - DIVERGE SWITCH	22	6WNL01.0TO 6WNL02.6	10	17,30

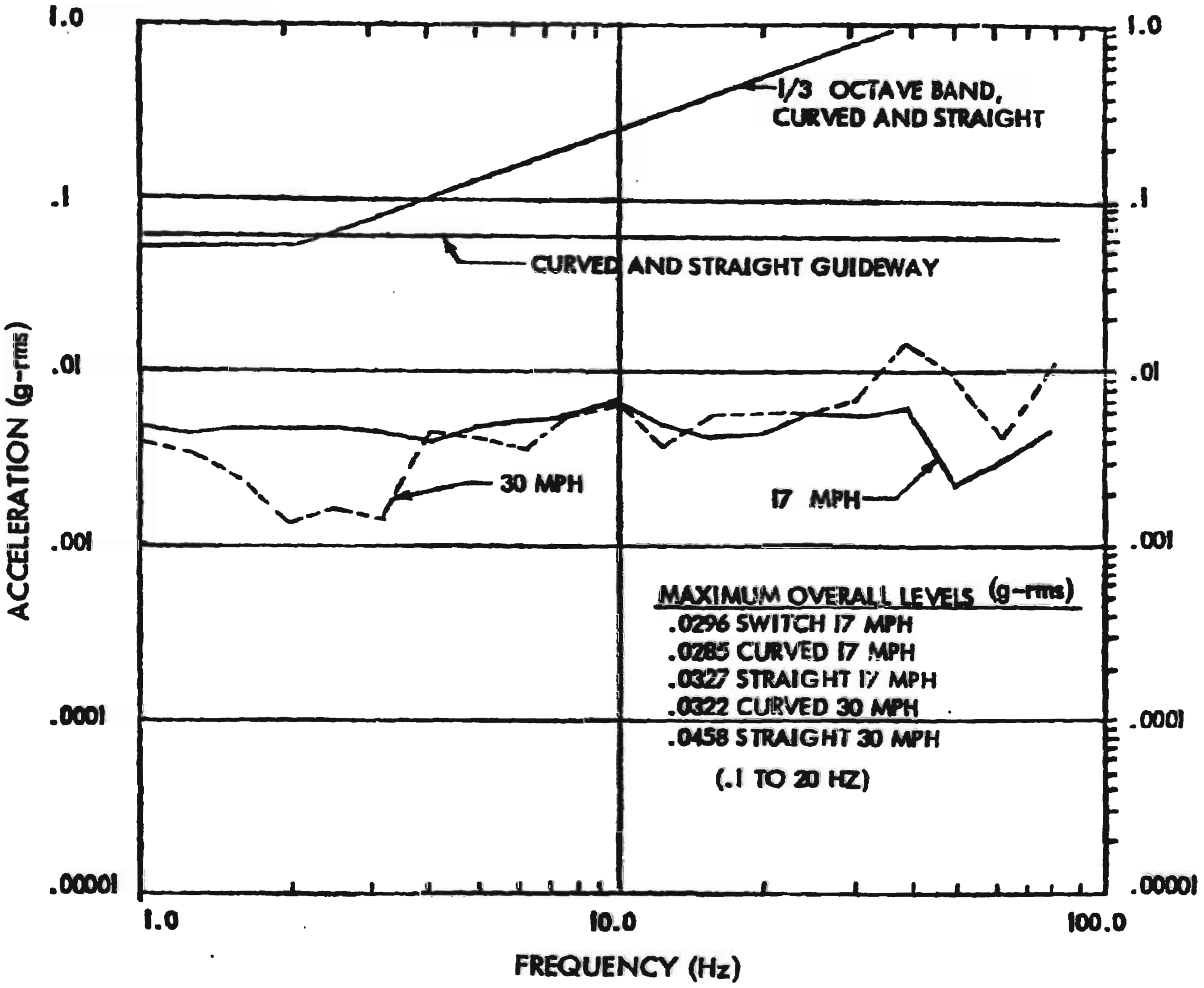


FIGURE 4-48 P40 RIDE QUALITY ANALYSIS, 1/3-OCTAVE BAND ENVELOPE VERSUS DPM GUIDELINES, LONGITUDINAL ACCELERATION

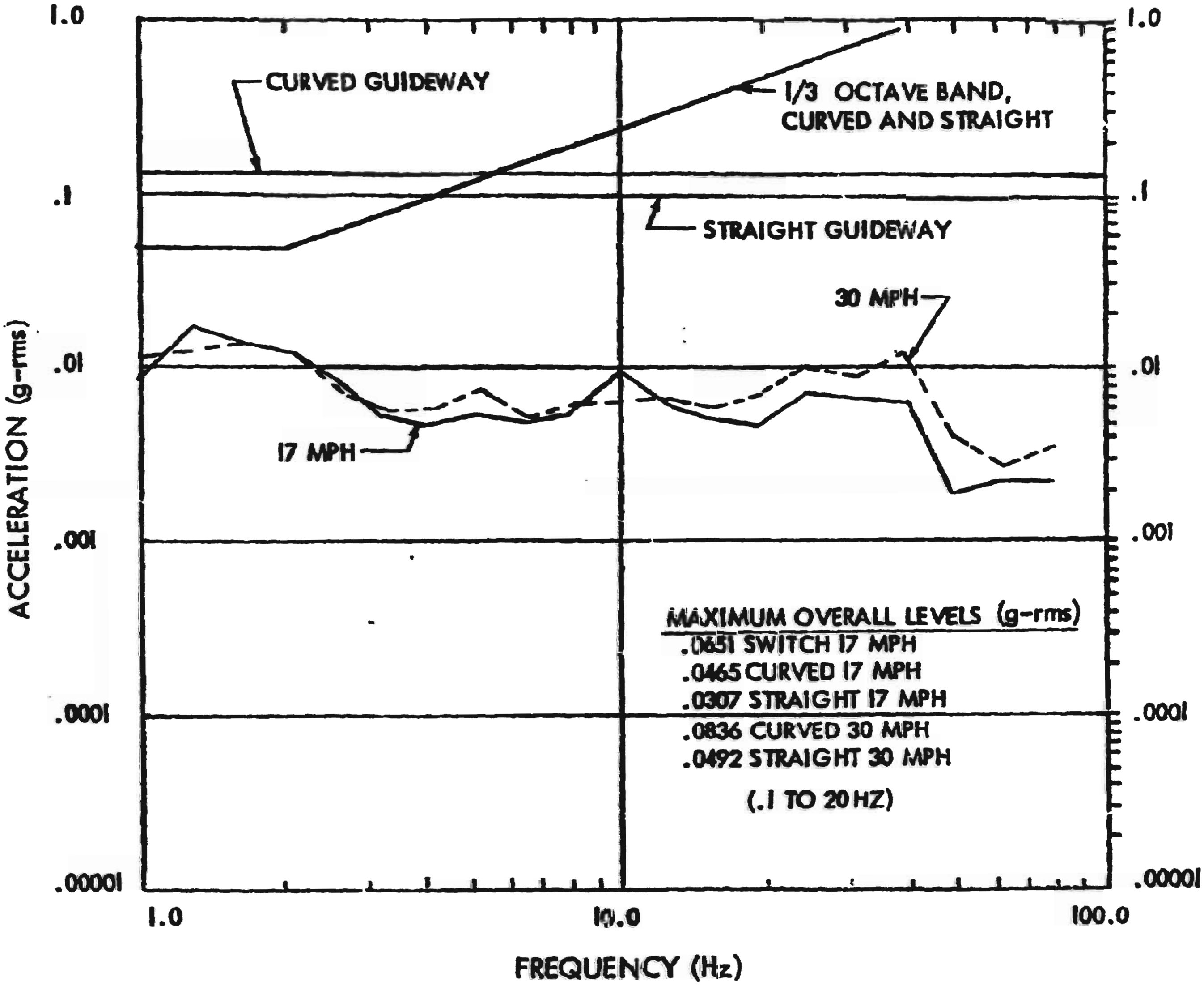


FIGURE 4-49 P40 RIDE QUALITY ANALYSIS, 1/3-OCTAVE BAND ENVELOPE VERSUS DPM GUIDELINES, LATERAL ACCELERATION

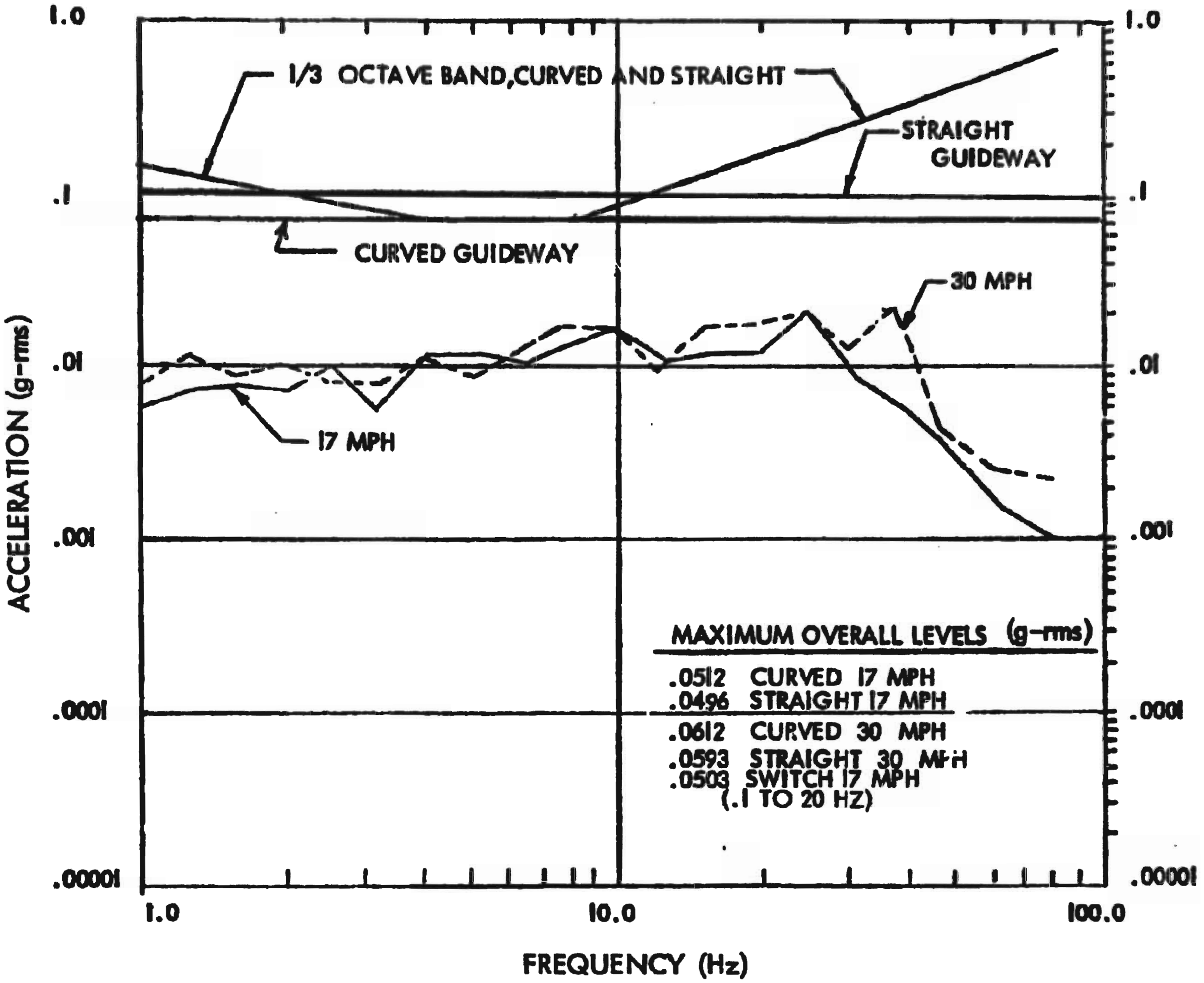


FIGURE 4-50 P40 RIDE QUALITY ANALYSIS, 1/3-OCTAVE BAND ENVELOPE VERSUS DPM GUIDELINES, VERTICAL ACCELERATION

TABLE 4-19 P40 RIDE QUALITY ANALYSIS, VEHICLE ANGULAR RATES VERSUS DPM GUIDELINES

TYPE GUIDEWAY	ANGULAR RATES - DEGREES/SECOND					
	ROLL		PITCH		YAW	
	P40	DPM	P40	DPM	P40	DPM
STRAIGHT	1.18	2.0	.67	2.0	.91	2.7
CURVED	1.34	3.7	.63	3.3	.68	6.6

NOTE: ROLL, PITCH AND YAW ARE DEFINED AS VEHICLE ROTATIONAL MOTIONS ABOUT THE LONGITUDINAL(X-AXIS), LATERAL(Y-AXIS) AND VERTICAL(Z-AXIS).

considering m_T = 0.08, which is the same as AIRTRANS, and taking a_T from Figure 4-50:

C = 2.34 for 17-mph operation

C = 2.71 for 30-mph operation

in a guideway designed for 17-mph operation. Obviously, a guideway designed for 30 mph would tend to reduce the ride comfort level to a value between the two above.

The vehicle's ability to meet the preliminary guidelines of ride comfort set forth for DPM operation, complemented by the vehicle's acoustic noise levels presented in paragraph 4.3.11, produces a vehicle capable of furnishing a comfortable ride, thus enhancing the vehicle's potential usage in a DPM system environment.

5.0 VEHICLE DEMONSTRATION TESTS

The successful completion of design verification, operation, and shakedown tests at Vought and D/FW Airport launched the vehicle into its demonstration program. To complement these tests, the vehicle entered into a demonstration phase of testing that closely simulates operation in an urban environment. Automatic coupling and reversing, improved communications, and an improved ride are significant improvements obtained during the P40 vehicle demonstration.

The AUT Program is fully realized with the implementation of revenue usage at the D/FW Airport. This revenue usage demonstration concludes the AUT Program with additional data proving the vehicles suitability in an urban environment.

5.1 DEMONSTRATION SUMMARY

The demonstration phase of the program provided verification of designs that were essential for the vehicles successful operation in an urban environment. The most significant of these results are as follows:

(1) Automatic steering reversal in straight sections of the guideway

(2) Antidive suspension system that limits brush travel

(3) Automatic mechanical coupling

(4) Lateral and vertical suspension system characteristics that provide adequate ride qualities for higher speeds

(5) TV surveillance and dynamic graphics

(6) An improved vehicle control system utilizing an urban prototype vehicle control electronics (VCE) unit

(7) Regenerative braking system

In addition to these results the vehicle accumulated many miles of successful operation at the D/FW Airport, miles that directly qualify the vehicle for immediate usage in an urban environment. Some qualifications must be noted concerning the vehicle's "immediate" availability for an urban application. The demonstration tests at the Airport did reveal minor problems associated with the vehicle's longitudinal control and the communication system to the vehicle. Numerous tests over a three-month period were conducted with results that were considered adequate for a prototype test vehicle. To be fully deployable in an urban application, however, additional fine tuning of these discrepancies will be addressed in future work on a production version of P40.

5.2 REVENUE USAGE

The vehicle entered revenue operation on a limited basis as the program was concluding. During the revenue operation period, personnel on the vehicle were unidentified to passengers and only witnessed comments or problems that occurred while the vehicle was in revenue operation. The ultimate test for the vehicle is its acceptance by passengers in revenue operation. It is therefore important that the vehicle is operating to its maximum potential for fair passenger evaluation. To reach this status, future work on the vehicle will be aimed at vehicle refinements required to obtain this potential passenger acceptance.

6.0 CONCLUSIONS, RECOMMENDATIONS AND IMPLICATIONS FOR URBAN APPLICATION

The fabrication, test and demonstration results documented in this volume have proven valuable toward future deployment of the P40 into an urban application. The task objectives presented in Section 2.0 have been achieved and demonstrated with a minimum of changes to the vehicle.

Fabrication of the vehicle utilized production line methods, tooling and planning even though only one vehicle (P40) was fabricated from T365. The vehicle fabrication went extremely well, with only minor procurement problems due to the single car buy. Transition to a production line assembly of urban AGT vehicles will present no fabrication problems to Vought or its suppliers.

Vought considers that vehicle tests, demonstration and revenue operation have resulted in the vehicle's acceptability for usage in an urban environment. Only minor action, as summarized in Table 1-1, was needed to verify the vehicle's acceptability. The following significant tests were successfully demonstrated at the D/FW Airport.

(1) Automatic coupling in straight guideway

(2) Automatic reversing in straight and curved guideway

(3) Successful demonstration of an urban prototype vehicle control electronics (VCE) unit

(4) Suspension system improvements provide an acceptable ride at increased speeds

(5) Approximately 3,000 miles of vehicle demonstration and revenue operation at D/FW Airport

(6) Regenerative braking system, providing improved longitudinal control

(7) Successful demonstration of TV surveillance, audio announcement unit and dynamic graphics displays

Several implications can be applied to urban AGT systems from the results accomplished in Phase II fabrication, testing, and demonstration. The most notable are as follows:

(1) Automatic coupling and reversing enhances the vehicles operational flexibility in an urban environment.

(2) Regenerative braking provides the potential for reduced system energy consumption, and with less friction, brake usage allows less maintenance to the brake system.

(3) Revenue and demonstration operation at the D/FW Airport helps strengthen the success of passenger acceptance.

(4) Successful subsystem testing demonstrated improved reliability, maintainability performance levels and reduced technical risks.

(5) TV surveillance, audio announcement unit and dynamic graphics reduce passenger confusion and potentially provide better passenger security while using an urban AGT, helping to assure passenger acceptance of the system.

(6) The improved suspension system, with its antidive capability, aids in keeping the guidewalls at minimum height, thus keeping capital costs down.

(7) The design, fabrication and successful demonstration of a more flexible (VCE) capable of controlling additional vehicle features needed for an urban vehicle.

APPENDIX A

LIST OF TESTS AND COMPONENTS TESTED

System	Item	Manufacturer	Tests Performed
Pneumatic*	Air compressor and motor	Atlas Copco, Inc. Wayne, NJ	Performance tests, and environmental tests
	Unloader valve	Atlas Copco, Inc	
	Moisture ejector	Baker Div. of Reef Baker Corp. Marine City, MI	
	Centrifugal separator	Graham White Sales Salem, VA	
	Pressure relief valve	Bendix-Westinghouse Automotive Air Brake Co., Elyria, OH	
Suspension*	Air spring	Firestone Industrial Products Co., Noblesville, IN	Lateral suspension system characteristics tests, vertical suspension system characteristics test, vehicle dynamic response characteristics test, tire stiffness tests, and air bag/spherilastik stiffness tests
	Dock level valves	Schrader Fluid Power Div. Wake Forest, NC	
	Dock level enable valve	Parker-Hannifin Pneumatic Div., Otsego, MI	
	Mechanical ride height valve	Delco Products Div, GMC Dayton, OH	

APPENDIX A

LIST OF TESTS AND COMPONENTS TESTED (CONTINUED)

System	Item	Manufacturer	Tests Performed
Suspension (Contd)	Shock absorbers	Monroe Auto Equip. Co. Monroe, MI	
	Dock level sensors	Warner Visolux Beloit, WI	
	Air tank relief valves	Continental NH3 Products Co., Inc. Dallas, Texas	
	Spherilastik bearings	Dunlop Ltd., England	
	Tires (SUP-R-FIL)	Firestone Industrial Products Co., Noblesville, IN	
Propulsion* and Braking	Brake control unit	New York Air Brake Co. Watertown, NY	Performance evaluations of motor and motor controller, regenerating braking and acceleration, power interruption tests, and environmental testing
	Motor	Robicon Corp. Pittsburg, PA	
	Rollback sensor, passive probe	General Railway Signal Co. Rochester, NY	
	Motor controller	Robicon Corp. Pittsburg, PA	

APPENDIX A

LIST OF TESTS AND COMPONENTS TESTED (CONTINUED)

System	Item	Manufacturer	Tests Performed
Propulsion and Braking (Contd)	Wheel velocity sensor	Airpax Electronics Controls Division Ft. Lauderdale, FL	
28 Vdc* Power	Transformer rectifier	Utah Research and Development Co. Salt Lake City, UT	Performance verification, environmental, GMI, shock and noise tests
Door*	Electric operator	Horton Automatic Div. of Overhead Door Corp. Corpus Christi, TX	Door opening and closing characteristics, environmental testing, and door sealing characteristics
	Pneumatic operator	Horton Automatic Div. of Overhead Door Corp. Corpus Christi, TX	
	Threshold	Vought Corporation	
Steering*	Rotary damper	Hydraulics Houdaille Buffalo, NY	Steering system impedance, steering system load/stroke, guide/switchwheel stiffness, automatic steering reversal, and towing
	Rubber spring	Vlier Engr. Corp. Burbank, CA	
	Guidewheel assembly	Vought Corporation	
	Switchwheel assembly	Kastalon Inc. Alsip, IL	

APPENDIX A

LIST OF TESTS AND COMPONENTS TESTED (CONTINUED)

System	Item	Manufacturer	Tests Performed
Steering (Contd)	Reverse mechanism actuator	ARO Corporation Bryan, OH	
	Reversing Valve	Scrader Fluid Power Div. Wake Forest, NC	
	Pilot-operated check valve	Williams Air Controls Portland, OR	
Acoustical	Vehicle and station		Acoustical measurements, both interior and exterior, of vehicle and at stations
Ride quality	Vehicle		Vehicle floor accelerations in typical guideway configurations and at various speeds
Heating ventilating and air conditioning (HVAC)	Heating and air conditioning unit	Ellis and Watts Company Cincinnati, OH	Design verification, environmental test, and grill velocities
Coupler	Vehicle coupler	Ohio Brass Company Mansfield, OH	Automatic coupling in straight guideway sections and coupler vibration tests

APPENDIX A

LIST OF TESTS AND COMPONENTS TESTED (CONTINUED)

System	Item	Manufacturer	Tests Performed
Lighting	Fluorescent lighting	Luminator Div. of Gulton Industries, Plano, TX	Interior illumination levels
Collectors*		Vought Corporation	

*Denotes system test under severe weather also, Volume 6.

REFERENCES

1 Urban Mass Transportation Administration, Assessment of Operational Automated Guideway Systems - AIRTRANS (Phase I), UMTA-MA-06-0067-76-1, September 1976.

2 Urban Mass Transportation Administration, AIRTRANS Urban Technology Program Phase I Final Report, UMTA-TX-06-0020-78-1, January 1978.