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URBAN RAPID RAIL VEHICLE AND SYSTEMS PROGRAM

Boeing Vertol Company
Surface Transportation Systems
Philadelphia, Pa. 19142

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16. Abstract

This report reviews the fifth year's efforts of the Urban Mass Transportation Administration's Urban Rapid Rail Vehicle and Systems Program. The objective of the Program is to enhance the attractiveness of rail rapid transit to the urban traveler by providing him with transit vehicles that are as comfortable, reliable, safe and economical as possible. Accomplishments for the year ending September 1976 include the following: Completed arrangements to further extend the operational demonstration of the SOAC vehicles to include approximately nine months of revenue service on the Lindenwold High Speed Line of PATCO; The design, development testing and fabrication portions of the ACT-1 program are in their final stages with delivery of the first vehicle to DOT Transportation Test Center, Pueblo, Colorado, scheduled for the end of February 1977. The second vehicle delivery is scheduled for March 1977; The Advanced Subsystem Development Program was formally initiated in October 1975 with a subcontract award to Delco Electronics for the design, fabrication and test of the Self-Synchronous Propulsion System. The Budd Company was awarded a subcontract in November 1975 for the design, fabrication and test of the truck, and WABCO was awarded a subcontract in February 1976 for the design, fabrication and test of the Synchronous Brake System.

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D174-10002	URRV&S ACT-1 Project Implementation Plan (PIP)
D174-10003	URRV&S SOAC Detailed Specification
D174-10004	URRV&S ACT-1 Detailed Specification
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D239-10007-1	ASDP Vehicle Integration Plan
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D239-10009-1	Truck Journal Retention With Ground Brush and Speed Sensor Integration Study

I. INTRODUCTION

On June 14, 1971 the Boeing Vertol Company was awarded Contract No. DOT-UT-10007 to perform as Systems Manager for the Urban Rapid Rail Vehicle and Systems Program. The program is sponsored by the U.S. Department of Transportation's Urban Mass Transportation Administration (UMTA) Office of Research and Development, Rail Technology Division. As Systems Manager, Boeing Vertol is responsible to UMTA for the overall planning and integration of the program as well as for all of its technical and management aspects.

The overall objective of the Urban Rapid Rail Program is to enhance the attractiveness of rail rapid transportation to the urban traveler by providing existing and proposed transit systems with service that is as comfortable, reliable, safe and economical as possible.

Eight separate tasks are performed under the program; they are:

1. Program Management
2. BART Review
3. State-of-the-Art Car (SOAC)
4. Advanced Concept Train R&D (ACT-1)
5. Advanced Subsystem Development Program (ASDP)
6. Advanced Concept Train Operational Demonstration Planning (ACT-3)

7. Economic Analysis

8. Human Factors Analysis

The State-of-the-Art Car is also being utilized by Boeing Vertol under Contract No. DOT-TSC-580 to perform engineering testing. This effort is also described in this report as it relates to the SOAC portion of the Urban Rapid Rail Program.

This fifth Annual Report reviews the fifth year's efforts under the Urban Rapid Rail Program. It describes the work accomplished and summarizes pertinent technical and design data. The report format is organized according to the program tasks listed above.

The first Annual Report, dated July 1972, is available from the National Technical Information Service, Springfield, Virginia. The order number is PB-212-848.

The second Annual Report, dated July 1973, is available from the National Technical Information Service, Springfield, Virginia. The order number is PB-222-141.

The third Annual Report, dated July 1974, is available from the National Technical Information Service, Springfield, Virginia. The order number is PB-245-310.

The fourth Annual Report, dated July 1975 is available from the National Technical Information Service, Springfield, Virginia. The order number is PB-254-727.

II. PROGRAM MANAGEMENT TASK

OBJECTIVE

As the Systems Manager for the Urban Rapid Rail Vehicle and Systems Program, the Boeing Vertol Company is responsible for the overall planning and integration of the program, regular and periodic reports of program status and activities; plus progress and financial status reports of all projects.

SUMMARY

Three major hardware tasks were active during this reporting period; the State-of-the-Art Cars (SOAC), the Advanced Concept Train (ACT-1) and the Advanced Subsystem Development Program (ASDP). The following summarizes the individual activities during the past year.

SOAC

The operational test and evaluation phase of the SOAC program, which was initiated on April 18, 1974, was completed April 20, 1975. Arrangements were completed to further extend the operational demonstration of the SOAC vehicles to include approximately nine months of revenue service on the Lindenwold High Speed Line of PATCO.

The objective of the PATCO program is to compare the SOAC reliability and maintenance characteristics during a relatively long term stable service period with existing PATCO equipment. The PATCO revenue service is scheduled to start in August 1976.

ACT-1

The design, development testing and fabrication portions of the ACT-1 program are in their final stages with delivery of the first vehicle to DOT Transportation Test Center, Pueblo, Colorado, scheduled for the end of February 1977. The second vehicle delivery is scheduled for March 1977.

Thirteen major design and program reviews were held during the past year. The technical reviews were highlighted by the Final Engineering Review in November 1975. This review was attended by UMTA, TSC, TDC and members of the Advisory Board. In May 1976 UMTA, TSC, TDC and the Advisory Board reviewed the ACT-1 cars in assembly at the AiResearch facility at Compton, California. Upon completion of the integration and assembly of the ACT-1 vehicles at Compton the cars will be moved to the AiResearch Western Avenue Facility for operational testing prior to delivery to TTC, Pueblo, Colorado.

ASDP

The Advanced Subsystem Development Program requires extensive testing and developmental evaluation of (1) Self Synchronous Propulsion System, (2) Improved Ride Quality Monomotor Truck, and (3) Synchronous Brake System. After initial development at their respective contractors these subsystems will be forwarded to Boeing Vertol for integration into the SOAC vehicles.

The Advanced Subsystem Development Program was formally initiated in October 1975 with the award of a subcontract to Delco Electronics for the design, fabrication and test of the Self Synchronous Propulsion System. The Budd Company was awarded a contract in November 1975 for the design, fabrication and test of the truck, and WABCO was awarded a contract in February 1976 for the design, fabrication and test of the Synchronous Brake System.

III. BART REVIEW TASK

This task is completed and is documented in Report No. IT-06-0026-73-1, available from the National Technical Information Service. The order number is PB-221-355.

IV. STATE-OF-THE-ART CAR (SOAC) PROGRAM

OBJECTIVE AND SUMMARY

The objective of the SOAC task has been the demonstration of the current state-of-the-art in rail rapid transit vehicle technology. This objective was fulfilled by the development, test, and demonstration of two rail rapid transit cars embodying the best available in current (1971-72) technology. Passenger convenience and operating efficiency were primary goals for the cars which were designed to be capable of demonstrating revenue service operation on at least one line of the rapid transit systems in New York, Boston, Cleveland, Chicago, and Philadelphia.

The two SOAC cars were designed, fabricated, functionally tested and delivered to the U.S. Transportation Test Center (TTC) in Pueblo, Colorado, 11-1/2 months after contract go-ahead by the St. Louis Car Division of General Steel Industries. In August 1972, the cars were shipped to the TTC at Pueblo, and on October 12, SOAC was unveiled and demonstrated.

During 1973, the SOAC vehicles underwent an extended period of engineering testing. A delay in operational testing and evaluation was caused by an accident in August 1973, necessitating major repairs to one of the two cars. These repairs were completed in December 1973. Systems testing was repeated on the repaired cars starting in January 1974, and was completed in April 1974.

The operational test and evaluation phase of the SOAC program started when the cars arrived in New York City on April 18, 1974. This final phase of the SOAC program, as originally scheduled, covered a period of one year, ending with the completion of the Philadelphia demonstration on April 30, 1975. A total of approximately 312,000 people rode on the SOACs during the five-city operational evaluation.

Arrangements have been made to extend the SOAC operational evaluation to include approximately nine months of revenue service operation on the Port Authority Transit Corporation (PATCO) Lindenwold High Speed Line. PATCO has requested this operation and will supply all the labor and facilities support necessary to maintain and operate the two transit cars for the Department of Transportation, under Boeing direction.

Objectives of the PATCO program are to sample the reliability and maintenance characteristics during a relatively long term, stable service period and compare them with existing PATCO equipment.

The initiation of the PATCO service was delayed due to necessary mechanical, electrical, and signal modifications and a protracted negotiation for liability insurance coverage.

DISCUSSION

Axle/Gearbox Coupling Modification

While undergoing high speed testing in Philadelphia (SEPTA) prior to shipment to PATCO, an objectionable vibration was noted on one car which was caused by a rocking resonance at the axle/gearbox coupling splined connection.

Corrective action to eliminate this condition was instituted on all SOAC couplings. This action involved nickel plating of the female splines of the coupling flange plates, remachining of the splines to an interference fit with the gearbox output shaft, and the balanced installation of locking plates on the coupler attaching nut.

The buildup of the reworked axle/gearbox couplings was completed in February 1976.

Wheel Change

As previously reported in the 1975 URRVS Annual Report (Report #UMTA-lT-06-0026-75-1), a decision to reinstall solid steel wheels prior to PATCO operation was made. In order to provide a level of wheel noise suppression, the steel wheels were grooved for ring-damping. Steel rings were fabricated and installed, and the wheels were pressed on the axles in February 1976.

Traction Motor Rework

In September 1975, Boeing Vertol was advised by Garrett AiResearch that failures had been experienced on the traction motors on the GT/E cars on LIRR. Although no similar distress had been encountered with the SOAC traction motors, AiResearch recommended, and Boeing concurred, that the SOAC motors should be examined and corrected, if necessary.

All SOAC motors were shipped to Garrett and the shunt field coils were examined. Although no field coil insulation had been chaffed through, some had moved and been abraided. The coils were reworked, the motors were cleaned and reassembled and new brushes were installed.

Overspeed Protection System

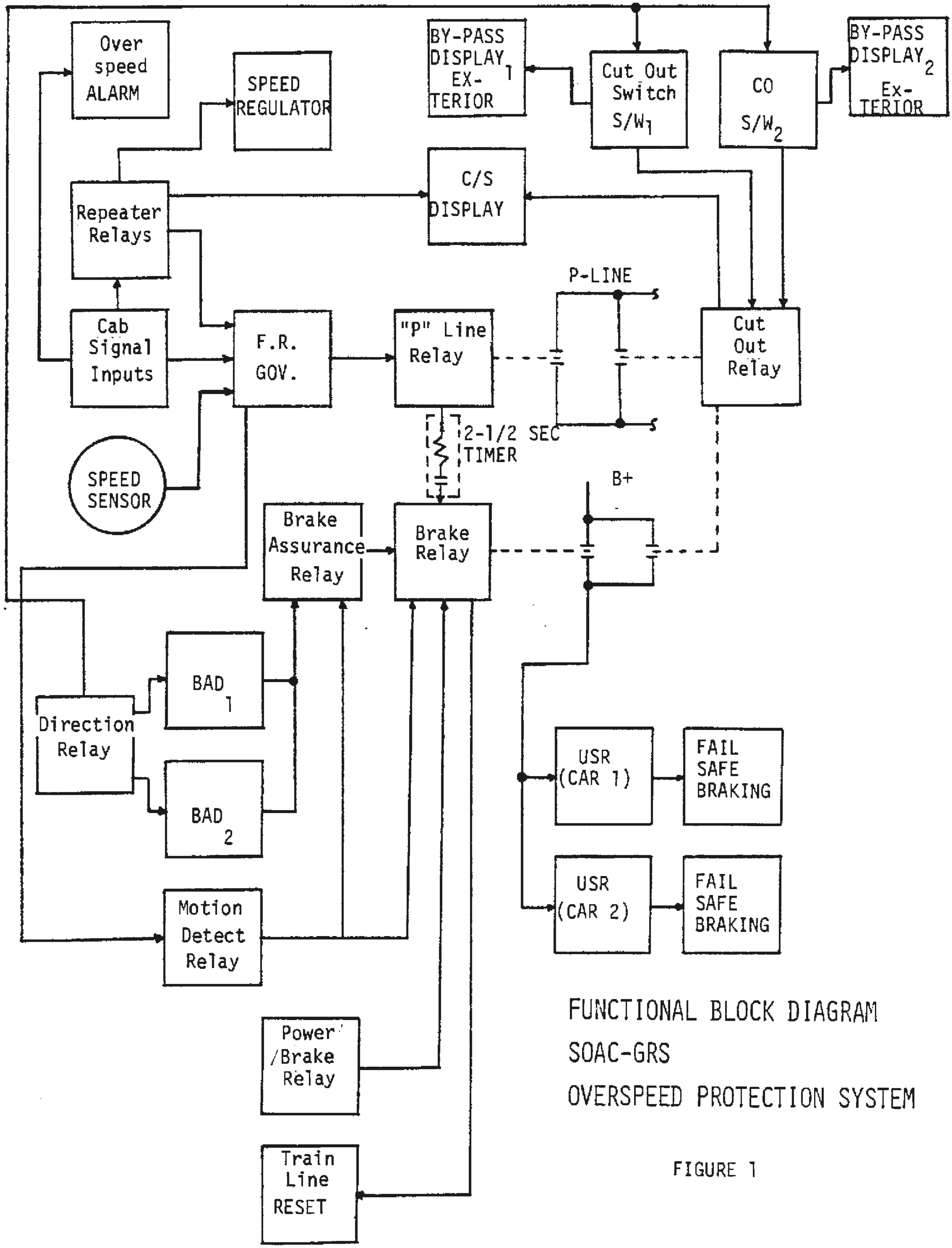
Boeing was requested by PATCO to provide a fail-safe Overspeed Protection System whose function would be similar to that of the property's existing equipment and a program was undertaken to develop an acceptable system.

Such a system guarantees safe train separation under any operating condition. Inputs to the Overspeed Protection System come from the cab signal system. A PATCO cab signal package was installed on the number 1 SOAC car for operation on PATCO. Cab signal receiver coils were installed on each SOAC. The cab signal system receives speed limit commands (including zero mph) from the track circuits and provides relay contact closures for use by the Overspeed system and for the motorman's display. The Overspeed system compares the actual train speed with the speed limit and, if the train is over speed, applies the train's brakes. At PATCO the system only applies the brakes until the train is no longer overspeed (a penalty stop is not made).

A review of the overspeed system requirements, the hardware available, and the interfaces with the SOAC equipment indicated that the best approach was to purchase a system offered by General Railway Signal Co. (GRS) rather than attempt to adapt the PATCO overspeed system to the SOAC.

The GRS system makes use of equipment that is used in overspeed systems on the WMATA and NYCTA R-44 cars. Two requirements of the PATCO/SOAC system prevented a complete existing overspeed system from being used: (1) the SOACs "P" wire braking was not considered to be fail safe, and (2) the brake application when an overspeed occurs has to be recoverable (i.e., not emergency brakes that are irretrievable).

Figure 1 is a functional block diagram of the GRS Overspeed Protection System with the PATCO cab signal and SOAC interfaces. The major active elements of the system are the F.R. Governor



FUNCTIONAL BLOCK DIAGRAM

SOAC-GRS

OVERSPEED PROTECTION SYSTEM

FIGURE 1

(frequency responsive governor), the BAD's (Brake Assurance Devices) and the various relays. The F.R. Governor receives inputs from the cab signal code relays and the speed sensor and determines whether an overspeed exists. If an overspeed does exist the F.R. Governor causes the PLR to open, which opens the "P" wire and commands a full service brake application. If the full service brakes are working then the resulting brake rate is detected by the BAD's (one for each direction of travel). The BAD's are pendulum-type accelerometers that close a contact when a deceleration greater than 2.5 mphps is detected. Detection of the deceleration holds off the fail safe braking mode through the BAR relay. If deceleration is not detected at any time during an overspeed, then 2-1/2 seconds later the BR relay will drop out causing each car to apply full emergency pressure to the friction brakes and disabling of the propulsion system until the train is again underspeed.

Additional parts of the system provide fail safe checks and other functions such as the motorman's cab signal display, inputs for SOACs speed regulator, an overspeed bypass (for operation in the yard, tail tracks, etc.).

The majority of the systems components are located in the ATO cabinet on car 1. The PATCO cab signal box is mounted on the underframe of car 1 next to the chopper. A USR (underspeed relay, AAR vital relay) is mounted in the Propulsion Power Control Unit of each car. Approximately 30 trainlines are required for this installation, the majority are for the motorman's displays and the speed regulator. To accommodate these trainlines a jumper cable was run between the two cars using a circle MS type connector.

Following the completion of the mechanical and propulsion modifications, the installation of the Overspeed Protection System, and the resolution of liability insurance difficulties, the SOAC vehicles were cleaned in preparation for motorman training and revenue service.

Service Experience at PATCO

The SOAC cars started revenue service at PATCO on August 12, 1976. At the end of the first day's operation a traction motor failure occurred due to an insulation breakdown in an armature coil.

On August 17, a chopper failure occurred on the number 1 car. One series pair of main SCR's and one series pair of commutating SCR's failed short. Miscellaneous secondary failures occurred due to the failed chopper. The suspected cause of the failure was an improperly calibrated main SCR gate pulse duration. The failures were repaired and the cars returned to service.

On September 9 a second chopper failure occurred on car 1. Again 2 main and 2 commutating SCR's failed short, plus secondary failures. Failure analysis indicated that the most probable cause of this failure, and the earlier failure, was either that the brake resistor circuit momentarily failed open while the cars were braking, or that an encapsulated snubber network that was found shorted caused the failure because of uncontrolled voltage transients. The brake resistor circuit was inspected (including a load test) and no anomalies were found. The failed encapsulated snubber units were replaced with higher rated units. The failed SCR's were replaced and the cars scheduled for service.

Prior to returning to revenue service the cars were routed through the car wash unit. While going through the car wash the number 2 car shutdown due to an overcurrent. Investigation revealed that the PATCO car wash was directing large amounts of water into the cooling air intakes. Water was found inside the chopper enclosure and in the traction motors. Water in the chopper box caused an arc over from a bus bar to the box (ground). Minimal damage occurred and this was readily repaired. Protective shields will be fabricated for the air intakes.

Future Plan

Following the completion of the PATCO program, the SOAC vehicles will be returned to Boeing Vertol for an extensive equipment and configuration change to incorporate the ASDP subsystems (see Section VI).

V. ACT-1

INTRODUCTION AND SUMMARY

Background

The ACT-1 Program is a two-phase development program intended to advance the state-of-the-art of rail rapid transit car design and construction. A further objective is to demonstrate the operational benefits of advanced technology on existing rapid transit systems in New York, Boston, Cleveland, Chicago, and Philadelphia. The two development phases and overall project schedule are shown in Figure 2. The Phase 1 evaluation was completed in January 1973, with a subsequent Phase 2 contract award (on January 2, 1974) to the AiResearch Manufacturing Company of Torrance, California, for a vehicle design, development and test.

The design, development testing, and construction portions of the program are in their final stages with the delivery of the first vehicle expected by February 1977 for Vehicle Testing at DOT Transportation Test Center, Pueblo, Colorado. The second vehicle delivery is expected by March 1977. Figure 3 shows the H-D carbody as shipped from AVCO.

The Component and Subsystem Testing Program was initiated in August 1975 and has resulted in the identification and resolution of design problems in the following areas:

- o Parking Brake - low coefficient of friction of pads.
- o Train Control - overspeed protection design concept.
- o Motors - armature construction and quality.
- o Trucks - motor mounts and lateral stops.

ACT-1 PROJECT SCHEDULE

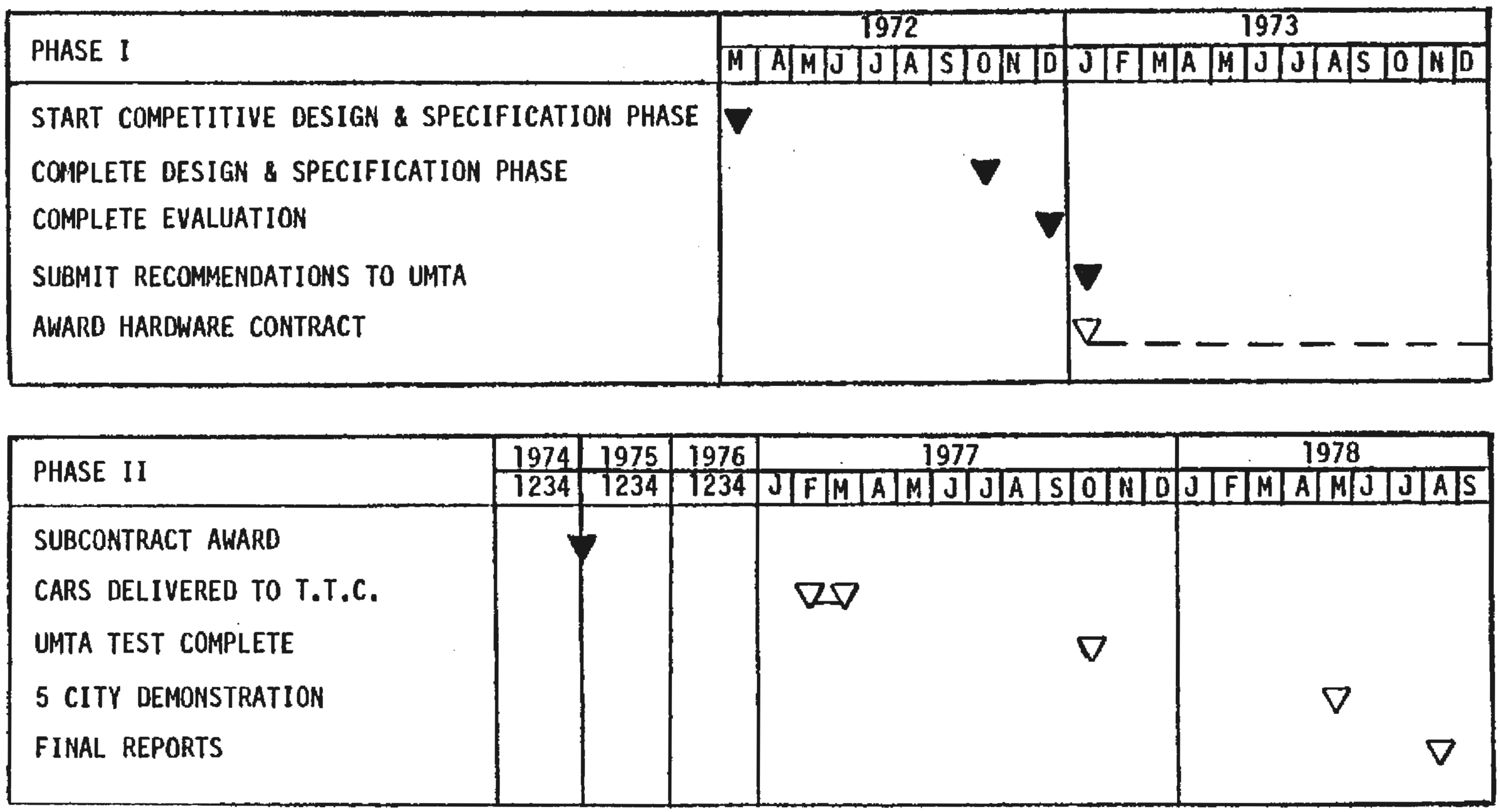


FIGURE 2.

Carbody loaded for shipment.

FIGURE 3.

- Master Controller - switch design and quality.
- Air Compressor - separator return line and valve.
- Half-Car Airbrake System - triple valve and electro-pneumatic unit (EPU) modifications.
- Friction Brake - pad definition, casting quality.
- Doors - actuator, linkage, and locking links.
- Flywheel - power losses, oil flow, and balance.
- Air Conditioning - vent fan alignment, water re-evaporation.
- Electronic Controls - ECU printed wiring assembly definition.

Although the identification and solution of the above problems has resulted in some program slippage, the comprehensive subsystem test program has been beneficial in identifying these problems prior to vehicle operation, where developmental problems can cause more severe slippages. This component and subsystem development and design substantiation testing will continue with truck structure testing scheduled to complete in late fall 1976 and propulsion (documented) half-car design substantiation testing in January 1977. Significant testing completed successfully in this reporting period are as follows:

o Side Panel Fatigue Test	October 1975
o Car Structural Test	December 1975
o Windshield Impact Test	August 1975
o HVAC One-Half Car Test	March 1976
o Propulsion System Development Test	July 1976
o Drive Train & Coupling Test	July 1976
o Air Compressor Endurance Test	July 1976
o Turbocompressor Containment Test	August 1975
o Flywheel Development & Power Loss Reduction Test	July 1976
o Propulsion & Friction Brake Interface Test	July 1976
o Door Life Cycle Test (1 million cycles)	October 1976

- Motor Design Substantiation Testing (Flywheel & Traction Motors) — October 1976

- Master Controller Design Substantiation Test — October 1976

- Half Car Pneumatic System Test — October 1976

Testing is still in progress for the following components and subsystems: (Completion dates estimated.)

- Propulsion Half-Car System Test (CSLT-Documented Testing — January 1977

- Truck Structural Testing (5 Million Total Cycles) — December 1976

- Brake Disc Dynamometer & Endurance Tests — December 1976

Subsystem functional testing on the first car, the high density car, was initiated in August 1976 and will continue through early February 1977. The original 12-week test schedule has been expanded to allow completion of various open manufacturing items (doors, liners, interior equipment) and to allow time for problem solutions. At the end of October, functional testing of the trainline controls, ECU, communications, ESU start and operation, and traction motor rotation had been completed. Preliminary data indicate a need for improved flywheel balance and increased noise treatment, and the current schedule is predicated on finding solutions to these two key problems. The high density car will be shipped from the Compton assembly plant to the Western Avenue track facility at the end of December 1976. Comprehensive noise, vibration, air comfort, lighting, door system, pneumatic, and dimensional tests must be performed prior to shipment to Pueblo in early February 1977.

The functional checkout of vehicle #2 is scheduled to start in November 1976 and complete in March 1977. The installation of the vehicle #2 propulsion equipment is paced by critical components, which are also being used in the CSLT setup. To improve schedule, additional spare hardware has been procured to permit independent operation of the Combined System Lab Test setup.

Program Changes

Following the major program and technical changes made in June 1975, the basic Revision 6 specification requirements have been maintained with most of the 46 SCCR's (Specification Clarification/Change Request) approved since June 1975 dealing with test sequence, clarifications, vehicle test weight, and motor testing.

Significant changes included allowing the empty weight of the prototypes to increase above the 83,000 lb. specification limit (to approximately 87,000 lbs.), while maintaining the compliance weights of AW1, AW2, and AW3, as specified in Revision 6.

Following review by the DOT Transportation System Center (TSC) and Boeing Vertol structural technology, AiResearch was directed to improve the collision post joint strength on both ACT-1 cars. The Revision 6 specification requirements were clarified and changed to require increased moment and torsional strength. AVCO strengthened the posts by addition of steel reinforcing angles and larger bolts in the area of the draft sills. Following detailed review of the carbody structural test data, Boeing Vertol will prepare an assessment of the maximum buff strength of the ACT-1 structure as an indication of its crashworthiness. The above collision post modifications were made to improve the vehicle crashworthiness in overclimbing collisions.

At the request of TDC, Boeing Vertol directed AiResearch to use a reduced-flammability hydraulic fluid on the collision attenuation cylinders.

During critical design review of the train control system it was recognized that the overspeed and brake assurance functions were not designed in accordance with transit industry criteria for fail safe operations. AiResearch had used a redundant design concept for these functions rather than the traditional railroad fail safe concept. While there is merit in pursuing redundant fail-operational concepts to improve overall train control and protection reliability and safety, Boeing Vertol determined that the traditional approach should be applied on ACT-1 for demonstration on the five properties, and AiResearch has been directed to obtain a fail safe overspeed protection and brake assurance system from a recognized supplier.

In September, Boeing Vertol approved a specification deviation allowing acceptance of flywheel and traction motors with a commutation grade of "2" and light streamers at the 600 volt, 900 amp maximum speed point. Increased warranty scope and period were obtained as a result of this deviation, which follows over one year of testing including redesign and rework of all armatures. Commutation grade at the continuous rated current (570 amps) is within the specification requirement. Limited brush wear testing indicates a life expectancy of approximately 80,000 miles, and AiResearch will supply brush replacements through the five city demonstration.

Status of Overall Benefits and Goals

o Technical Goals

The ACT-1 program has identified three major categories for improvement: (1) passenger comfort and appeal, (2) economics and operating efficiency, and (3) environmental impact. The progress in the subsystem designs are constantly monitored to ensure the maintenance of the original program benefits and goals.

Passenger Comfort and Appeal

Ride Quality

ACT-1 ride quality will be significantly improved over the SOAC. A low frequency (.8 Hz) secondary air suspension, combined with a low carbody bending frequency (6 to 7 Hz), will provide vertical g-levels in the range of .01g to .03 g, depending on car speed and passenger compartment location. Figure 4 shows analytical results for the ACT-1 operating on the specified Pueblo track profile. Both AiResearch (Battelle Inst.) and Boeing Vertol predictions of vertical ride quality are shown in Figure 4. The carbody bending frequency of 6 to 7 Hz will reduce the ACT-1's sensitivity to wheel flats and out-of-round wheels compared to the SOAC (8.5 Hz), since the body natural frequency will be excited at a lower vehicle speed with reduced energy input. Vehicle motions occur at the suspension and vertical bending natural frequencies of the carbody structure. Vertical, pitch and roll responses contribute to C.G. and over bolster accelerations in the .8 Hz to 2 Hz frequency range. Carbody bending produces accelerations in the 4 Hz to 20 Hz frequency range. In addition, the vehicle will respond at any discrete frequencies present in the track roughness. For the predictions presented in Figure 4, the predominate 2 Hz response results from excitation of the carbody pitch frequency on the dirspring suspension system. Comprehensive instrumentation and testing are planned for the Pueblo test program. Figure 5 shows results of lateral ride quality predictions in comparison with the ACT-1 goal and ISO comfort criteria.

Acoustic Noise

AiResearch has conducted analytical studies to determine the impact of wheel/rail, aerodynamic, and equipment noise upon the acoustic environment within the ACT-1 passenger compartment and at the wayside. The noise sources and their respective transmission paths are shown in Figure 6.

Interior Noise

The analytically predicted interior noise levels with all equipment operating are within the specification requirements below 60 mph and only slightly higher above 60 mph as shown in Figure 7. The predicted wheel/rail noise causes the noise level to exceed the specification above 60 mph and some additional local acoustic treatment may be required as determined by vehicle test data to be recorded at the Pueblo TTC. Note that the SOAC test data in Figure 8 indicates that wheel/rail noise may not increase as rapidly with speed as estimated. The predicted interior noise levels shown in Figure 7 are based on each of the vehicle subsystems meeting their individual noise allocation. These allocations are very stringent and detailed test data has not yet been obtained to verify compliance on a total car level. Boeing Vertol considers the Figure 7 predictions to be somewhat optimistic.

VERTICAL RIDE QUALITY OF ACT-1

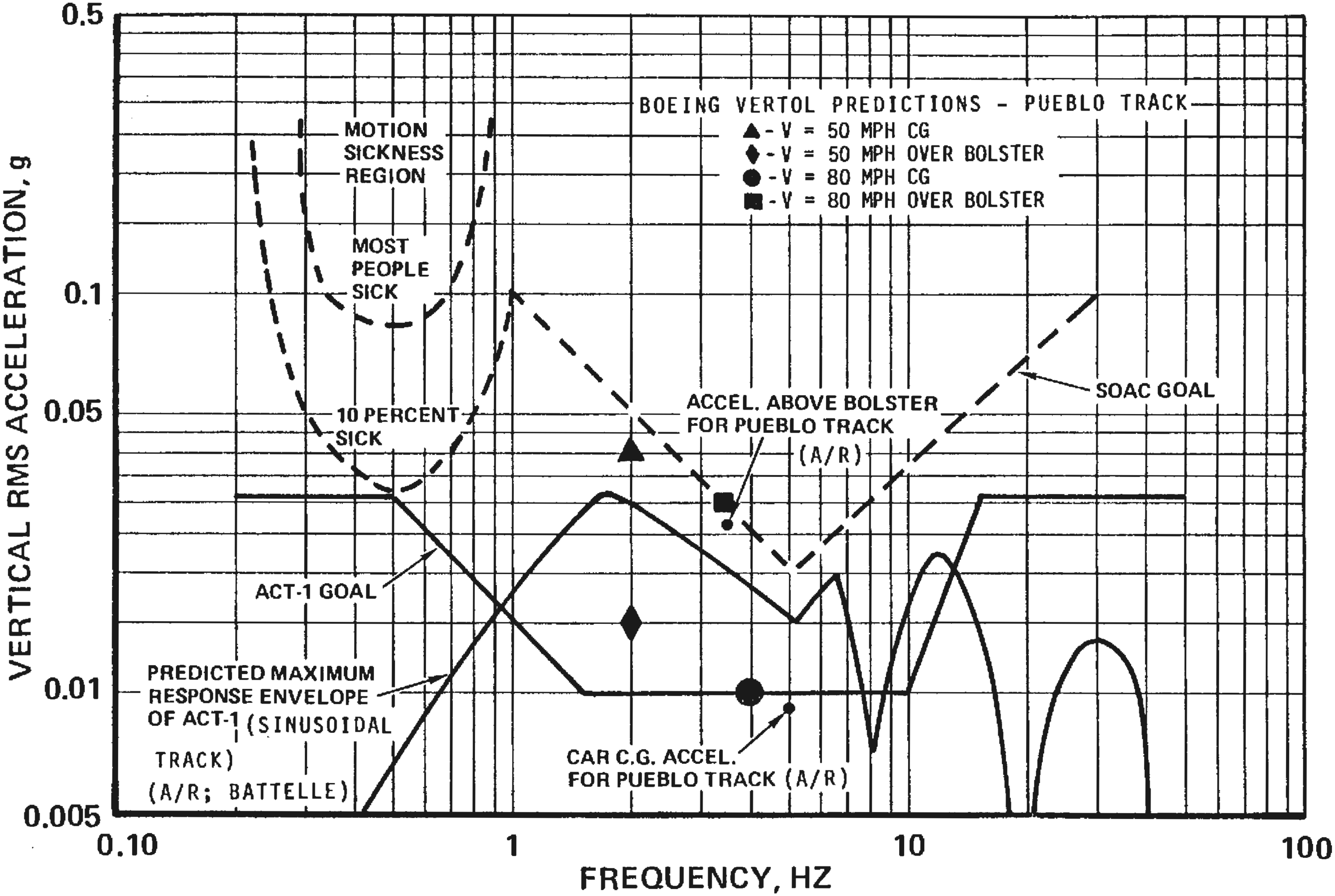


FIGURE 4.

LATERAL RIDE QUALITY OF ACT-1

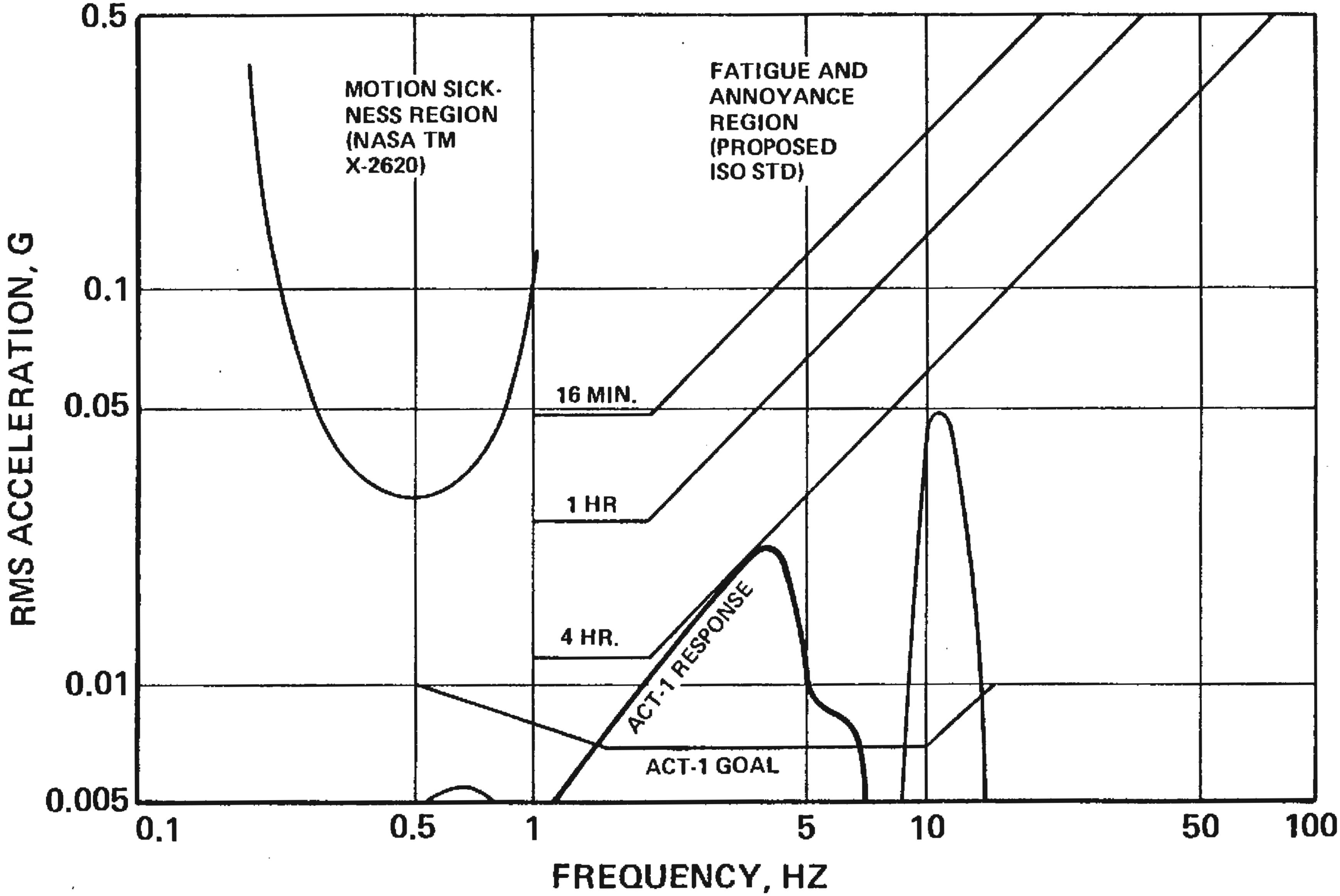
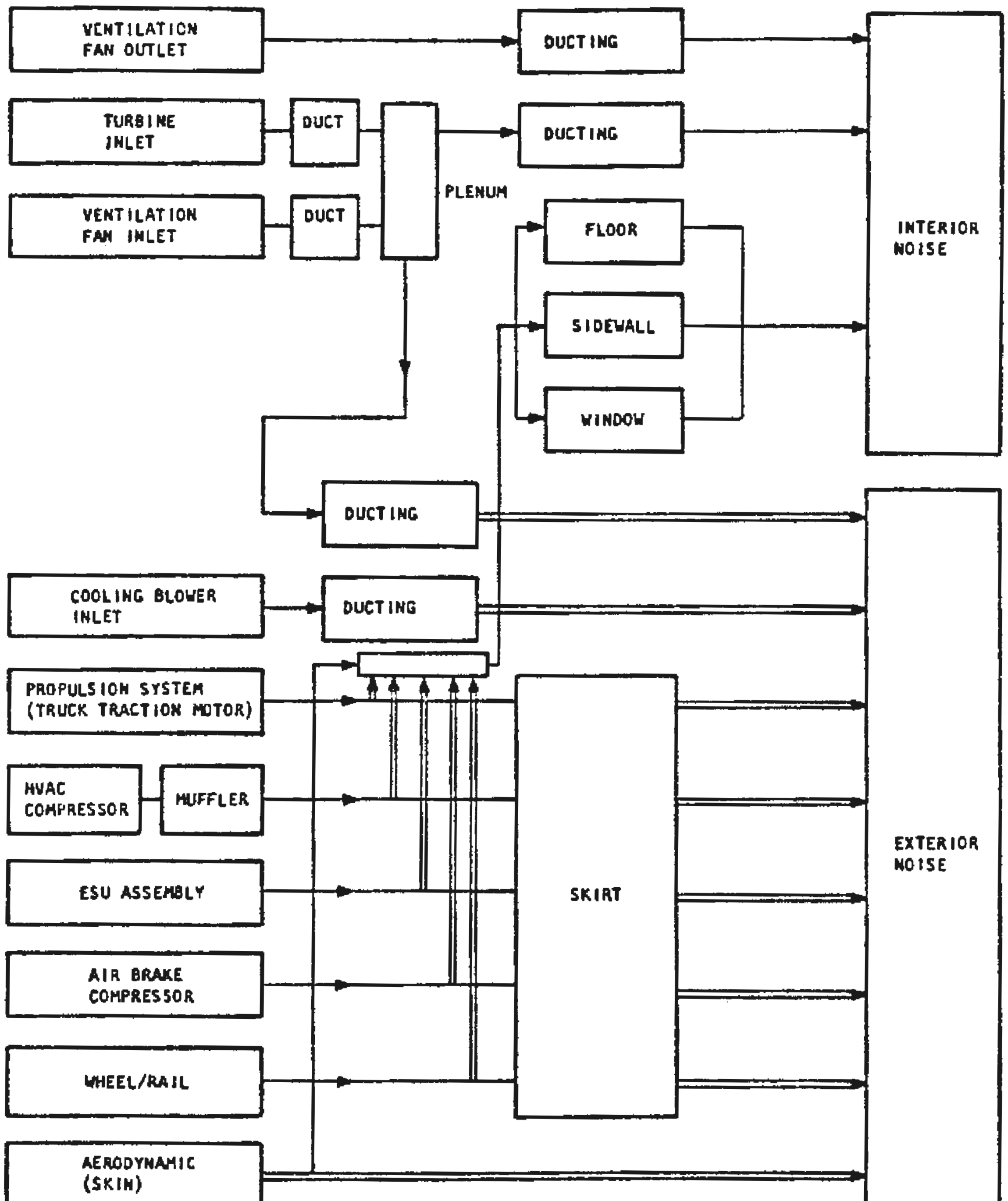


FIGURE 5.



NOISE SOURCES AND THEIR RESPECTIVE TRANSMISSION PATHS

FIGURE 6.

CALCULATED INTERIOR NOISE WITH ALL EQUIPMENT OPERATING

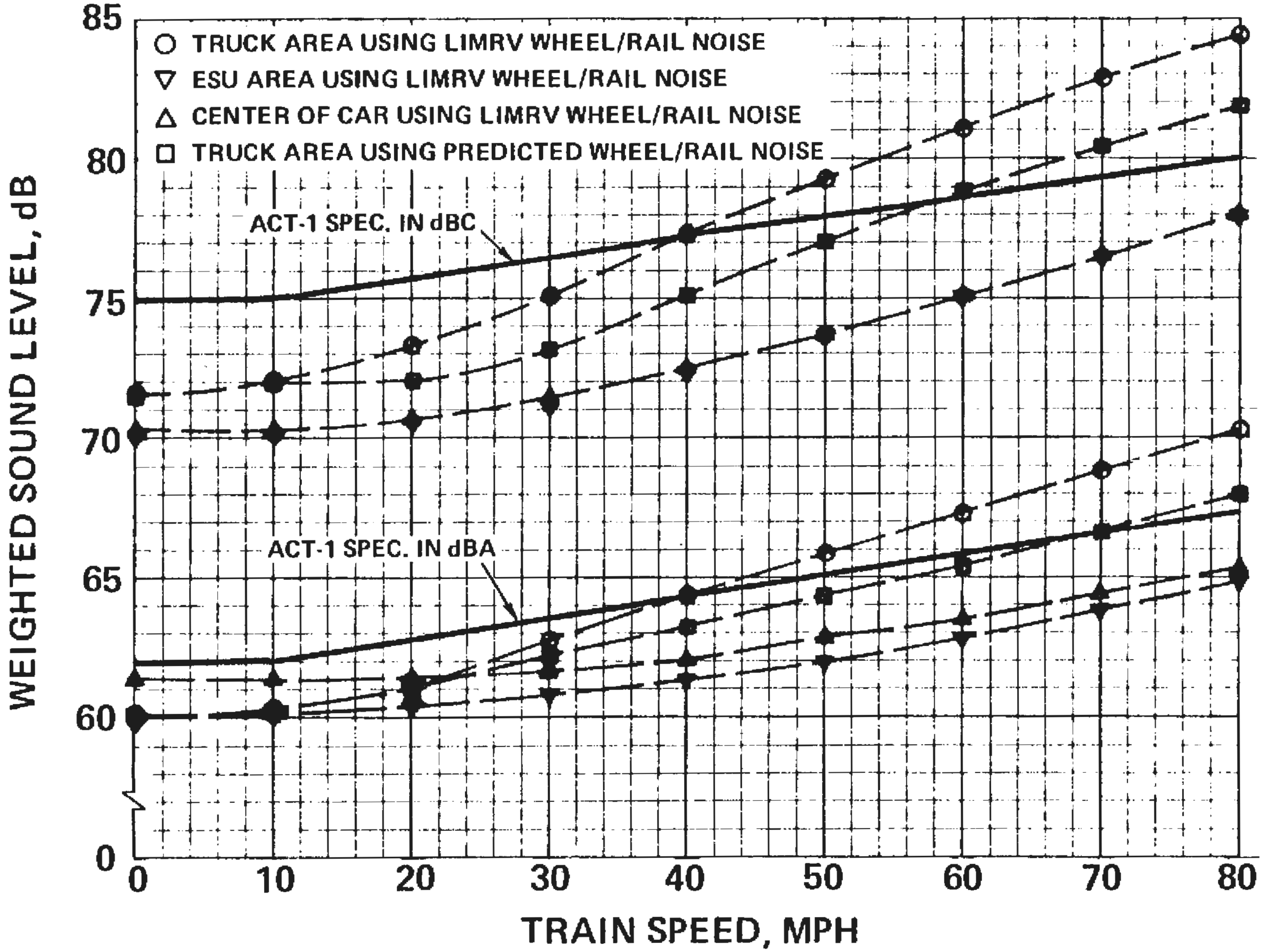


FIGURE 7.

Both interior and wayside noise levels at zero car speed will be measured on each car during functional testing at AiResearch. This preliminary compliance data will be utilized to determine any additional treatment requirements prior to delivery of the cars to Pueblo.

Wayside Noise

The predicted wayside noise levels shown in Figure 8 exceed the specification requirements by approximately 2 to 3 dBA over most of the normal operating speed range. A comparison of test data obtained for the State-of-the-Art Car with its predicted goals shows that the rate of increase in noise level with speed is less than that for the predicted goal. With this as a guide, it is expected that the ACT-1 will also be within the predicted goal for most of its operating range. The ACT-1 wheel design incorporates a wheel damping ring rather than a resilient layer as was used on SOAC.

Air Comfort

The half-car HVAC system tests have been completed by AiResearch and detailed results are shown in later paragraphs. Test data indicates that an interior temperature of 79°F with relative humidity of 54% will be obtained at the extreme design ambient of 105°F with 100 passengers. The design requirement is for 75°F and 60% relative humidity; however, the test results are within the current ASHRAE comfort zone. (See Figure 13)

Interior Design

The ACT-1 interior modular design concept has been maintained throughout the fabrication and assembly phase. The ACT-1 cars will demonstrate several concepts in seating supported standee units, and a special section for elderly and handicapped passengers. This latter section is located in the rear of the high density car and includes both single and double upholstered raised seats with special grab rails. Crutch holders and an area for wheel chairs are also provided.

Economic Analysis

NYCTA "A" Line

Economic studies have been conducted comparing the operating, maintenance, acquisition and 20 year life cycle costs of the R46, R46 ESU and optimized ACT-1 vehicles for typical NYCTA fleet mixes. The optimized ACT-1 considers a reduced weight, single ESU car optimized for typical NYCTA route revenue service. Preliminary Boeing Vertol weight analysis indicates that 5000 lb. could be saved as a minimum for a production ACT-1. Weight saving areas include carbody structure, collision attenuation, and wiring. The ACT-1 truck and air comfort system are currently among the lightest weight transit equipment of their type.

CALCULATED WAYSIDE NOISE
50 FT FROM TRACK CENTERLINE

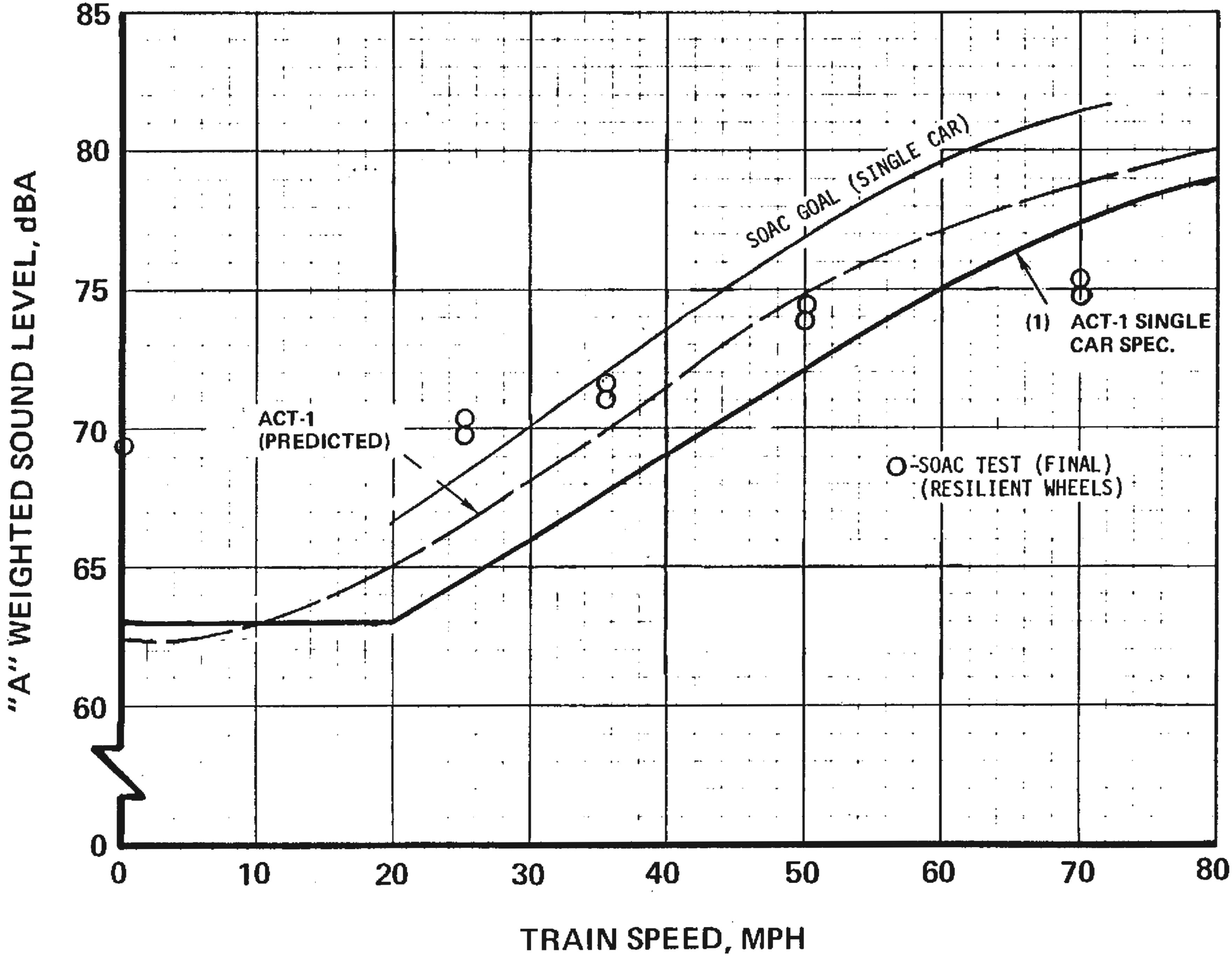


FIGURE 8.

The average energy consumption for the various types of vehicles are shown in Table I. These costs are based on a projected 1977 rate of 5.096/KW-HR and an annual vehicle mileage of 50,000 miles and a 50 passenger car weight. The data show that the optimized ACT-1 vehicle consumes approximately 30% less energy than the R44/R46 vehicle.

Table II provides a comparison of total 20 year system life cycle costs for various mixes of ESU cars with the existing NYCTA fleet. As a basis of comparison, equal and unequal fleet scenarios were considered. The unequal fleet size was derived by taking into account reductions in reserve fleet size made possible by improvements in unscheduled maintenance of the newer cars. The ACT-1 mixes show a significant cost savings over the R46 vehicles.

Table III provides a comparison of 20 year system life cycle costs for a fleet of all new vehicles. The unequal fleet considered a reduced reserve fleet size because of improvements in unscheduled maintenance. The optimized ACT-1 provides the lowest cost over the 20 year period.

Performance and Power Consumption

Analytical studies were completed by AiResearch to evaluate the impact of increased car weight on vehicle performance and power consumption. The energy consumption requirements for the 18.5 mile Pueblo route are 7.0 to 7.2 KW-HR/mile for a 98,000 pound vehicle, which is equivalent to the specification AWO weight of 83,000 pounds plus 100 passengers. However, an actual AWO weight of 90,000 pounds plus 100 passengers yields a weight of 105,000 pounds. Current empty weight estimate is 89,500 pounds. Table IV shows a comparison of performance and energy consumption for the specification AW1 weight and a projected weight vehicle. For compliance testing, an AW1 vehicle weight of 98,000 pounds will be used.

The analytical studies show that the ACT-1 prototype power consumption continues to represent approximately a 25% reduction over existing systems. Performance at 98,000 pounds will be improved over the SOAC at its design AW1 weights.

Environmental Impact

The effect of the ACT-1 upon the surrounding environment has been a major consideration during the design and development phases. The Test Plan currently being formulated for ACT-1 testing at Pueblo includes testing to validate the environmental impact. Wayside noise under all operating conditions will be measured. Radio frequency interference tests will determine the levels of broad band radiated electro-magnetic emission from the test vehicle to the wayside.

TABLE 1

NYCTA A-LINE ROUTE

AVERAGE ENERGY CONSUMPTION

CAR	ESU		EMPTY WEIGHT-LB	50 PASS. WEIGHT-LB	ENERGY CONSUMPTION AT 50 PASS. CAR WEIGHT KW-HR/CAR-MILE (1) (5)
1973 NYCTA FLEET	No	Some	75,000	82,500	5.57 (System Average) (4)
R32	No	No	70,000	77,500	5.11 } Test data adjusted for weight of 50 passengers.
R32-ESC	Two	No	81,000	88,500	3.52
R44/R46	No	Yes(2)	89,000	96,500	6.49 } R32 & R32 ESC test data adjusted for differences in car weight, aux. load and no. of ESU's
OPT. ACT-1	One	Yes(3)	76,300	83,800	4.52
R-46/ESU	One	Yes(2)	94,000	101,500	4.49

NOTES:

(1) Except for 1973 NYCTA data, all values are power at vehicle.

(2) Air conditioning based on SOAC-type vapor cycle units.

(3) Air conditioning based on ACT-1 air cycle units.

(4) NYCTA consumption for February 1975 is 5.99 KW-HR per car mile.

(5) Energy consumption with air conditioned cars is comprised of the basic propulsion energy plus an annual "weighted" auxiliary power load consisting of: Six (6) months of heating at one-half heat load, three (3) months of fresh air ventilation, and three (3) months of air condition at one-half capacity.

TABLE II

EXISTING FLEET MIX STUDIES

	EXISTING FLEET OF 2901 R-10/42 AND 1050 R-44/66 CARS PLUS		
(SCENARIO A) EQUAL FLEET	2900 R-46's	2900 R-46 ESU's	2900 OPT. ACT-1's
20 YEAR SYSTEM COST ($M)	5252	5171	5112
COST SAVINGS COMPARED TO R-46 ($M)	-	81	140

	EXISTING FLEET OF 2901 R-10/42 AND 1050 R-44/46 CARS PLUS		
(SCENARIO B) UNEQUAL FLEET	496 R-46's	496 R-46 ESU's	485 OPT. ACT-1's
20 YEAR SYSTEM COST ($M)	5242.9	5162.9	5067.8
COST SAVINGS COMPARED TO R-46	-	80.0	175.1

TABLE III

NEW VEHICLE COMPARISONS

(SCENARIO C) EQUAL FLEET	500 R-46's	500 R-46 ESU's	500 OPT. ACT-1's
20 YEAR SYSTEM COST ($M)	544.0	530.86	520.69
COST SAVINGS COMPARED TO R-46 ($M)	-	13.14	23.31

(SCENARIO D) UNEQUAL FLEET	496 R-46's	496 R-46 ESU's	485 OPT. ACT-1's
20 YEAR SYSTEM COST ($M)	542.55	529.31	512.88
COST SAVINGS COMPARED TO R-46 ($M)	-	13.24	29.67

TABLE IV

ACT-1 PERFORMANCE DATA AND ENERGY CONSUMPTION

	UNITS	SPEC. REV. 6 AW1 = 98,000 LB	CALCULATED AW1 = 98,000 LB	CALCULATED AW1 = 105.00 LB
INITIAL ACCELERATION @ AW1	MPHPS	3.0 ± 0.2	2.9	2.82
DECELERATION @ AW1	MPHPS	3.0 ± 0.3	2.9	2.85
MAXIMUM SPEED	MPH	80	80	80
TIME TO 80 MPH W/O 0.5 SEC. DEADTIME	SEC	52	52	61.6
DISTANCE TO 80 MPH	FEET	3800	3800	4670
PUEBLO ROUNDTRIP TIME AW1, 2 CARS, W/O 3 MIN. TURNAROUND	MIN.	39	37.9	38.2
DISTANCE IN 20 SEC.	FEET	700	715	680
BALANCE SPEED ON 4 PERCENT GRADE	MPH	70	70	64
SPEED TO ACCELERATE TO 5400 FT., 2.75 PERCENT GRADE, AW1	MPH	72	72	67
ENERGY CONSUMPTION PUEBLO ROUTE, 2 CARS	KW-HR/	7.0 - 7.2	7.14 (7.46 INCLUDING FW TEST DATA)	7.79

PROGRAM ACCOMPLISHMENTS

Design and Program R-views

Thirteen major design and program review meetings were held during the past year as summarized in Table V.

The technical reviews were highlighted by the Final Engineering Review in November 1975. This review was attended by UMTA, TSC, American Public Transit Association (APTA), and the Advisory Board in addition to the Boeing Vertol management and technical staffs. During this review the following major subsystems were discussed:

- Wiring
- Pneumatic System
- Heating, Ventilation & Air Conditioning System (HVAC)
- Crash Attenuation System
- Passenger Door System
- Interior
- Passenger Compartment
- Carbody Structure
- Power & Traction Systems
- Truck/Brake Systems
- Vehicle System

In May 1976, UMTA, TSC, APTA, and the Advisory Board were invited to review the two ACT-1's in assembly at AiResearch. Detailed comments were obtained from the review and AiResearch has made several assembly changes as a result of comments on wire installation and circuit protection.

ACT-1 Non-Metallic Materials Program

Boeing Vertol issued Document D174-10040-1, "Advanced Concept Train (ACT-1) Non-Metallic Materials Selection Program (Interim Report)". This report is concerned with the flammability and smoke generation characteristics of all of the non-metallic materials used in the fabrication and assembly of the ACT-1 vehicles. The suitability criteria for non-metallic materials for use in rail transit vehicles are defined in TSC letter No. 611, "Guidelines for Flammability and Smoke Emission Specifications - TSC-75-LFS-4". The scope of this report includes the description of non-metallic materials initially proposed for use in the ACT-1 vehicle including the tests conducted upon them, the redirection of the ACT-1 Program that was caused by the unacceptable test performance of the initially specified materials, and the resultant, comprehensive Flammability Qualification Program conducted to obtain suitable non-metallic materials for use in the ACT-1 vehicle. Table VI summarizes the results of the Qualification Program.

TABLE V

MAJOR ACT-1 DESIGN, MANUFACTURING, AND TEST REQUIREMENTS REVIEW MEETINGS

DATE	LOCATION	SYSTEM	TYPE	ATTENDANCE					
				AIRESEARCH	VENDOR	BOEING VERTOL	UMTA	TSC	TDC
1975									
July	Airline Products	L-D Seats	CDR	X	X	X			X
July	Fiber Science	H-D Seats & Liners	CDR	X	X	X		X	X
Aug.	AiResearch	Communications	CDR	X		X			X
Aug.	AiResearch	Crash Attenuation	CDR	X		X		X	X
Sept.	Fiber Science	Cab Liners	CDR	X	X	X			X
Sept.	AiResearch	Train Control	CDR	X		X			X
Oct.	Boeing Vertol	Pre-Vehicle CDR	-			X			X
Nov.	AiResearch	Final Eng. Rev.	CDR	X		X	X	X	X
Dec.	AiResearch	ATO-Safety	CDR	X		X			
1976									
Jan.	AiResearch	Motor Status	-	X		X			
Mar.	AiResearch	Door System	-	X	X	X			
April	AiResearch	Eng. Program Status	-	X		X	X	X	
May	AiResearch	Car Assembly Review	x	X		X	X	X	X

TABLE VI

RESULTS OF NON-METALLIC MATERIALS FLAMMABILITY QUALIFICATION PROGRAM

Meeting the ACT-1 flammability requirements for non-metallic materials intended for use in the ACT-1 vehicle is being assured either by vendor certification or by conducting of the required test(s). Certain materials such as adhesives, sealants, and potting compunds were excluded from the requirements due to minor quantities and minimal fuel contribution.

1. Materials Qualified by Certification

Item	Material	ACT-1 Vehicle Application	Flammability Test Method
(A)	Chloroprene	Glazing Stripping	ASTM C542-71a
(B)	Polyurethane Paint System (Sterling U1000 Primer w/2 coats of Sterling U1001)	Paint (Exterior & Interior)	ASTM E162-67 & NBS TN 708
(C)	Plymetal	CAR Floor	ASTM E84-61
(D)	Polyurethane Paint System (7502U #31 Dupont)	Hand-grab coating	ASTM E162-67
(E)	Type I Sandwich Panel	Side Doors	ASTM E162-67 ASTM D635-72
(F)	"Canfield" (by Bigelow)	Carpeting	ASTM E84-61
(G)	"Gropoint" (by Bigelow)	Carpeting	ASTM E84-61

TABLE VI (CONT'D.)

Item	Material	ACT-1 Vehicle Application	Flammability Test Method
(H)	"Flame-Out" (by Barwick)	Carpeting (Hi-Den.)	ASTM E84-61
(I)	HALAR	Wire Insulation	UL 94 V-0
(J)	EXANE	Wire Insulation	IPCEA-S-19-81
(K)	PANDUCT	Wire & Cable Ducting	UL 94 V-1
(L)	TBD	Door, A-End	ASTM D635-72
(M)	TBD	Door, B-End	ASTM D635-72
(N)	TBD	Door, Cab	ASTM D635-72
(O)*	TBD	Crutch-holder	FAR 25.853
(P)*	FMX 10197-42	Splice for H/C in Roof & Side Panels	ASTM D568-72
(O)	Dapcotac 3008 (Potting Adhestive)	Some edges of side panels	ASTM D635-72
(R)*	CREST 3150 (Potting Adhestive)	Fastener locations in roof and side panels	-
(S)*	MIL-S-8802 & MIL-S-81733 (Polysulfide Sealant)	Faying Surfaces between panels & car structure	-
(T)	Microlite	Floor Insulation	UL 723
(U)	Exact-O-Board	Ducting internal insulation	UL 723
(V)*	Non-Slip Walk way Coating	Horizintal surfact of anti-climber	-

TABLE VI (CONT'D.)

Item	Material	ACT-1 Vehicle Application	Flammability Test Method
(W)	AMS 32 43 (Neoprene Pads)	Fastener locations in floor	ASTM C542-71a
(X)	Federal Spec. ZZ-T-831 (Neoprene)	Sleeves for floor fasteners	ASTM C542-71a
(Y)*	3M EC2210 (Adhesive)	Bonding of rubber pads and grommets to subfloor	-
(Z)*	FM 137 (Adhesive Film)	Roof Panels - doublers & edges to core side side panels - core transitions	-
(AA)*	Dapcotac 3050-50	Through-fastener locales	ASTM D635-72
(BB)*	3M No. 35 (Adhesive)	Bonding of Exact-O-Board insulation to A/C Ducting	-

NOTES:

(1) Asterisk (*) denotes accepted deviation from the ACT-1 Specification due to the small quantity of this material used in the ACT-1 Vehicle.

(2) The following test standards were evaluated and found acceptable to ACT-1 Flammability Requirements:

(a) UL-94, "Test for Flammability for Plastic Materials for Parts, Devices, and Appliances".

(b) UL-723, "Test for Surface Burning Chracteristics of Building Materials".

(c) IPCEA-S-19-81, "Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy".

TABLE VI (CONT'D.)

2. Materials Qualified By Test

The following materials were tested for compliance with the ACT-1 flammability requirements:

Item	Candidate Material	Potential ACT-1 Vehicle Application	Flammability Test Method
(A)*	Hooker Hetron 301P (FRP)	Noise Fairing & Car Interior	ASTM E162-67 & NBS TN 708
(B)	Hooker Hetron 301P Primed w/Sterling U1000 & finished w/2 coats Sterline U1001	Noise Fairing & Car Interior	" "
(C)	Hooker Hetron 800 FR/800L (FRP)	Interior liners	" "
(D)	Hooker Hetron 800 FR/800L, (FRP) Primed w/Sterling U1000 & finished 2/coats Sterling U1001	Interior liners	" "
(E)*	Royalite 59 ABS	Interior trim	" "
(F)*	Narmco 3203 (FRP)	B-end fairing	" "
(G)*	Narmco 3203 (FRP) Primed w/Sterling U1000 & finished w/2 coats Sterling U1001	B-end fairing	" "
(H)*	Polysulfone	Interior trim	" "
(I)	Polycarbonate	Windows (Exterior), Light Diffusers, & Windscreen	" "
(J)	Narmco 3203-(FRP) w/Stainless Steel	Exterior panels	" "
(K)	Narmco 3203-(FRP) w/ss & painted	Exterior panels	ASTM E162-67

TABLE VI (CONT'D.)

Item	Candidate Material	Potential ACT-1 Vehicle Application	Flammability Test Method
(L)	Hooker Hetron 301L (FRP) coated with Ferro V-34106 gel-coat	Nose Fairing & B-end Fairing	ASTM D635-72
(M)	Hooker Hetron 301L (FRP)	Nose Fairing & B-end Fairing	ASTM D635-72
(N)	Pneumacel, Grade 1500	Seat Cushioning	ASTM E162-67
(O)	FRP with Diamond Shamrock #6657 coated with 4 Mils Polyurethane	Interior liners, Molded Seats, Supported Standee Modules, & Compartment Dividers	ASTM E162-67 & NBS TN 708

NOTE:

Asterisk (*) indicates failure to meet ACT-1 flammability or smoke requirements and consequently will not be used in the vehicle.

Since there was transit operator concern about the ability of the ACT-1 roof panel (a sandwich panel with a water-resistant paper honeycomb core) to successfully withstand the electric arc caused by an energized catenary falling on it, Boeing Vertol had ITE Imperial Corporation's High Power Electric Laboratory conduct a test to simulate such an event. The sample ACT-1 roof panel satisfactorily withstood second (approximately) contacts by a 600v, 4000 amp catenary in two tests, one test simulated an ACT-1 vehicle moving at one mph. The panels retained their structural integrity and the flames self-extinguished within four minutes of power removal. The results are contained in ITE Test Report R-J-75185-B1.

AiResearch submitted, and Boeing Vertol approved, Report 76-12364-2, "Safety Analysis - Fire Hazards, ACT-1 Vehicle". This report hypothesized various types of ignition/heat souces impinging on the non-metallic materials of the ACT-1 vehicle and analyzed the resulting performance of the materials. The conclusions were that the ACT-1 met the flammability and smoke emission requirements imposed by AiResearch Document 72-8771-3, Revision 6, "ACT-1 Design Specification".

PROGRAM SCHEDULE

The current ACT-1 Program Master Schedule, as shown in Figure 9, calls for delivery of the first ACT-1 car to the Transportation Test Center, Pueblo, Colorado in Feburary 1977. The second vehicle is scheduled for delivery in March 1977.

Based on a 35 week test schedule, vehicle acceptance testing is now targeted to complete in November 1977.

DESIGN SUMMARY

Vehicle Characteristics

The latest tabulation of the ACT-1 physical dimensions is shown in Table VII. Only minor changes have occurred in these dimensions since the 1975 report.

Car Body Structure

An ACT-1 car body structure test assembly consisting of the car body shell structure of welded aluminum frames, extruded aluminum roof rails, welded aluminum underframe structure, honeycomb side and roof panels with stainless steel outer skins, plus a side door installation, and a single window installation was subjected to static load tests for the following loads:

1. Vertical crush load (325 passengers.
2. Coupler compression load (135,000 lbs.).
3. Anticlimber compression load (300,000 lbs.).
4. Torsional (jacking) load.

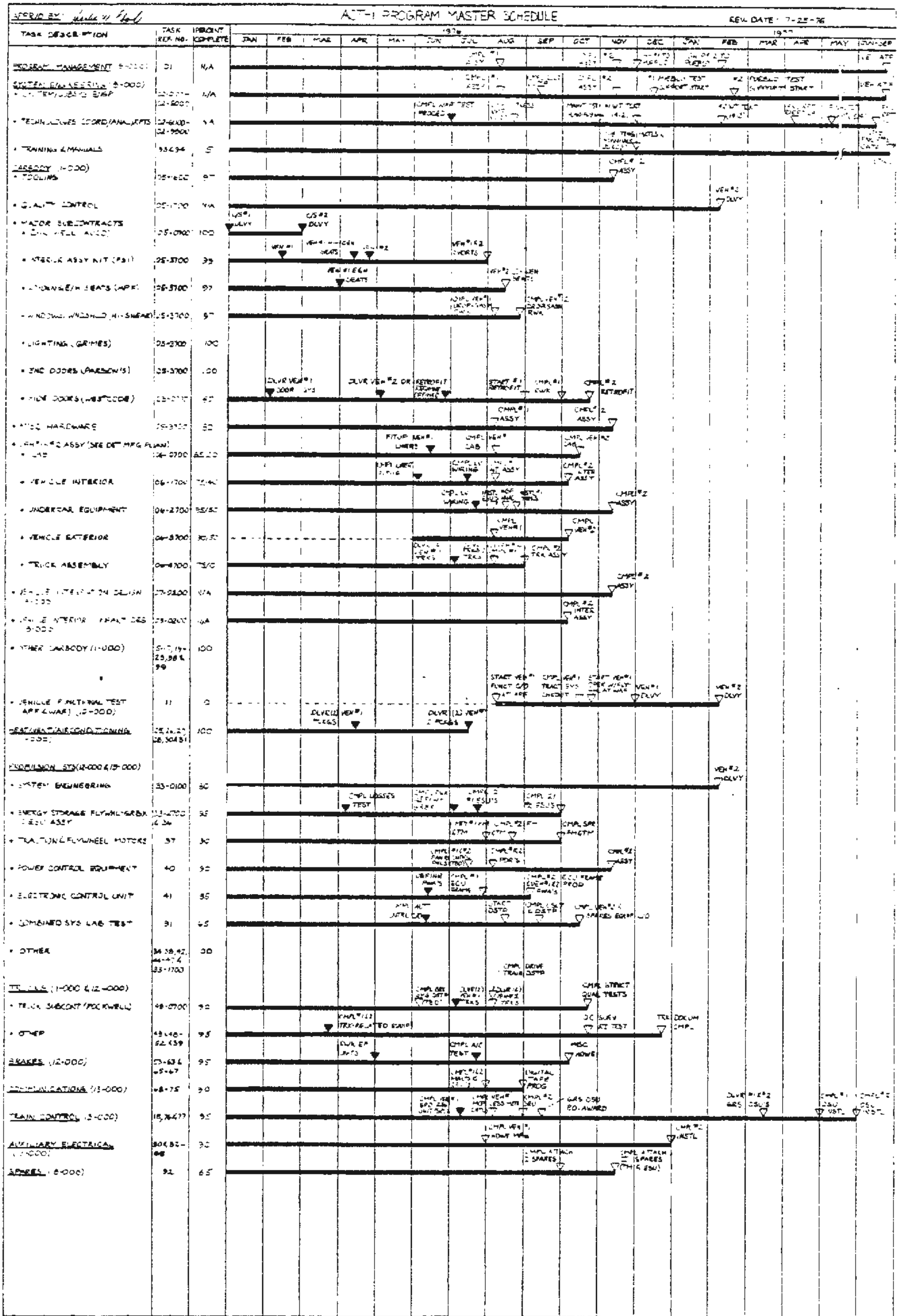

ACT-I PROGRAM MASTER SCHEDULE
TASK DESCRIPTION
TASK REF NO.
PERCENT COMPLETE
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
TRUCKS (1-000 & 12-000)
BRAKES (12-000)
COMMUNICATIONS (13-000)
TRAIN CONTROL (3-000)
AUXILIARY ELECTRICAL
SPARES (8-000)
LEGEND: ▽ - PROGRAM MILESTONE; ▼ - COMPLETED MILESTONE

FIGURE 9.

TABLE VII

ACT-1 VEHICLE CHARACTERISTICS

Length of car over coupler faces	75 ft 1/2 in
Length of car over anticlimbers	77 ft 10 in
Distance, center to center of trucks	50 ft 9/2 ft
Width of car body, maximum	9 ft 11 in
Width over threshold	9 ft 5-13/16 in
Height of car (AW0)	
Top of rail to top of roof (adjustable)	11 ft 3-7/8 in to 11 ft 9-12 in
Top of rail to pantograph (locked down) if used	12 ft 4-7/8 in to 12 ft 5-3/8 in
Top of rail to top of floor, new wheels (adjustable)	43-7/8 to 49-1/2 in
Top of rail to top of anticlimber (adjustable)	42 to 49-1/2 in
Top of rail to centerline of coupler (adjustable)	25.5 to 31.12 in
Interior width at seat line, minimum	9 ft 2 in
Height, minimum, floor to headlining at centerline of car	7 ft
Width of side door openings	50 in
Width of No. 1 body end door openings	2 ft 4 in
Width of No. 2 body (B) end door door openings	2 ft 6 in
Width of cab emergency door	2 ft
Height of side door openings	6 ft 5 in
Height of body end door openings	6 ft 5 in "B" End 6 ft 6 in "A" End
Height from floor to bottom of side window frame	33.7 in
Height from floor to top of side window	76.8 in
Width of window (clear opening)	7 ft in
Maximum vertical distance from top of floor to bottom of all undercar equipment	33 in
Truck wheelbase	6 ft 11 in
Wheel diameter, new	31 in
Wheel diameter, worn (minimum)	29 in
Wheel gauge	4 ft 7.7 in
Maximum consist	2
Minimum consist	1
Seating capacity	1
H-D (Incl. standing unit)	68 passengers
L-D	56 passengers
Normal load car weight	98,000 lb
Peak load (high density) car weight	116,000 lb
Car weight	131,750 lb

The tests successfully demonstrated that the car body structure meets or exceeds the requirements of the ACT-1 Design Specification. See Figure 10.

Both car shells have been completed by AVCO in Nashville, Tennessee and delivered to AiResearch at Compton, California. Car shell No. 2 for vehicle No. 1 (H-D car) and car shell No. 1 for vehicle No. 2 (L-D car) were delivered to AiResearch in December 1975 and February 1976 respectively.

Side Panels and Frames

A special section of the car body structure consisting of a roof rail window and door posts, side sill and honeycomb side panel extending from car body station 620.5 to 902.5 was subjected to fatigue loads representative of operations at AW1. The specimen (Figure 11) sustained AW1 load $\pm$ .15g for one million cycles without failure and an overload of AW1 $\pm$ .30g for over 470,000 additional cycles prior to sustaining fatigue failures in the door post and window corner areas. This test was considered successful based on the completion of the first one million cycles at design load without failure. The results also indicate that the ACT-1 car body will be satisfactory under the expected fatigue environment.

Weights

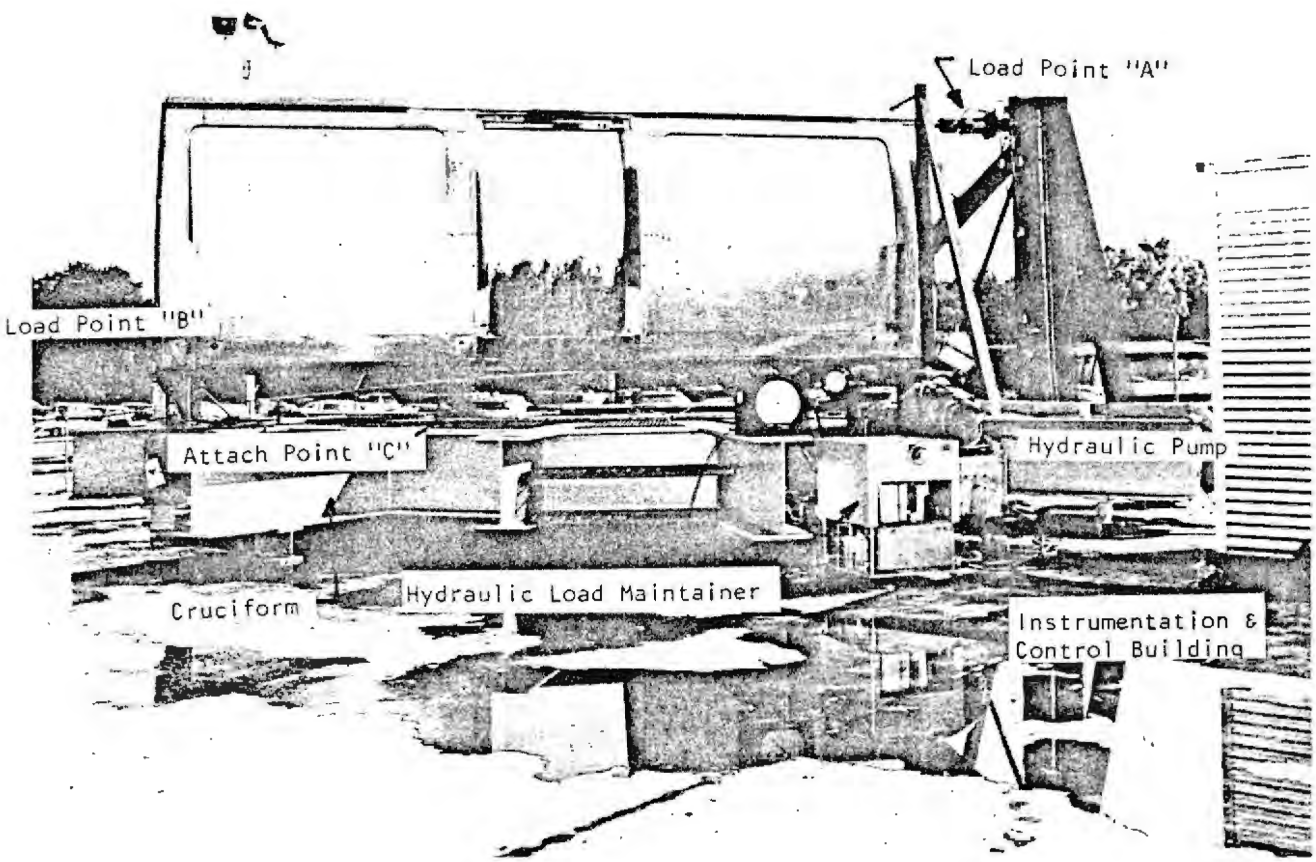
Weight growth continues to be experienced. Since the Specification Revision No. 6, dated June 2, 1975, in which the maximum weight empty allowable was defined at 83,000 lbs. + 2%, the empty weight of the Low Density car has grown to 89,556 lbs. This value is based on 79% of actually weighed components. Based on Boeing Vertol experience, system tests can produce unexpected weight growth, so until the truck frame fatigue tests and the car acoustic tests, etc., have reached satisfactory completion, further weight growth is possible.

Major overweight systems in the prototype cars include the primary structure which has a non-optimum roof rail configuration, and the energy attenuation system which utilizes a heavy design configuration. Substantial growth has also been experienced in wiring and car end closures.

Some success in weight reduction has been achieved. The current weight of trucks at 26,114 lbs. per car set represent a saving of 2154 lbs. or 7.6% over the State-of-the-Art Car (SOAC) truck weights.

In comparison with the SOAC vehicle empty weights, the ACT-1 vehicles, including their unique and weight impacting features of energy attenuation and electrical energy storage, are competitive.

FIGURE 10.



TEST RIG ACT-1 CARBODY
SIDE PANEL FATIGUE TEST.

FIGURE 11.

	Car No. 1 (Low Density)	Car No. 2 (High Density)
SOAC Empty Weight	88,071	88,831
ACT-1 Empty Weight	89,566	88,036

The vehicle weight breakdown summary is shown in Table VIII.

Door Systems

Considerable effort was devoted to improving the ACT-1 plug door system during this reporting period. Detailed hardware reviews of the door installation at AVCO in December 1975 and at AiResearch in March 1976 indicated several areas requiring redesign and rework:

- Door Seals
- Fastener Locking
- Linkage Locking
- Life Test Failures
- Obstruction Recycling
- Trailing Edge Seal

In late March 1976, Boeing Vertol directed AiResearch to take the necessary steps to ensure that the door system would comply with the specification. As a result of this direction, AiResearch and Westcode have made several detailed changes, which have resulted in an improved door system. As of October 1976, the test rig at Westcode had accumulated over 1,000,000 total cycles and the wear-out life of two replaceable parts had been established at 200,000 cycles (fixed trolley) and 100,000 cycles) "cotton reel" spool). The ACT-1 Pueblo and property demonstrations are expected to accumulate about 60,000 total cycles. Westcode experimented with an improved cotton reel on a non-interference basis. Door seals remain a problem and in July 1976 a U.S. vendor was selected to design and fabricate these seals. The above actions, while they should lead to improved door operation and life, have resulted in some delay in vehicle fabrication and delivery. Retrofit of improved-design parts is scheduled for October 1976, but door seals are not expected until December 1976, during functional checkout of the H-D car.

Heating and Ventilating System (HVAC)

The HVAC systems have been installed in both vehicles No. 1 and No. 2 except for the turbocompressor units, which are scheduled to be installed with the ESU's in December 1976. They incorporate all the design changes resulting from the half-system tests performed between November 1975 and February 1976, which combined both subsystem development and design substantiation testing. The development phase of the half-system test resulted in the following:

- Air inlet and turbine discharge ducting strengthened.

TABLE VIII.

VEHICLE WEIGHT BREAKDOWN SUMMARY

	2-10-76	3-30-76	% Actual	Δ
CARBODY	((39,095))	((38,934))		
PRIMARY STRUCTURE	(20,273)	(20,273)	(100)	
ROOF	1,238	1,238		
SIDE FRAMING	7,929	7,929		
UNDERFRAME	6,662	6,662		
CAB STRUCTURE AND ANTI-CLIMBER	1,004	1,004		
ENERGY ATTEN. 'A' END	1,394	1,394		
ENERGY ATTEN. 'B' END	1,296	1,296		
'B' END STRUCTURE AND ANTI-CLIMBER	750	750		
SECONDARY STRUCTURE	(13,211)	(13,050)	(83)	
FLOOR PANELS	1,836	1,896		
WINDOWS AND GLAZING	2,843	2,843		
DOORS AND TRACKS	1,692	1,692		
SIDE PANELS AND SKIRTS	1,466	1,465		
CAR END CLOSURES	1,181	1,181		
COUPLERS	1,550 ①	1,550		
BELLY PANS AND A/C DUCTS	-	-		
EQUIPMENT BRACKETRY	1,372 ②	1,349		-23
SIDE BEARERS	896	800		-96
CENTER PIN ASSY	165	123		-42
PAINT, TRIM, AND SEALER	150	150		
INTERIOR	(5,611) ③	(5,611)	(0)	
FLOOR COVERING	514	514		
TRIM AND PANELING	2,442	2,442		
SEATS (LOW-DENSITY)	2,655	2,655		
WINDSCREENS	- ⑧	-		
TRUCKS	((25,867))	((25,867)) ⑦	(90)	
NON-ROTATING PARTS	(12,376)	(12,376)		
MOTOR MOUNTS	564	564		
AXLE HOUSING	2,010	2,010		
CALIPER	2,120	2,120		
RUBBER SLEEVES	244	244		
FRAME AND TRANSOM	3,270	3,270		
AIR SPRINGS	446	446		
TORSION BARS AND LINKAGE	306	306		
SHOCK ABSORBERS	114	114		
SUSPENSION ADAPTER	1,830	1,830		
RADIUS RODS	92	92		
SPIDER WELDMENT	300	300		
MISC	1,080	1,080 ⑨		
ROTATING	(13,576)	(13,576)		
MOTOR	5,990	5,990		
COUPLING	300	300		
AXLE SHAFT	948	948		
CARRIER ASSY	1,604	1,604		
WHEELS	4,562	4,562		
TRUCK BEARINGS	- ④	-		
OIL (172 PINTS)	172	172		
EQUIPMENT	((23,031))	((24,765))		
PROPULSION	(13,988)	(13,988)	(96)	
PROP. CONTROL	1,590 ⑥	1,590		
INDUCTOR	775	775		
MOTOR, ESU	5,869	5,869		
FLYWHEEL AND GEARBOX	5,454	5,454		
FORCED AIR COOLING	300	300		
AIR COMFORT SYSTEM	(1,940)	(1,940)	(80)	
AIR COMFORT	1,765	1,765		
HEATERS	25	25		
HEATER CONTACTORS	150	150		
AUXILIARY POWER AND CONTROLS	(4,665)	(6,399)	(11)	
AUXILIARY POWER	1,725 ⑤	1,725		
WIRING AND RACEWAYS	2,940	4,676		+1734
PNEUMATIC SYSTEM	(969)	(969)	(53)	
PNEUMATIC SYSTEM	891	891		
COUPLER CONTROL	48	48		
AIRLINE CONTROL	18	18		
ROTARY SWITCH	12	12		
GEAR	-	-		
HYDRAULIC PUMP	-	-		
MISC	(1,469)	(1,469)	(11)	
COMMUNICATIONS	300	300		
DESTINATION SIGNS	195	195		
ATC SYSTEMS	517	517		
MOTORMAN'S EQUIPMENT	47	47		
LIGHTING	410	410		
TOTAL EMPTY WEIGHT (Low Density Config.)	87,993	83,566	79%	
TOTAL EMPTY WEIGHT (High Density Config.)	86,542	83,036	80%	

① BRACKET WEIGHT MOVED TO UNDERFRAME
② WEIGHT TAKEN FROM TRUCKS
③ HIGH DENSITY INTERIORS WILL BE 4166 lbs.
④ WEIGHT MOVED TO SECONDARY STRUCTURE
⑤ AUX. POWER AND CONTROL INCLUDES 672 LB. BATTERY
⑥ PANTOGRAPH NOT ON CAR WHEN SHIPPED TO PUEBLO
⑦ 'B' END CONFIGURATION TO BE 25,782 lbs.
⑧ WEIGHT INCLUDED IN TRIM AND PANELING
⑨ 'B' END WILL REDUCE THIS WEIGHT BY 85 lbs.

- A 4 nozzle water spray configuration.

- Heat exchanger condensate collection system connection to water spray system.

- Heat exchanger assembly modified with a tilted fan, improved vent fan, new baffle in inlet plenum, depth of discharge plenum increased 2".

The basic test setup used for the half-system test is shown in Figure 12. All the system package ducting, which interfaces the heat exchanger assembly, turbocompressor, and supply air return air ducting were included in the setup. Simulated ambient temperature and humidity conditions for cabin return air and fresh air supply were obtained by injection of hot air and super-heated steam to obtain the correct temperature and humidity at the package interfaces.

The results of the half-system testing show that for maximum hot day (105°F) operation the car interior temperature is within the latest ASHRAE comfort zone revised for energy conservation as shown in Figure 13.

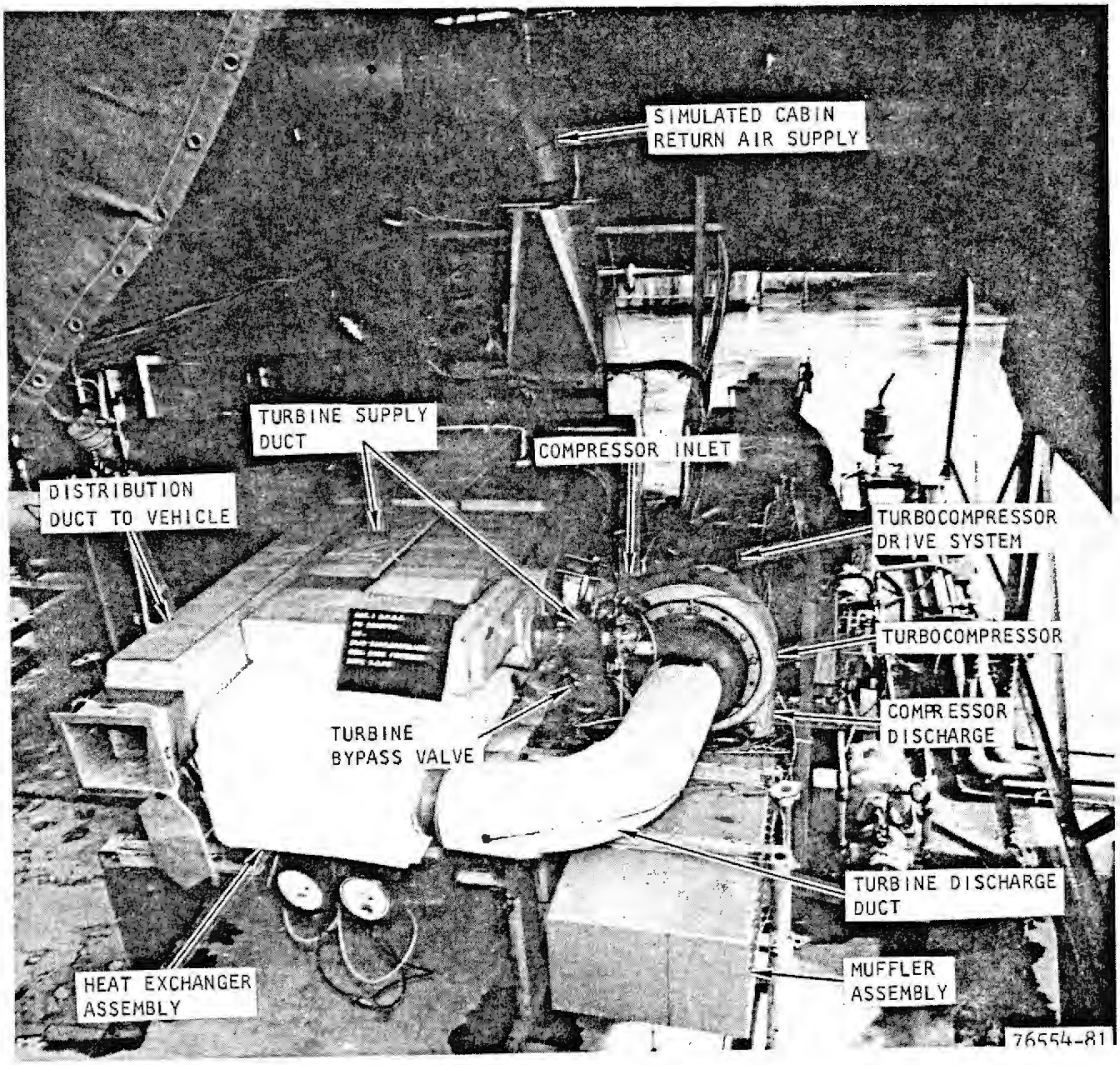
As previously noted, the test results of 79°F interior temperature and 54$ relative humidity are slightly below the design requirements of 75°F and 60% respectively. A final check of hot-day cooling performance will be made during Pueblo testing.

Table IX presents a summary of the predicted performance of the HVAC system as derived from the half-system laboratory testing. Configuration of these results will be obtained from both subsystem functional tests at AiResearch before shipment of the cars to Pueblo and from the vehicle systems testing at the Transportation Test Center, Pueblo, Colorado.

<u>Auxiliary Power Systems</u>

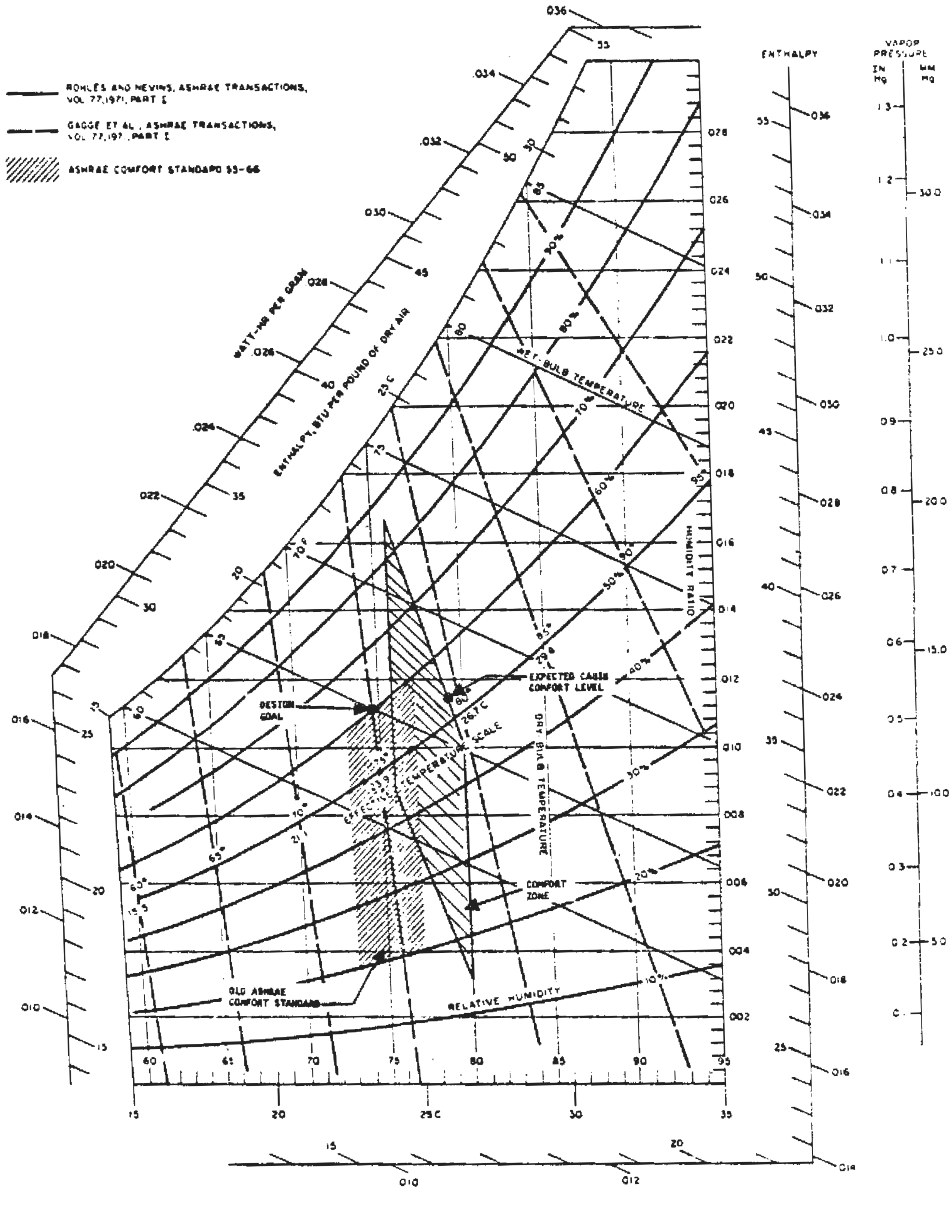
The Combined System Laboratory Test (CSLT) facility was utilized to optimize the auxiliary power system design and to acceptance test auxiliary power components and subsystems. Design substantiation testing in the CSLT facility is scheduled to be complete in January 1977.

The majority of the auxiliary power system hardware has been fabricated and installation in the two vehicles is scheduled to be complete by the end of 1976. The No. 2 vehicle Low Voltage Power Supply (LVPS), one AC distribution panel, and several critical pieces of power control equipment are being utilized in the CSLT and additional hardware has been authorized to improve the manufacturing schedule.



FUNCTIONAL TEST SETUP DEPICTING
HVAC VEHICLE INLET DUCT

FIGURE 12.



NEW ASHRAE COMFORT CHART ILLUSTRATING
TEMPERATURE AND HUMIDITY LIMITS

FIGURE 13.

TABLE IX

ACT-1 HVAC SYSTEM PERFORMANCE SUMMARY

PARAMETER	TEST RESULTANT AND CALCULATIONS	GOAL
+COOLING: (2 Packs Per Vehicle)		
Average Cooling Capacity	16 tons	---
Average Cabin Temperature	79°F max.	75°F max.
Average Cabin Humidity	54% R.H.	60% R.H.
Average Cabin Flow	4170 cfm	3900 cfm min.
Percent Fresh Airflow (of total cabin in flow)	40%	1500 cfm
+HEATING: (2 Packs Per Vehicle)		
Duct Heater Capacity	22 kw	20 kw
Supply Air Temperature to	88°F	---
Average Cabin Flow	4250 cfm	3900 cfm min.
Percent Fresh Airflow (of total cabin flow)	35%	1500 cfm
*POWER: (2 Packs Per Vehicle)		
Input Shaft Power (2 turbocompressors)	84 hp	74 hp
Input Ventilation Fan Power (2 Fans)	5.92 kw	5.3 kw
Input Scavenge Fan Power (2 Fans	0.06 kw	---
Input Controls Power (2 HVAC Packs)	0.08 kw	---

+Average values given for flywheel speed ranging from 70 to 100 percent (7700 to 11,000 rpm).

*Power measurements presented at 79 percent flywheel speed (8700 rpm).

Propulsion

Motor Rework

Early testing of the traction motors and flywheel motors revealed that several armatures had short circuits to ground and turn-to-turn. Additionally, the flywheel motors exhibited excessive brush sparking. An armature rework and commutation improvement program was initiated to correct the deficiencies as summarized in Table X. The reworked motors are currently in acceptance testing, with the final acceptance test scheduled for November 1976.

Preliminary results indicate that flywheel motor commutation grade has improved from previous levels; however, slight streaming at the 900 amp maximum current point is being experienced on about 60% of both motor types. Motors are being installed in the cars pending detail data review. As previously stated, Boeing Vertol allowed slight streamers at 900 amps on these 10 prototype motors.

Three flywheel motor-generators and two traction motors have completed acceptance testing. Acceptance testing of the remaining units and spares of each is scheduled for completion in September 1976. A sixth armature (spare) of each unit is also undergoing rework.

Flywheel Losses Reduction Program

The initial coast down test of the Energy Storage Unit (Figure 14) showed high flywheel losses compared to the 1974 CDR estimates. A test unit was modified to convert from a wet sump to a dry sump configuration and test data shows the flywheel losses were reduced substantially. The coast down test of the first production unit confirmed the advantages of the dry sump configuration. Table XI summarizes the ESU losses. The total losses of the first production unit of 30 hp are within acceptable limits of the 1974 CDR estimates of 29 hp. The test setup for the ESU losses test is shown in Figure 15. Acceptance testing of the two vehicle No. 1 ESU's has been completed and the two vehicle No. 2 and spare ESU's are scheduled to complete acceptance testing in early October 1976.

Combined Systems Laboratory Test (CSLT)

The Combined Systems Laboratory Test was initiated in July 1975 with the manual checkout of the Energy Storage Unit (ESU).

The CSLT load stand consists of load flywheels driven by the traction motor to simulate the mass of the vehicle and a SOAC motor-generator and load resistor to simulate the vehicle drag. The load stand is arranged as shown in Figure 16. The CSLT also includes one ESU and essentially a half-car set of power control equipment.

TABLE X

ARMATURE REWORK

	TRACTION MOTOR					FLYWHEEL MOTOR				
SN	1	2	3	4	5	1	2	3	4	5
REVIEW OF REJECTIONS										
LIFTED WEDGES		X				X				
UNBALANCE				X		X			X	XX
UNCURED FRONT SPRING BRAND								X		
MARRED COMMUTATOR								X		
SPLIT IN COIL BAND	X									
FAILED DIELECTRIC TEST										
TURN-TO-TURN				X		X		X	X	
COIL-TO-GROUND							X	X		
TOTAL RUNNING HOURS	330	90	15	50	70	260	26	120	50	100

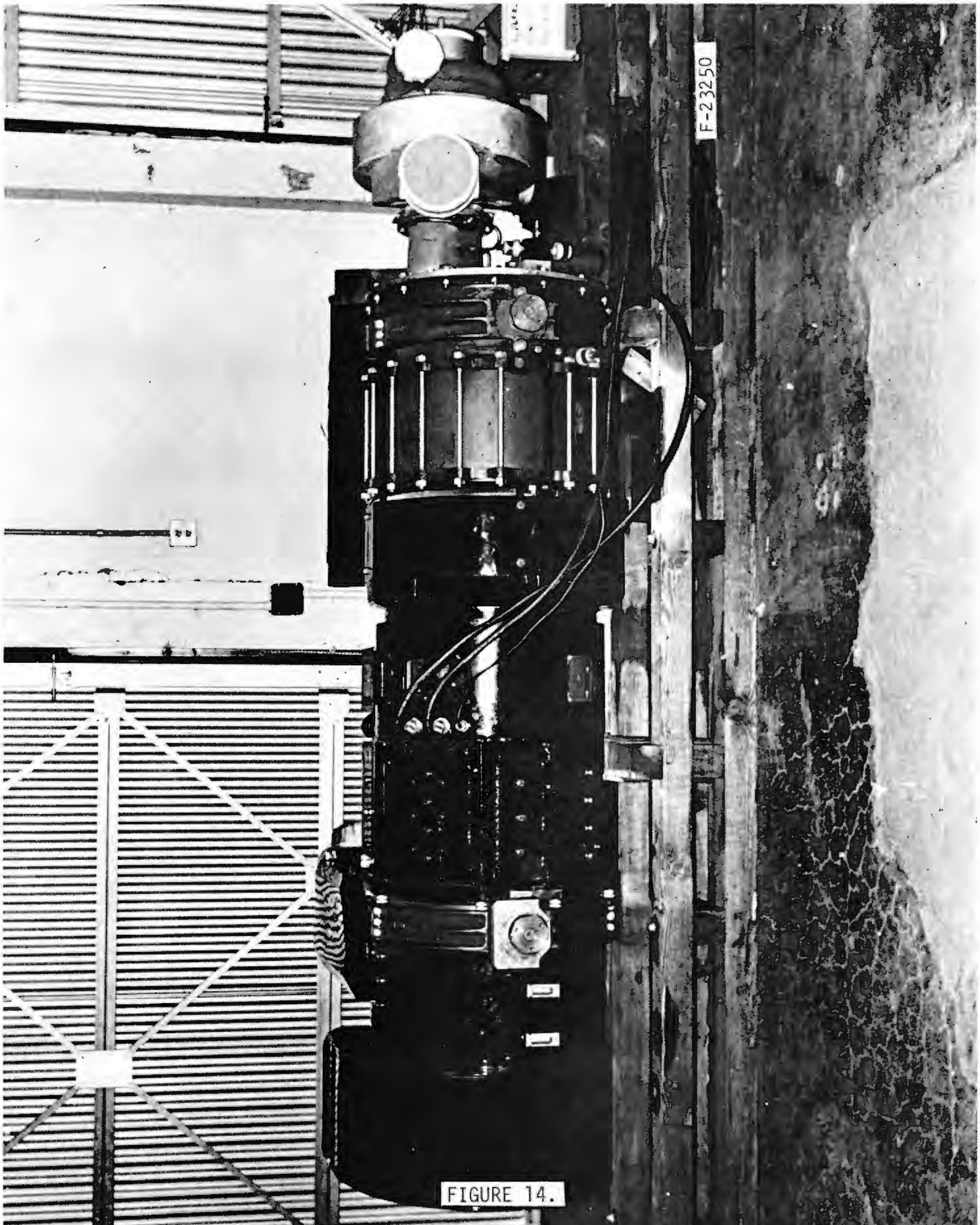


FIGURE 14.

TABLE XI

ENERGY STORAGE UNIT LOSSES TEST

	1974 CDR (EST)*	3/76 ROLL-DOWN	LOSSES TEST 4/76 WET SUMP	LOSSES TEST 4/76 DRY SUMP	7/76 ROLL-DOWN 1ST PROD. UNIT
MOTOR AND ALTERNATOR	10.0 HP	8.9 HP			8.85 HP
COOLING BLOWER	11.3	10.7			11.25
TOTAL	(21.3 HP)*	19.6 HP			20.10 HP
ROTOR WINDAGE	1.5 HP		(3.0)*	(3.0)*	
RING GEAR	1.5		8.0	1.0	
PLANET BEARINGS	0.9		4.0		
ROTOR BEARINGS AND SEALS	2.4		4.0	(7.0)*	9.9 HP
ACCESSORY GEARS AND BEARINGS	0.6		NEG.		
LUBE - VACUUM PUMP	0.8	2.2	2.2	(1.0)*	
TOTAL	(7.7 HP)*	25.0 HP	21.2 HP	12.0 HP	9.9 HP
TOTAL LOSSES	(29.0 HP)*	43.6 HP	40.8 HP	(31.6 HP)*	30.0 HP

( )* ESTIMATED

TEST SETUP FOR LOSSES TESTS

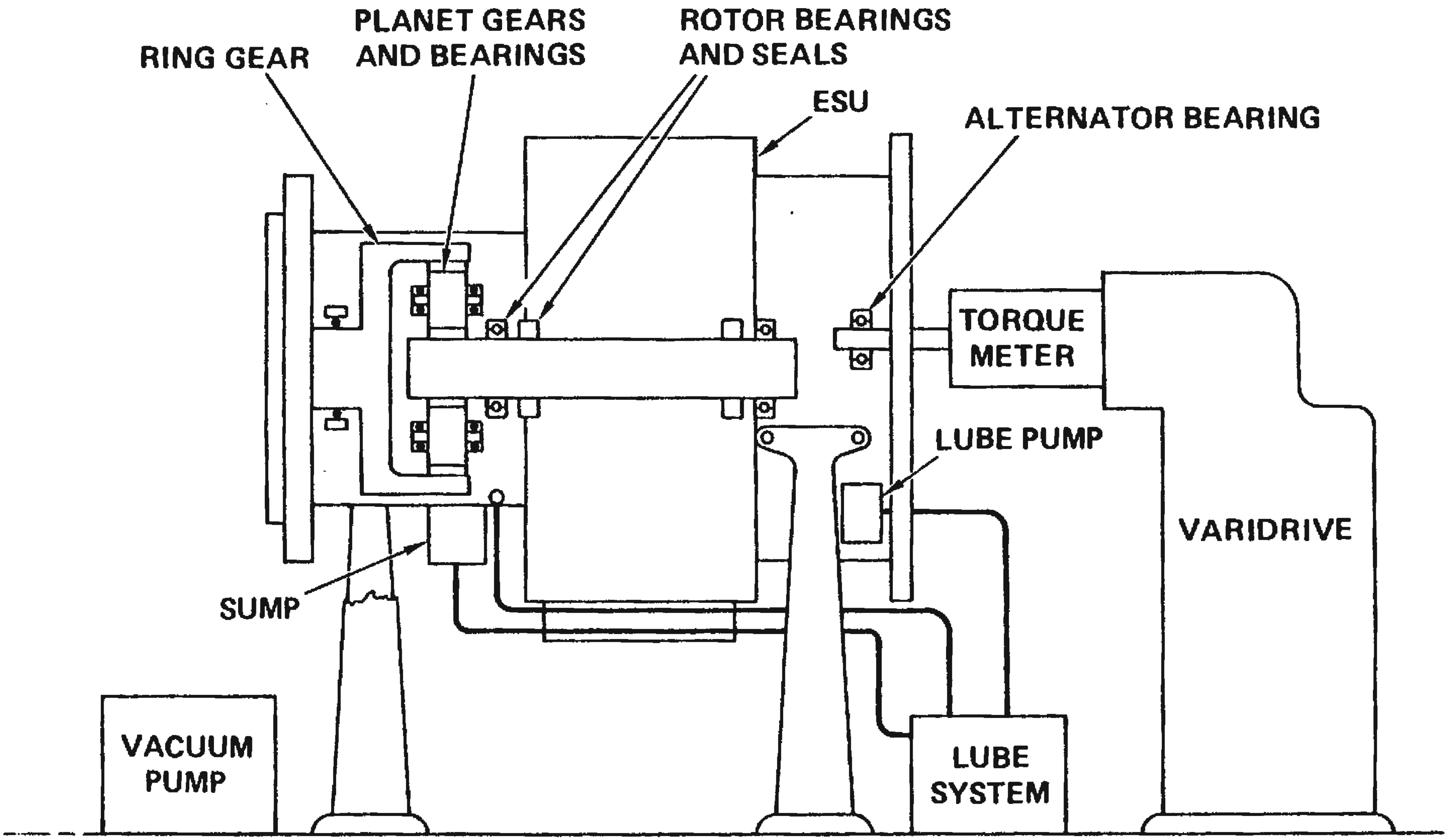


FIGURE 15.

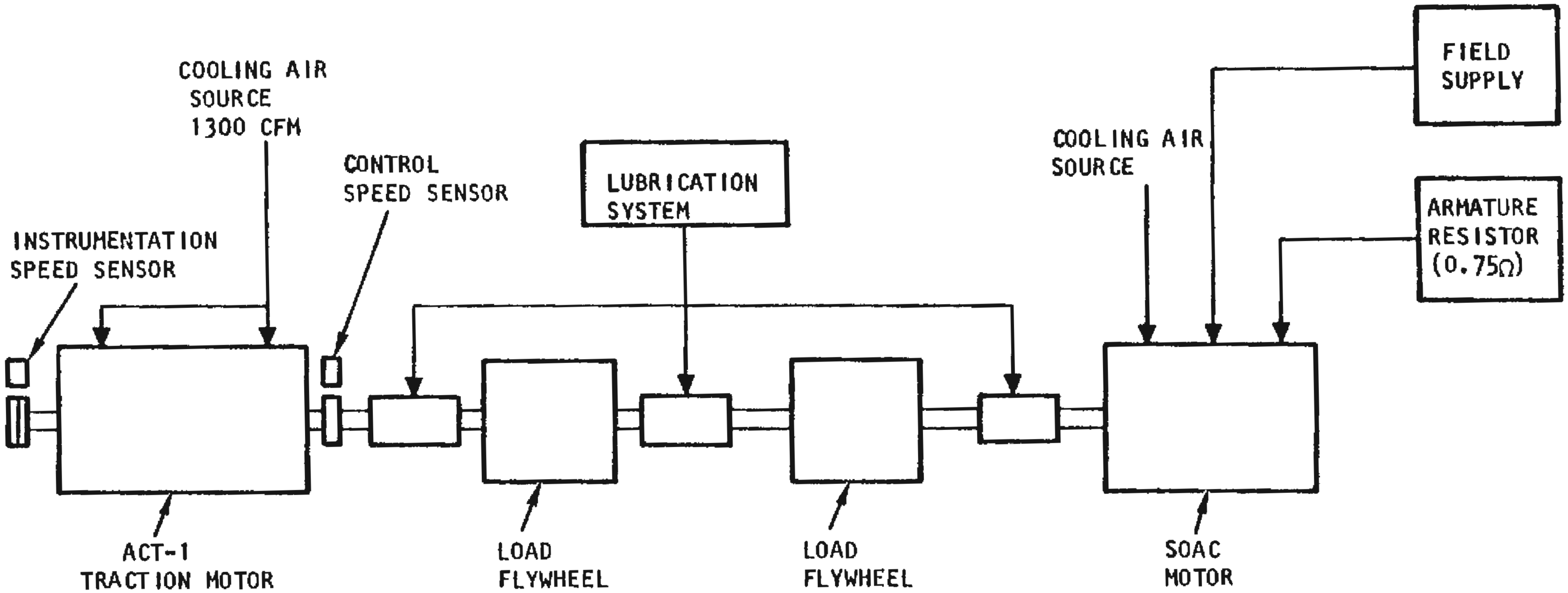


FIGURE 16.

ACT-1 COMBINED SYSTEM LABORATORY
TEST LOAD STAND

The CSLT serves three very important functions in the ACT-1 propulsion system progress: 1) development testing of propulsion and auxiliary power system hardware; 2) acceptance testing of components and subsystems in the system environment; and 3) design substantiation (documented) testing of the propulsion system.

Initial testing of the ESU in the CSLT revealed higher losses in the lubrication system than was predicted, which resulted in a flywheel gearbox loss reduction program as described previously. Development testing in the CSLT was utilized to finalize the design parameters and responses of the alternator, ac distribution panel, low voltage power supply, and to optimize the printed wiring assemblies required for the propulsion system control, the Electronic Control Unit (ECU).

Significant CSLT schedule delays were caused by the ESU losses reduction program and the flywheel and traction motor armature rework programs. However, all development testing was completed in June 1976 with the design finalization of the ECU printed wiring assemblies.

Operation of the CSLT is continuing for design substantiation testing and component acceptance testing. First priority is being given to component acceptance testing in order to maintain the vehicle manufacturing schedule.

Truck System

The ACT-1 truck structure assembly (side frame, motor mounts, axle housings, and suspension adapter) has been undergoing a series of structural tests under various design load conditions to determine the most critical condition for the fatigue load testing and to confirm the overall structural integrity of the design for use on rapid transit properties. The truck test rig is shown in Figure 17. To date, the tests have resulted in the redesign of the motor mounts and the lateral stops. Following static tests, the three-piece aluminum motor mount was redesigned to a two-piece mount with thicker sections in some areas. The frame lateral stop configuration is being modified to incorporate two stops per side rather than one. The static load tests are continuing with the redesigned hardware and the fatigue testing is expected to be completed in the fall of 1976 prior to vehicle testing at the Pueblo test track. Figures 18 and 19 illustrate the ACT-1 truck assembly.

The axle gearbox test assembly has completed the oil level test and the 100 hour endurance test. Examination of the splines, gear teeth, and other carrier assembly components showed no signs of abnormal wear. The three piece input gear coupling assembly exhibited surface distress and heat discoloration due to improper assembly and use of incorrect lubricating oil; however, this was not considered to be grounds for test failure. The test coupling was cleaned and reinstalled for use during the noise test. Following this test, the coupling will be returned to the manufacturer for detailed inspections and a formal report.

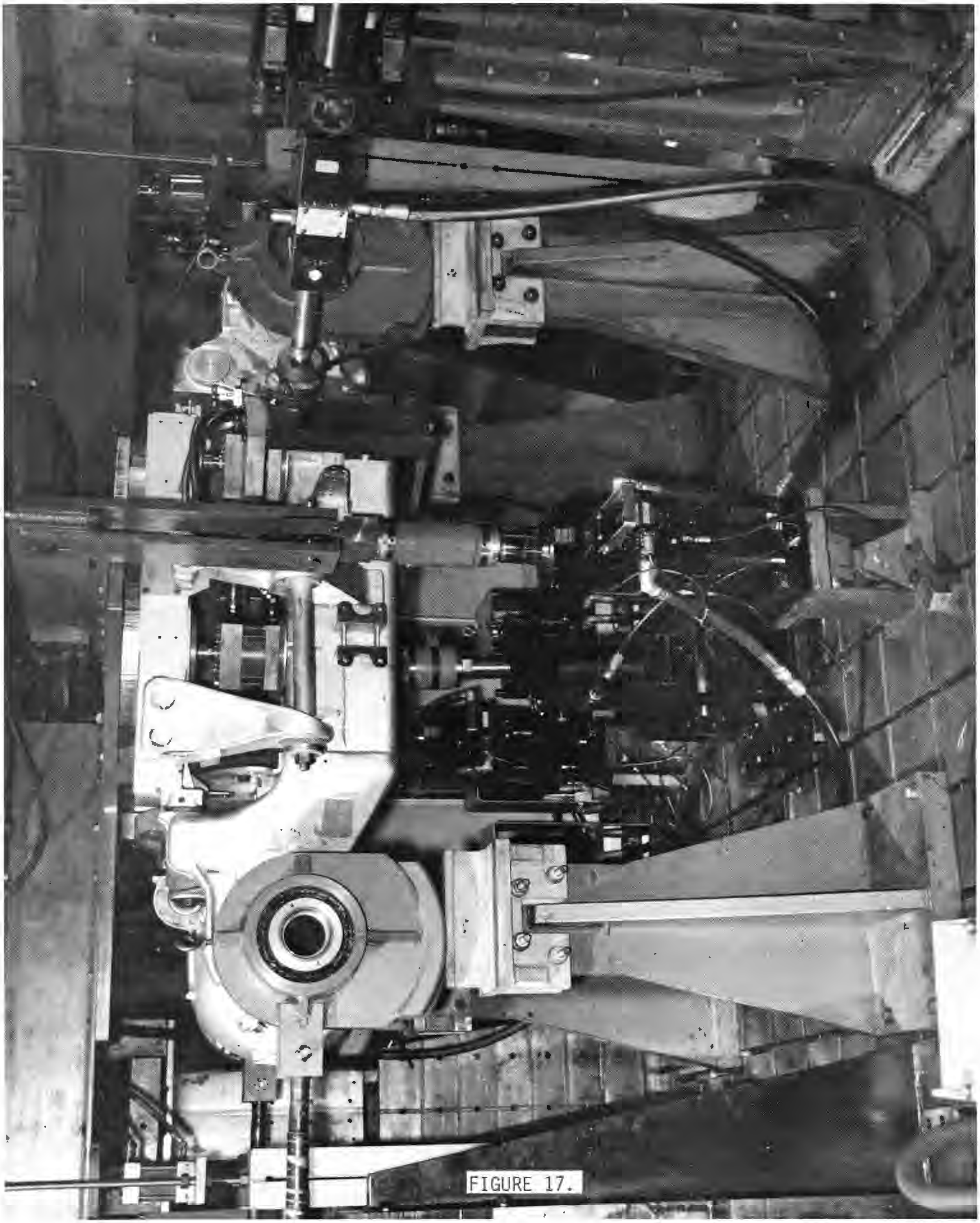


FIGURE 17.

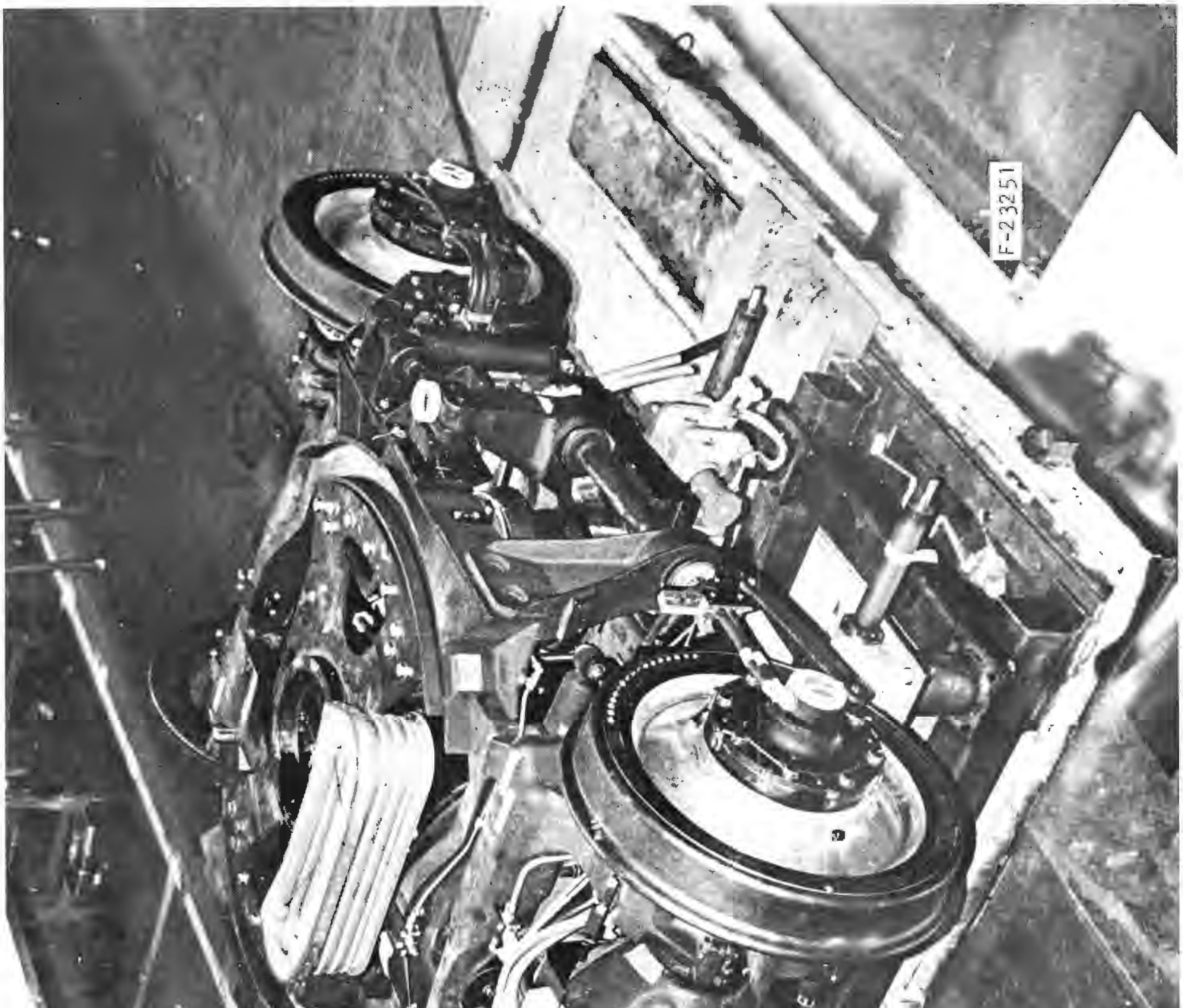


FIGURE 18.

FIGURE 19.

The ACT-1 truck has non-rotating axle housings and a fully enclosed drive train as shown in Figures 18 and 19. The wheels, axle shafts, and brake discs can be removed without wheel pressing. During a component change-out at AiResearch, the maintainability of the ACT-1 truck was clearly demonstrated. Removal of all four wheels, axle shafts, and brake discs from an uninstalled truck required a total of one hour for a three man crew. This maintainability will be further demonstrated during specified tasks to be accomplished at Pueblo.

Friction Brake System

A substantial portion of the friction brake system has completed acceptance and design substantiation testing at various manufacturers' facilities. The air compressor has completed the 1000 hour endurance test at NYAB. The brake disc and caliper (Figures 20 and 21) passed the simulated Pueblo route tests on the Rockwell dynamometer. Following successful completion of the Pueblo duty cycle, the disc and caliper began an extended endurance cycle of stops from 60 mph at AW2. During this testing, temperature limit procedures were not followed correctly and the disc was cracked under extended high temperature use. Detailed inspection of the disc indicated that unlike iron disc cracks, the crack in the copper alloy disc was not catastrophic and the disc material remained ductile. To confirm disc integrity, Rockwell will run a 5000 cycle endurance test using friction braking only. This test is in addition to the successful 100,000 cycle low temperature endurance cycle previously run on the disc and caliper.

A half-car piped layout of the major air brake components was utilized to substantiate the design of the brake system and was used as a test rig for acceptance testing subsystems and components. The half-car piped layout tests are complete except for the parking brake tests, which are awaiting parts from Rockwell. A schematic of the half-car piped layout test installation is shown in Figure 22. System response times indicate general compliance with the specification requirements and goals. Table XII compares preliminary response data with SOAC and ACT-1 specification goals.

Communications & Train Control

The critical design review of the communications system was conducted during August 1975. The design has been finalized and breadboard testing of subsystems were completed during the past year. Test results indicate communication system operation and performance exceeds original expectations. Functional testing of this equipment in the H-D car was completed in October 1976.

The subsystems have been functionally tested and installation in the vehicles was complete by October 1976. The vehicle No. 2 Tape Transport Unit (TTU), Main Audio Unit (MAU), and the Communications Electronic Unit (CEU) will be utilized to continue combined component lab testing prior to installation of these components into the vehicle.

ACT-1 BRAKE DISC AND CALIPER ASSEMBLY

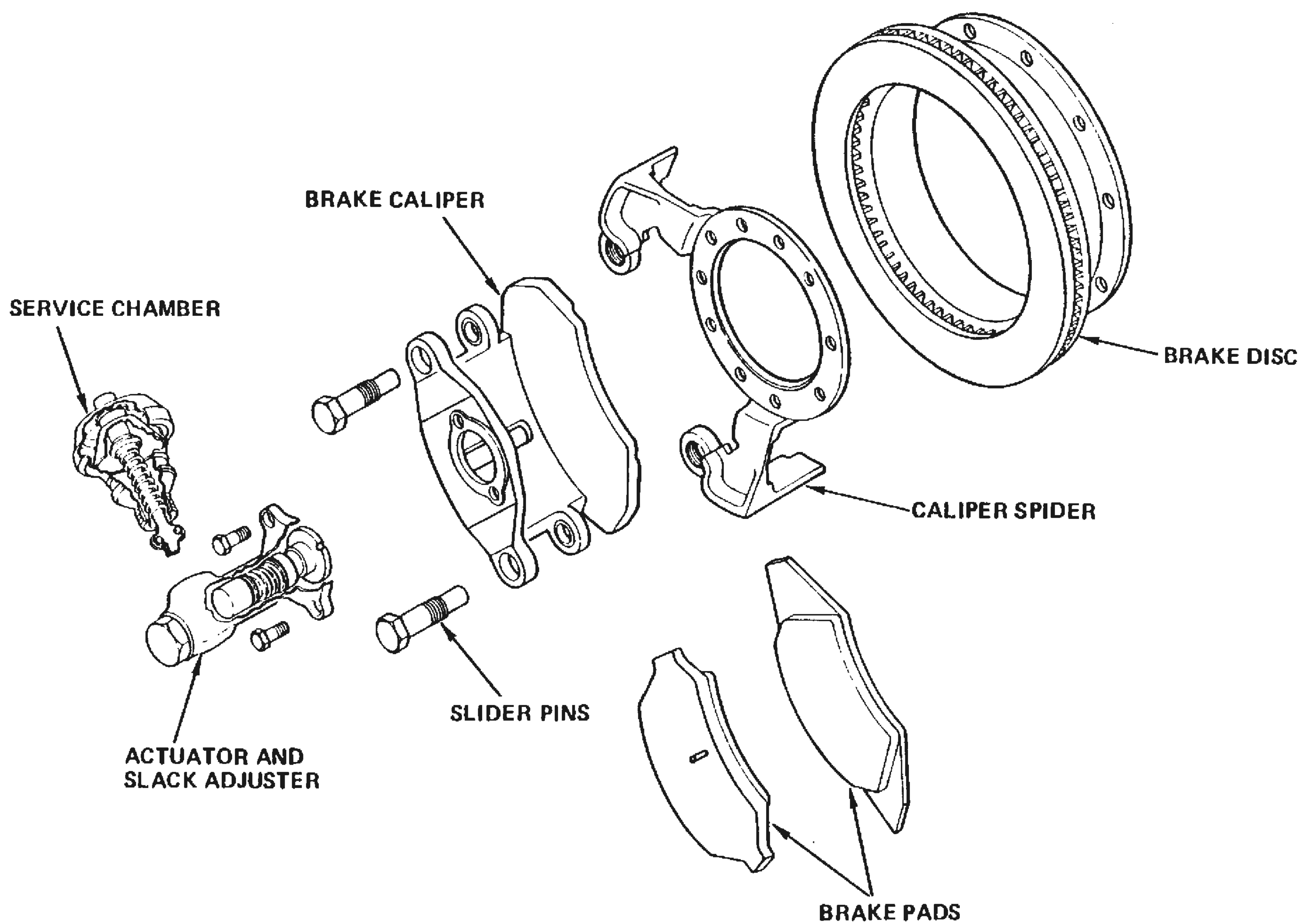


FIGURE 20.

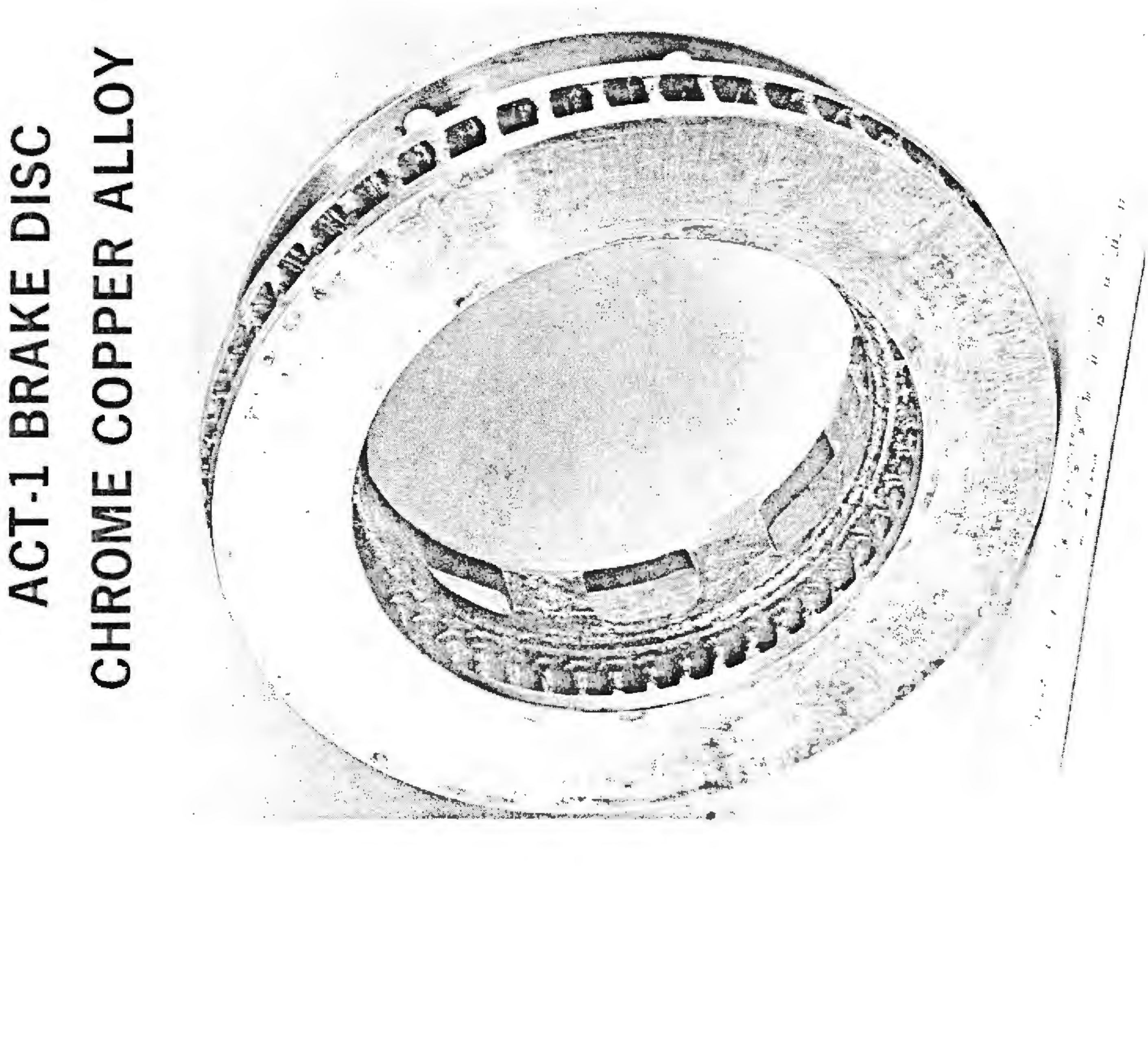
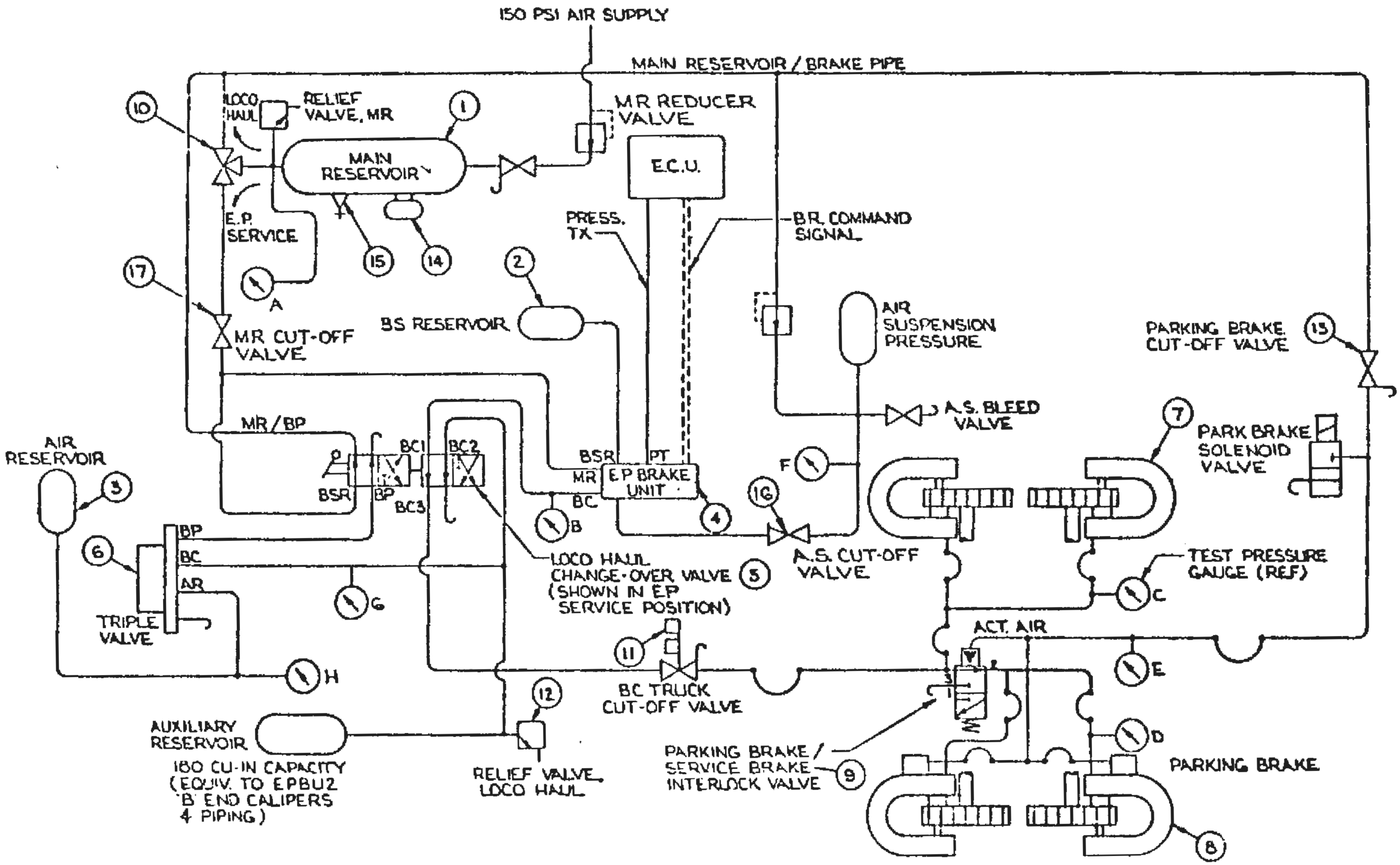


FIGURE 21.



SCHEMATIC OF "HALF-CAR PIPED LAY-OUT" TEST INSTALLATION

FIGURE 22.

The automatic train control equipment is being redesigned to provide overspeed protection safety criteria which is compatible with standard transit practices. AiResearch has been directed to procure an overspeed protection and brake assurance system from General Railway Signal Company (GRS). The design criteria for this system are compatible with existing transit criteria. This system is scheduled to be installed in the cars at Pueblo by May 1977. AiResearch will deliver the cars with GRS cab signal equipment, AiResearch speed regulation equipment, with GRS overspeed equipment added at Pueblo. Boeing Vertol review of control system and brake safety analyses has resulted in several changes in friction brake application equipment. A vital relay is now used to apply friction brakes in the emergency mode and also directly open the traction circuit contactors. Slide-protected emergency braking has been deleted in all but one application mode (dead man) since a review of the slide control logic did not indicate adequate fail safety. Since the SOAC dead man applies normal, blended service braking, the ACT-1 slide-protected emergency feature (dead man) was retained to allow testing of this high-rate (3.5 mphps) brake.

Master controller testing continues at the manufacturer's facility (Adams-Rite). Several failures have occurred during extended cycling and environmental (salt-fog) testing. Each problem has been addressed and the testing is to be repeated until successful. Retrofit to the two vehicle units will follow completion of the testing.

VI. ADVANCED SUBSYSTEM DEVELOPMENT PROGRAM

INTRODUCTION

Background

The objective of the Advanced Subsystem Development Program (ASDP is to develop subsystems based on future reports of the rapid rail operators. Although these systems are beyond the current state-of-the-art, they are being designed and developed to be capable of being incorporated into near-term new car procurement and/or retrofitted into existing rapid rail transit cars.

The program reflects current UMTA program funding limits. Technical as well as industry inputs have been considered in selecting the subsystems to be developed. The current plans for the ASDP reflect developments in two separate areas, as follows:

Part 1 - SOAC Integration

This part of the program involves those subsystem candidates which require extensive testing and developmental evaluation. These candidates have, therefore, been assigned to the State-Of-the-Art Car (SOAC) for incorporation, evaluation, and demonstration. After initial development at their respective vendors' plants, these subsystems will be forwarded to Boeing for integration into the SOAC.

Using the SOAC engineering and demonstration data base, the SOAC with the advanced subsystems installed will perform engineering tests at the U.S. DOT-TTC followed by a five-city demonstration and evaluation. This new data base can then be directly compared to the initial SOAC program. The subsystems to be so evaluated and their selected vendors are:

Subsystem	Vendor
Self-synchronous propulsion system	Delco Electronics GM Corp., Santa Barbara Operations Goleta, Calif. 93017
Improved ride quality monomotor truck	The Budd Company Technical Center Fort Washington, Pa. 19034
Synchronous brake system	Westinghouse Air Brake Co. Westinghouse Air Brake Div. Pittsburgh, Pa. 15148

Subsystem Specifications - SOAC Integration

These specifications comprise the detail requirements for the design, construction, and testing of each subsystem to be evaluated for rapid rail transit application. The evaluation of these systems will be accomplished by using the SOAC as a prototype test and demonstration vehicle. Data requirements are also included in these specifications. The following are brief description of each of the subsystems to be installed and evaluated on the SOAC.

Subsystem	UMTA Specification	Boeing Document
Self-synchronous propulsion	IT-06-0026-75-1	D239-10000-1
Improved ride quality monomotor truck	IT-06-0026-75-2	D239-10001-1
Synchronous brake	IT-06-0026-75-3	D239-10002-1

The incorporation of these subsystems into the SOAC will be documented by a "Modified SOAC Specification".

Self-Synchronous Propulsion System

The self-synchronous propulsion system is an improved electrical propulsion system for rapid transit car application.

This system has the desirable high starting torque of the dc series motor, but uses brushless, liquid-cooled, low weight traction motors and a solid-state control system. The system has the capability of power regeneration during the braking cycle. These system features are expected to provide transit authorities with a significant improvement in operating and maintenance benefits. An ASDP Monitor Panel is also provided.

Improved Ride Quality Monomotor Truck

The truck assembly shall be of twin-axle design, configured to accept the Delco monomotor, right-angle drive propulsion system. Truck assembly overall dimensions are:

Track gauge	56 1/2 inches
Wheel gauge	56 1/4 inches
Truck wheel base	90 inches (maximum)
Wheel diameter	30 inches
Overall length	124 inches (maximum)
Overall width	82 inches (maximum)

Ride quality vibration characteristics are to be similar to the ACT-1 goals.

Synchronous Brake System

This friction braking system shows an increase in efficiency over the conventional friction brake systems of today and results in a more precise braking control. The braking distances are maintained regardless of track conditions through the intelligence of a synchronous brake valve. This is accomplished by detecting the rate of change of wheel speed and applying corrective action to prevent wheel slides. An air/oil actuation system using two split discs per axle assembly will form the basic braking assembly.

Part 2 - Transit Authority Participation

This part of the program involves subsystems selected for transit authority participation which are best evaluated on a particular transit authority property. Evaluation during the initial test period will enable the transit property's engineering and operations personnel to assess the benefits of each subsystem. The revenue service demonstration will expose these subsystems to the riders and provide an evaluation from the passenger's viewpoint. Discussions with the transit authorities resulted in the following interest:

Multiplex trainline signals
Auxiliary electric power, static type
Pulse width modulated AC propulsion system
Improved door installation
Steerable self truck
Improved materials
Air conditioning, modular type

Subsystem Specifications - Transit Authority Participation

Specifications will establish the design, function and test requirements for several subsystems to be installed on an assigned transit authority rapid transit car for test and evaluation. The evaluation will take place on specific transit properties that have agreed to provide support and test bed equipment. Boeing will act as the systems manager for these subsystems developments.

Implementation

Part 1 - SOAC Integration

Boeing Vertol was directed by UMTA in October 1975 to implement Part 1 of the Advanced Subsystem Development Program (ASDP). Approval was granted by UMTA for Boeing Vertol as Systems Manager to contract with Delco Electronics for the Self Synchronous Propulsion System, with The Budd Company for the Improved Ride Quality Monomotor Truck, and with Westinghouse Air Brake Company for the Synchronous Brake System. Boeing Vertol is to serve as the contractor for the incorporation of these ASDP subsystems into the SOAC.

Part 2 - Transit Authority Participation

Boeing Vertol was directed by UMTA in October 1975 to postpone implementation of Part 2 of the Advanced Subsystem Development Program (ASDP) until UMTA authorized a "go-ahead".

STATUS OF PROGRAM

Program Management Activities

The program management techniques being used to direct and control the implementation of the Advanced Subsystem Development Program (ASDP), Part 1 - SOAC integration include the following endeavors.

Directive Documentation

The plan for the development, design, testing and evaluation of the ASDP Subsystems which will be installed into the SOAC and the SOAC modifications required to accomplish this effort is defined by UMTA Specification No. UMTA-IT-06-0026-76-2, Advanced Subsystem Development Program (ASDP) Program Implementation Plan (Boeing Document No. D239-10010-1).

The plan for the incorporation of the ASDP Subsystems into the SOAC in a timely, compatible manner is defined by UMTA Specification No. "UMTA-IT-06-0026-76-1", Advanced Subsystem Development Program (ASDP) Vehicle Integration Plan (Boeing Document No. D239-10007-1).

Key Event Schedule

The schedule of Key Events, which describes the major milestones in the implementing of the Advanced Subsystem Development Program (ASDP) Part I - SOAC Integration, is shown in Figure 23. The scope of this schedule encompasses the activities from "go-ahead" through disposition of U. S. Government Property after completion of the 5-cities demonstration and evaluation activity.

Significant Meetings Held

Date	Place	Purpose
07/09/75	Boeing Vertol Phila., Pa.	Discuss Synchronous Brake
09/17/75	Boeing Vertol Phila., Pa.	WABCO Brake Proposal Review
09/23/75	Boeing Vertol Phila., Pa.	ABEX Brake Proposal Review
09/24/75	DOT/UMTA Wash., D. C.	ASDP Proposal Discussion
09/26/75	Boeing Vertol Phila., Pa.	ASDP Propulsion System Review
10/14/75	Boeing Vertol Phila., Pa.	Budd Co. Review of ASDP Work Statement
11/13/75	DOT/UMTA Wash., D. C.	ASDP Brake Evaluation
11/18/75 11/19/75	Boeing Vertol Phila., Pa.	ASDP Kickoff Meeting Provide Delco and Budd Co. with current program information
12/09/75 12/10/75	Delco Electronics Goleta, Calif.	Program Review
12/17/75	WABCO Pittsburgh, Pa.	Technical Interface and Review of SOW and Spec.
12/16/75	Budd Co. Ft. Wash., Pa.	Discuss Interfaces, Specification and SOW
*01/07/76	Boeing Vertol Phila., Pa.	Negotiate Purchase Order
01/09/76	DOT/UMTA Wash., D. C.	ASDP Contract Negotiation
01/12/76	Velbert Co. Dusseldorff Germany	Review Gearbox Coupling Proposal with Velbert Mfg.

Date	Place	Purpose
01/14/76	BBC Zurich Germany	Review BBC Coupling Proposal
01/15/76	Hurth Co. Munich, Germany	Review Hurth's Gearbox Coupling Proposal
01/20/76	Delco Products	Delco Products Design Review of ASDP Motor
01/21/76	Rockwell Corp. Troy, Mich.	Review Rockwell's Gearbox Coupling Proposal
01/22/76	WABCO Pittsburgh, Pa.	Kick-off Meeting for ASDP
02/04/76	Budd Company Ft. Wash., Pa.	Monitor Truck PDR
02/05/76	Delco Products	Monomotor Design PDR
02/11/76 02/12/76	Delco Electronics Goleta, Calif.	Propulsion System PDR
02/26/76	Budd Company Ft. Wash., Pa.	Specification Change Review
03/02/76	Budd Company Ft. Wash., Pa.	Axle Bearing Review
03/05/76	Budd Company Ft. Wash., Pa.	Review Specification Changes
03/11/76	Boeing Vertol Phila., Pa.	Equipment Review
	SEPTA Phila., Pa.	Maintenance Review
	PATCO Lindenwold, N. J.	SOAC Review
03/17/76	Budd Company Ft. Wash., Pa.	Interface and Drawing Review
03/22/76	Boeing Vertol Phila., Pa.	Review SOAC
	PATCO Lindenwold, N. J.	Undercar & Cab Structure

Date	Place	Purpose
03/30/76	Budd Company Ft. Wash., Pa.	Review Structural Design Criteria
04/01/76	WABCO Wilmerding, Pa.	PDR - Disc, Hub and Truck Interfaces
04/06/76	Budd Company Ft. Wash., Pa.	Ride Quality & Truck Dynamic Analyses
04/23/76	WABCO Wilmerding, Pa.	Program Review PDR - Disc Brake
04/27/76	Delco Electronics Goleta, Calif.	Train Control Systems Review
05/04/76	Delco Electronics Goleta, Calif.	Program Review & PDR on Cooling System
05/12/76	WABCO Wilmerding, Pa.	PDR - Slip/Slide, Pneumatic Controls
05/25/76	Budd Company Ft. Wash., Pa.	Truck Stress Analysis & Testing
06/02/76	Delco Electronics Goleta, Calif.	CDR of the Propulsion Systems
06/08/76	BBC Zurich, Switz.	CDR of Axle Coupling
06/09/76	Velbert Velbert, Germany	CDR of Gearbox
06/10/76	Budd Company Ft. Wash., Pa.	CDR on Truck
07/07/76 07/08/76	WABCO Wilmerding, Pa.	CDR on Disc Brake, Parking Brake, and Pneumatic Control
07/09/76	Budd Company Ft. Wash., Pa.	Ride Analysis Review
07/14/76	Budd Company Ft. Wash., Pa.	Technical Status Review and Program Review
07/21/76	Delco Electronics Goleta, Calif.	Program Review and CDR on Train Control Systems
08/25/76	Budd Company Ft. Wash., Pa.	Technical Status Review and Program Review

Date	Place	Purpose
09/08/76	Delco Products Dayton, Ohio	Review Technical Status
09/09/76	WABCO Wilmerding, Pa.	Program Review and CDR - Electronics
09/28/76	BART San Francisco, CA	Review BART Disc Brake Experience
09/29/76	Delco Electronics Goleta, Calif.	Technical Status Review and Program Review

ASDP PROGRAM SCHEDULE - SOAC INTEGRATION

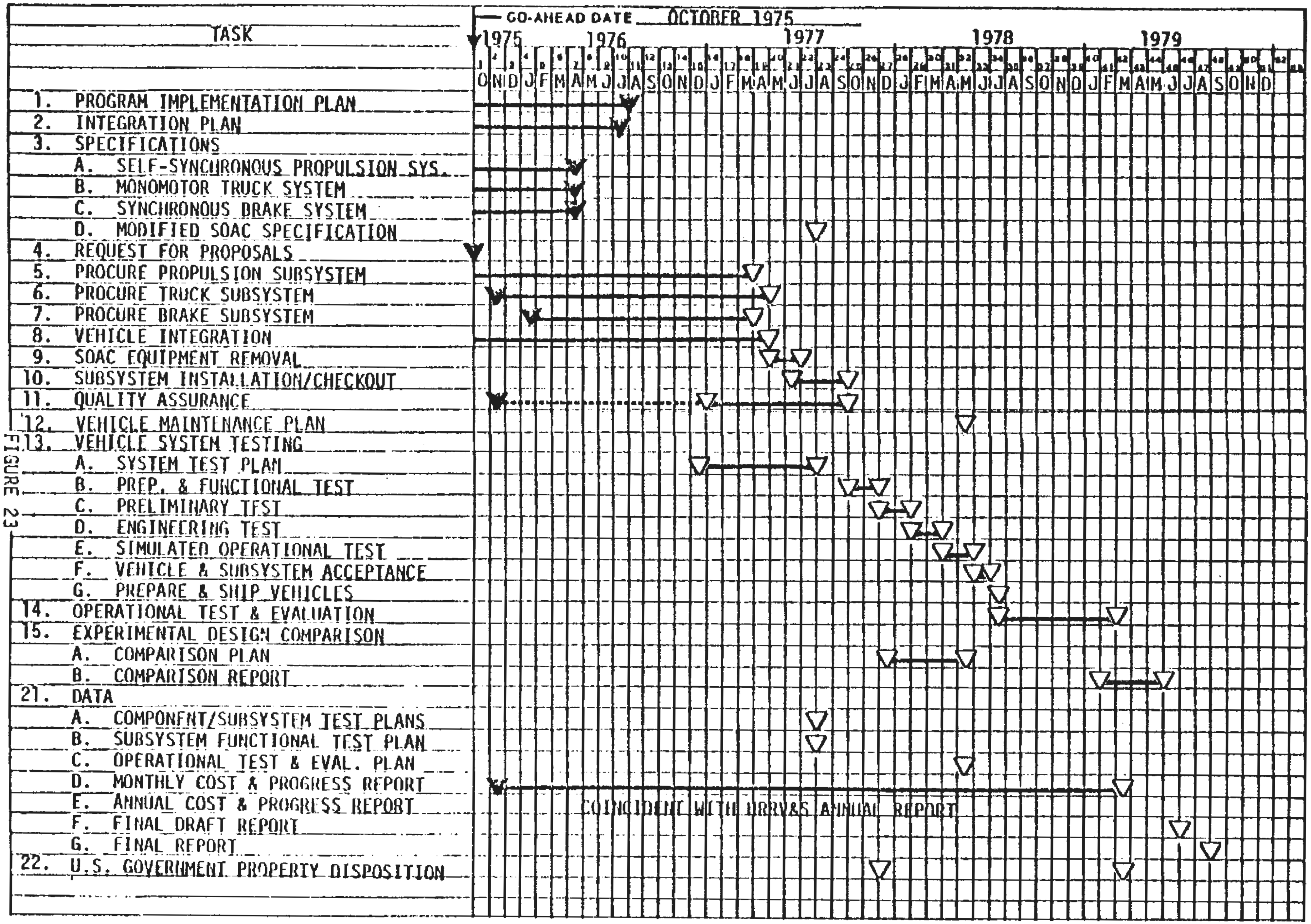


FIGURE 23

Program Hardware Design Accomplishments

Self-Synchronous Propulsion System

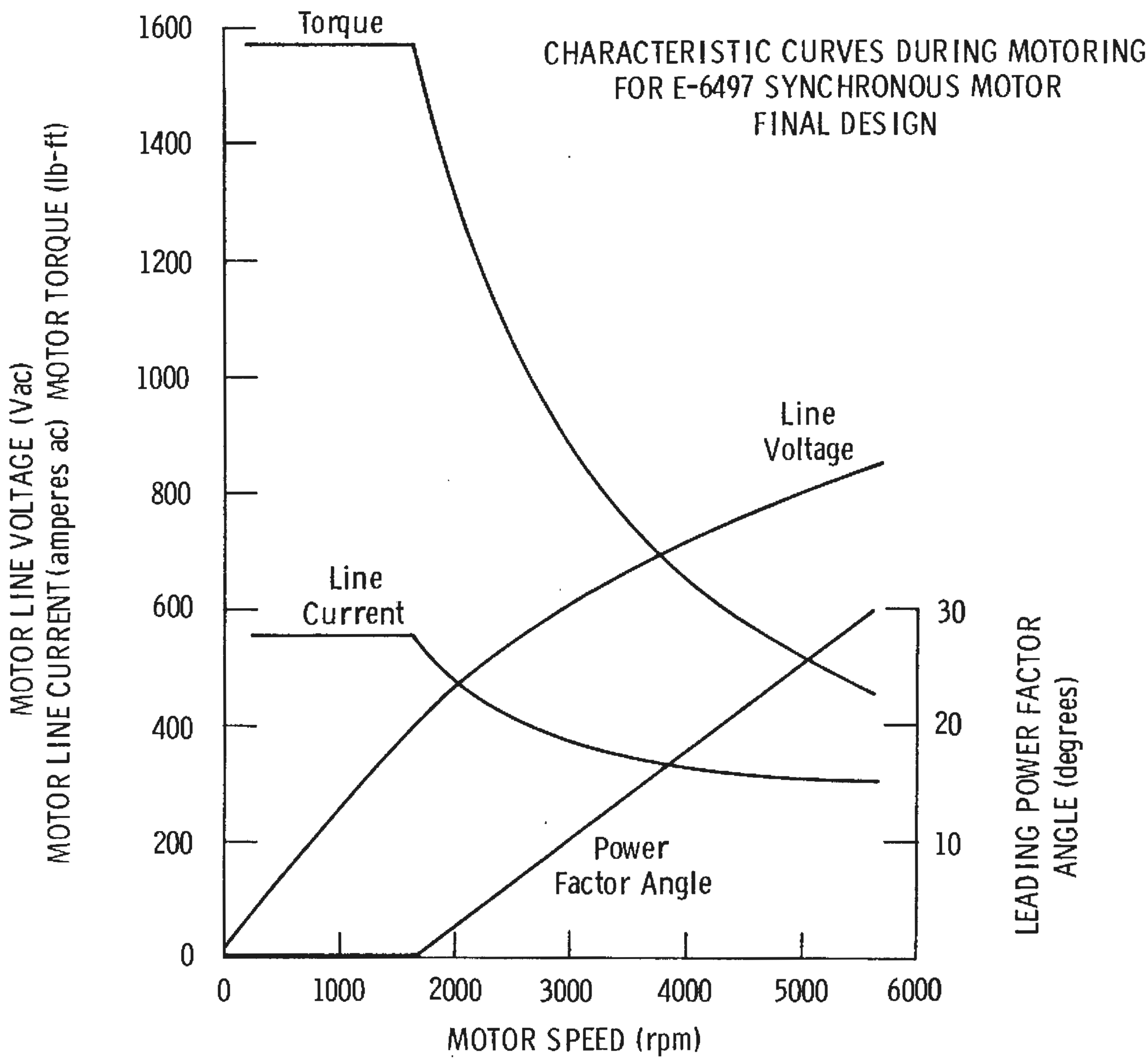
Technical Description

The Delco propulsion system represents a departure from convention in both the motor and the controller. The motor is a wound rotor synchronous machine, made brushless by means of a rotary transformer/rectifier, Figure 28, and made self-synchronous by the addition of a rotor position sensor. Rotary transformer excitation is derived from a current transformer which results in dc field current proportional to armature current, as in a series dc traction motor Figure II. The solid-state power converter developed to provide controlled armature current at the synchronous frequency as well as excitation for the rotary transformer/rectifier field supply is matched to the requirements of the synchronous machine.

A unique feature of the Delco propulsion system is the liquid cooling, using a nonflammable coolant, for the motor and the power electronics. Liquid cooling results in significantly reduced motor size and weight and permits a completely closed system with a clean thermally controlled environment for increased reliability and reduced maintenance. The synchronous machine, operating as an alternator with separate field control, has excellent regenerative and/or dynamic braking characteristics capable of developing full braking power at high speed and resulting in high energy recuperation and reduced mechanical brake wear Figure 25. The provision of separate power converters for each monomotor truck results in a completely redundant propulsion system, significantly increasing reliability. Details of design and operation are as follows:

Functional Operation - The Delco self-synchronous propulsion system shown in the block diagram (Figure 26 consists of a resonant sine wave inverter, a cycloconverter, and a self-controlled synchronous machine). Three-phase power at 300 to 1200 Hz is generated by the inverter and coupled to the cycloconverter via coupling capacitors and a current transformer. Inverter frequency determines the current through the capacitor, and hence the motor armature current. A fraction of this current is diverted by the current transformer to the field supply, thus providing series dc motor characteristics. This type of power converter was chosen over conventional inverter approaches because of its natural current source characteristic, simple means of series field excitation, low current, and simple control circuitry.

Major Components/Assembly - The self-synchronous propulsion system equipment will be incorporated into the SOAC car as shown in the undercar layout (Figure 27). The major assemblies are as follows:



CHARACTERISTIC CURVES DURING MOTORING
FOR E-6497 SYNCHRONOUS MOTOR
FINAL DESIGN
Torque
Line Voltage
Line Current
Power Factor Angle
MOTOR LINE VOLTAGE (Vac)
MOTOR LINE CURRENT (amperes ac) MOTOR TORQUE (lb-ft)
LEADING POWER FACTOR ANGLE (degrees)
MOTOR SPEED (rpm)
0
200
400
600
800
1000
1200
1400
1600
1000
2000
3000
4000
5000
6000
10
20
30

FIGURE 24

CHARACTERISTIC CURVES DURING BRAKING FOR E-6497 SYNCHRONOUS MOTOR

FINAL DESIGN

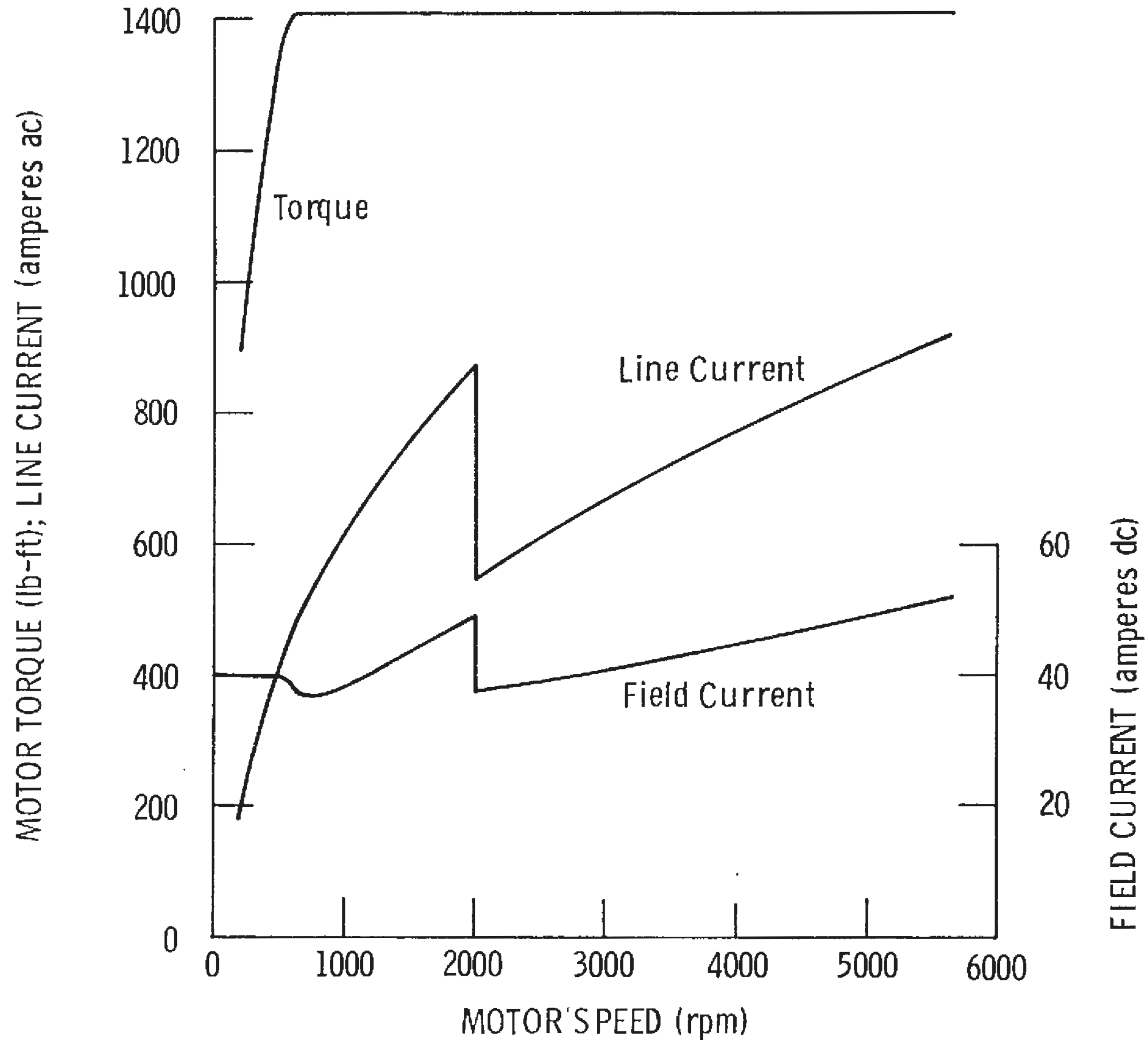
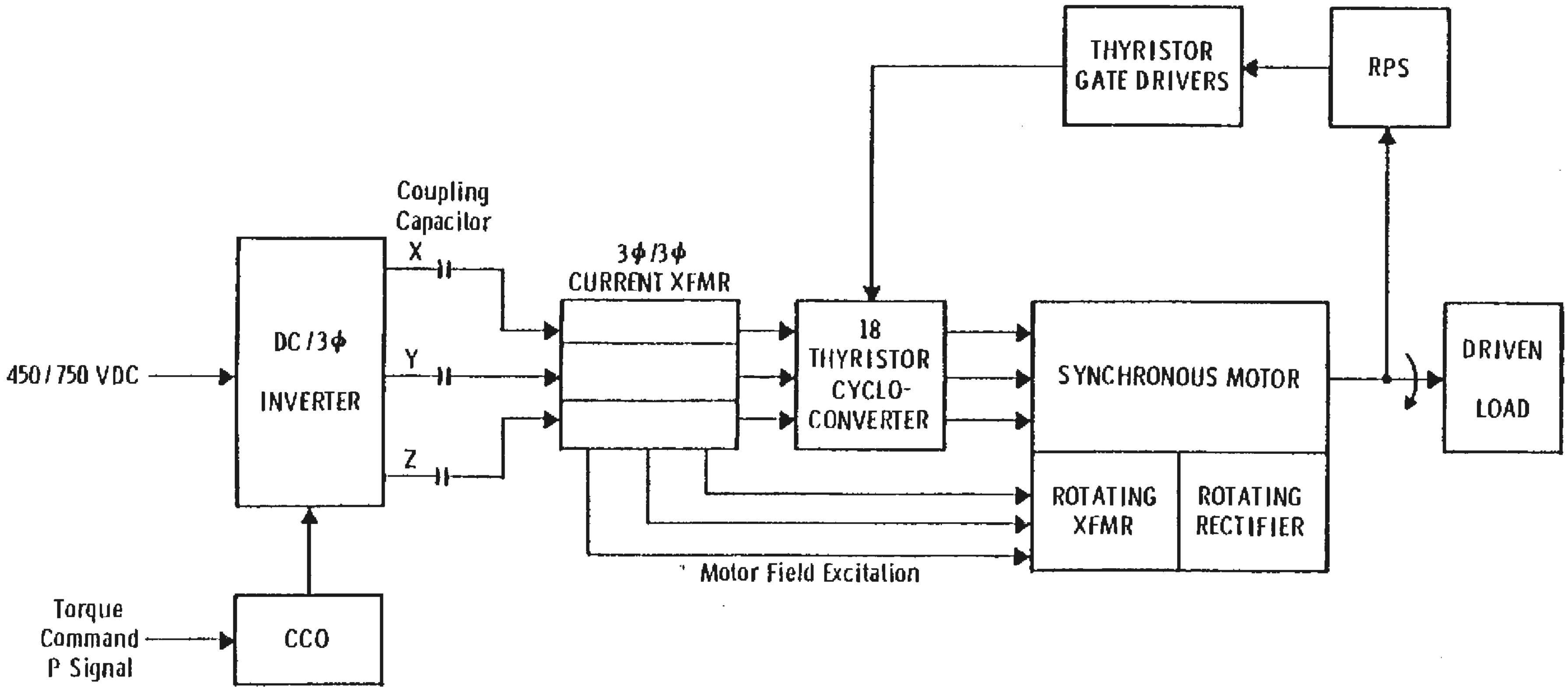


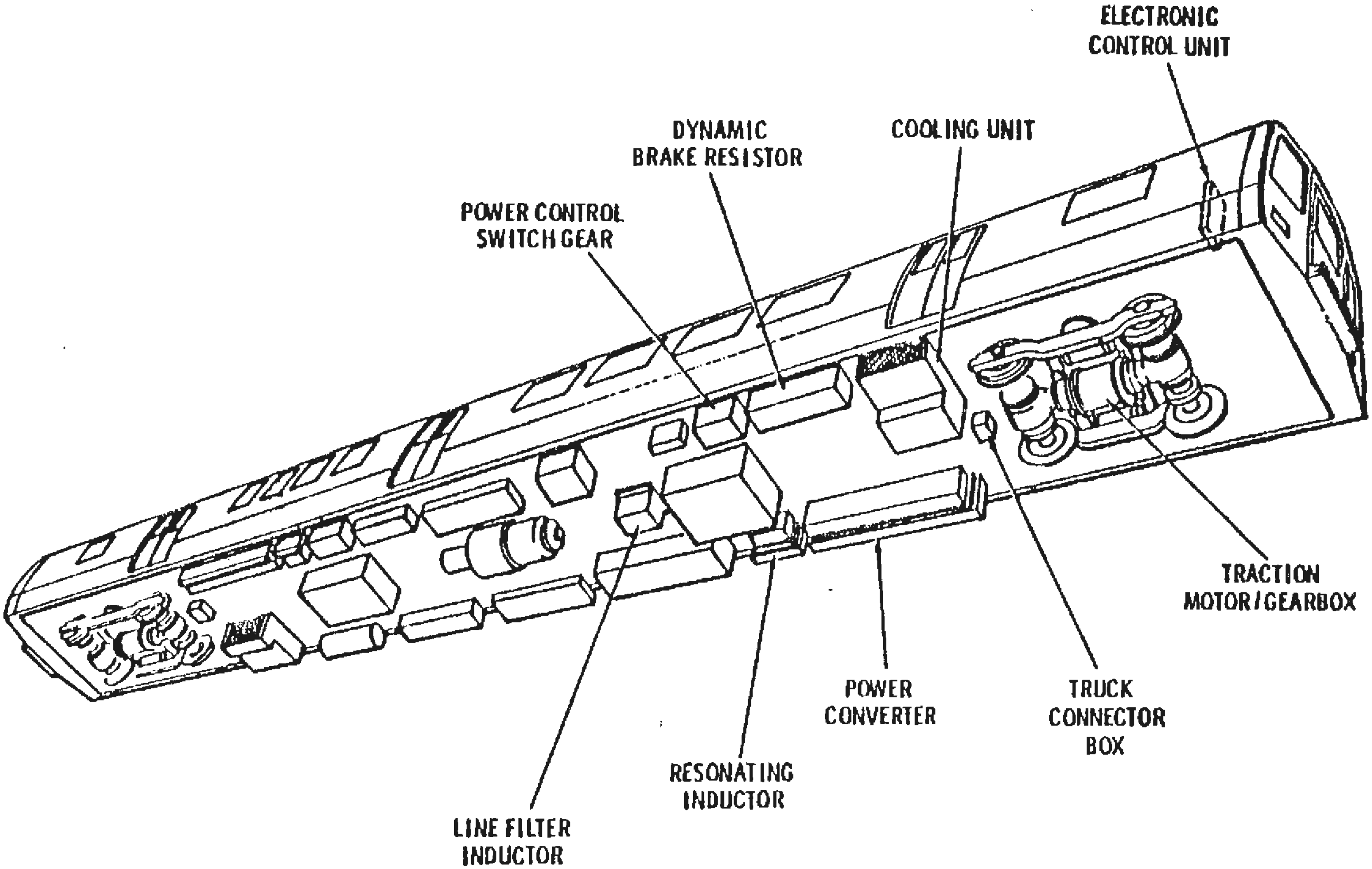
FIGURE 25

FIGURE 26



ASDP: SELF-SYNCHRONOUS MOTOR PROPULSION SYSTEM

FIGURE 27



PROPULSION EQUIPMENT LOCATION

	Number of Units
Truck Connector Box	2
Electronic Control Equipment	1
Power Control Switchgear	2
Line Filter Inductor	2
Power Converter	2
Traction Motor	2
Gear Drive and Coupling	4
Cooling System	2
Dynamic Brake Resistor	2
Resonating Inductor Module	2
ASDP Monitor Panel	1

The propulsion and controls contractor is Delco Electronics: the traction motors supplied by Delco Products, and the gearbox and axle couplings supplied by Brown-Boveri. The electrical interconnections are shown in Figure 28.

Traction Drive Assembly - The traction drive assembly consisting of a traction motor, two gear drives, and two couplings is based on a monomotor truck design. The advantages of the monomotor truck design include: a) improved ride dynamics due to reduced motor weight and lower mass moment of inertia; b) reduced system complexity, maintenance, and cost; c) better traction due to elimination of slip/slide within each truck.

The traction motor has a double-shaft output for driving the two axles. Each axle is driven by a single reduction bevel gear designed for bi-directional service. The output of the gear drive is connected to the truck axle through a flexible coupling, allowing adequate axle movement for the primary suspension. (See Fig.29).

Traction Motor Design - The traction motor (Figure 30 is a liquid-cooled self-synchronous machine designed to produce 300 hp continuously and 450 hp intermittently, with a maximum speed of 6000 rpm. The term "self-synchronous" describes a synchronous ac machine which, by means of a rotor position indicator and a solid state power converter, performs as a brushless dc motor. The motor consists of: a) a four-pole, salient pole synchronous machine with stationary armature and rotating field; b) a three-phase rotating transformer and rectifier to provide dc field excitation; c) a rotor position sensor to provide signals to control the switching of the cycloconverter thyristors.

Electrical Equipment Packaging - Electrical components are packaged in replaceable subassemblies (modules) according to the function they perform. This modular design principle employs slide-out modules and quick-disconnect electrical and cooling fluid connections, and will allow easy maintenance and replacement at the subassembly level. The power converter assembly (shown in Figure 31 contains all the electrical power circuits and components necessary to control the traction drive for one truck. It consists of a light-weight frame assembly, six slide-out modules, and interconnecting cabling and fluid lines. The assembly is mounted to the car underframe through rubber shockmounts.

PROPULSION SYSTEM EQUIPMENT DIAGRAM

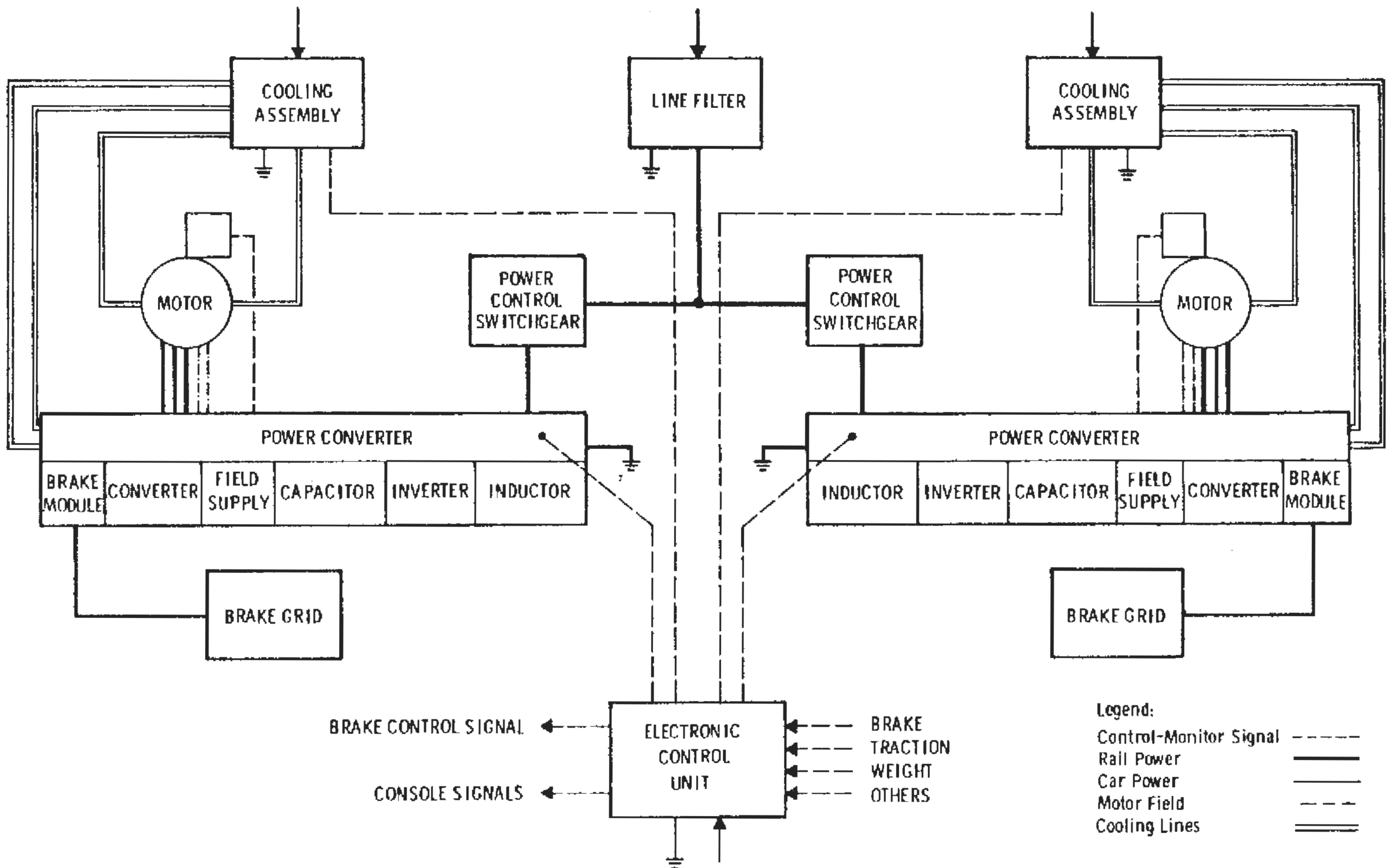


FIGURE 28

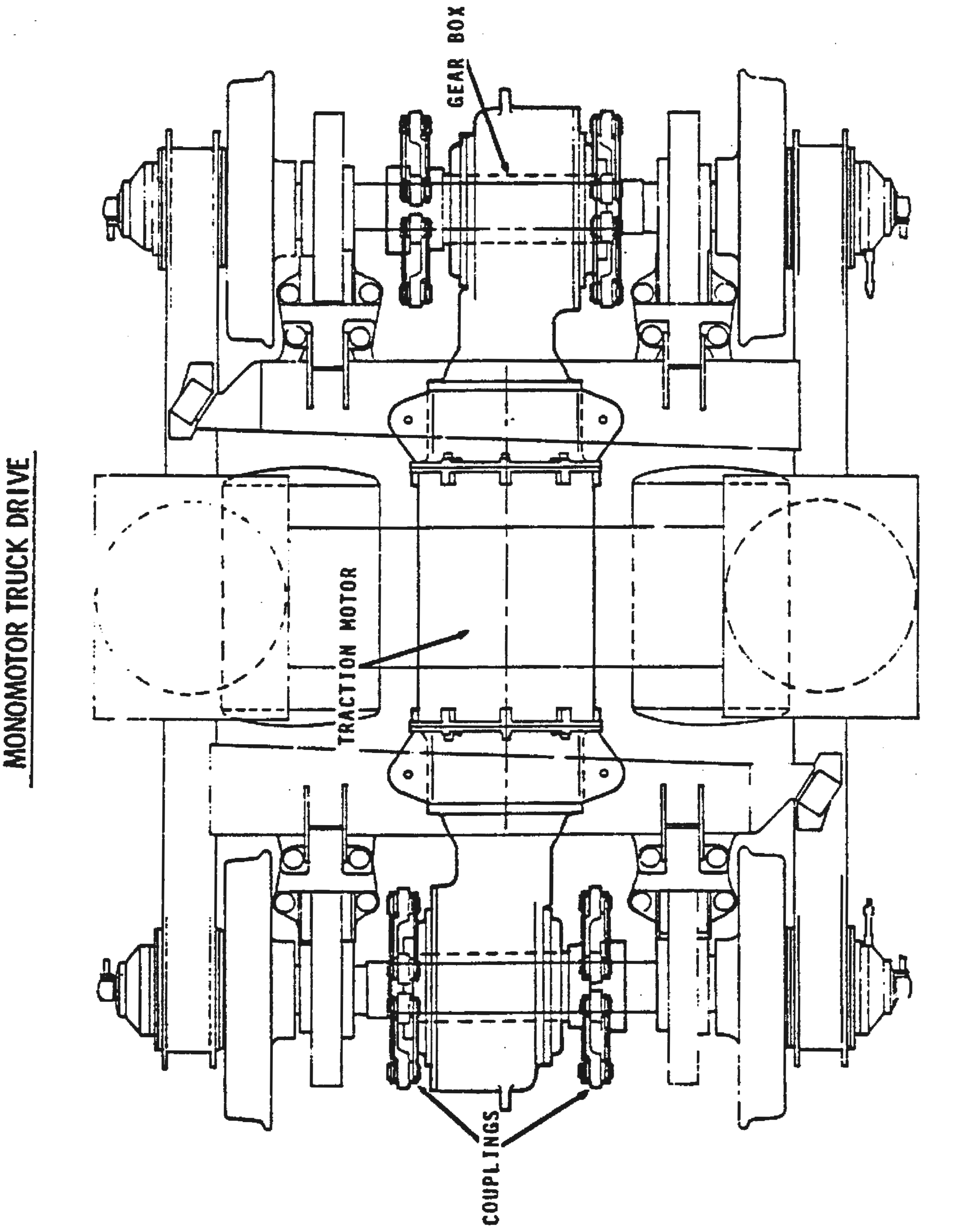


FIGURE 29

TRACTION MOTOR

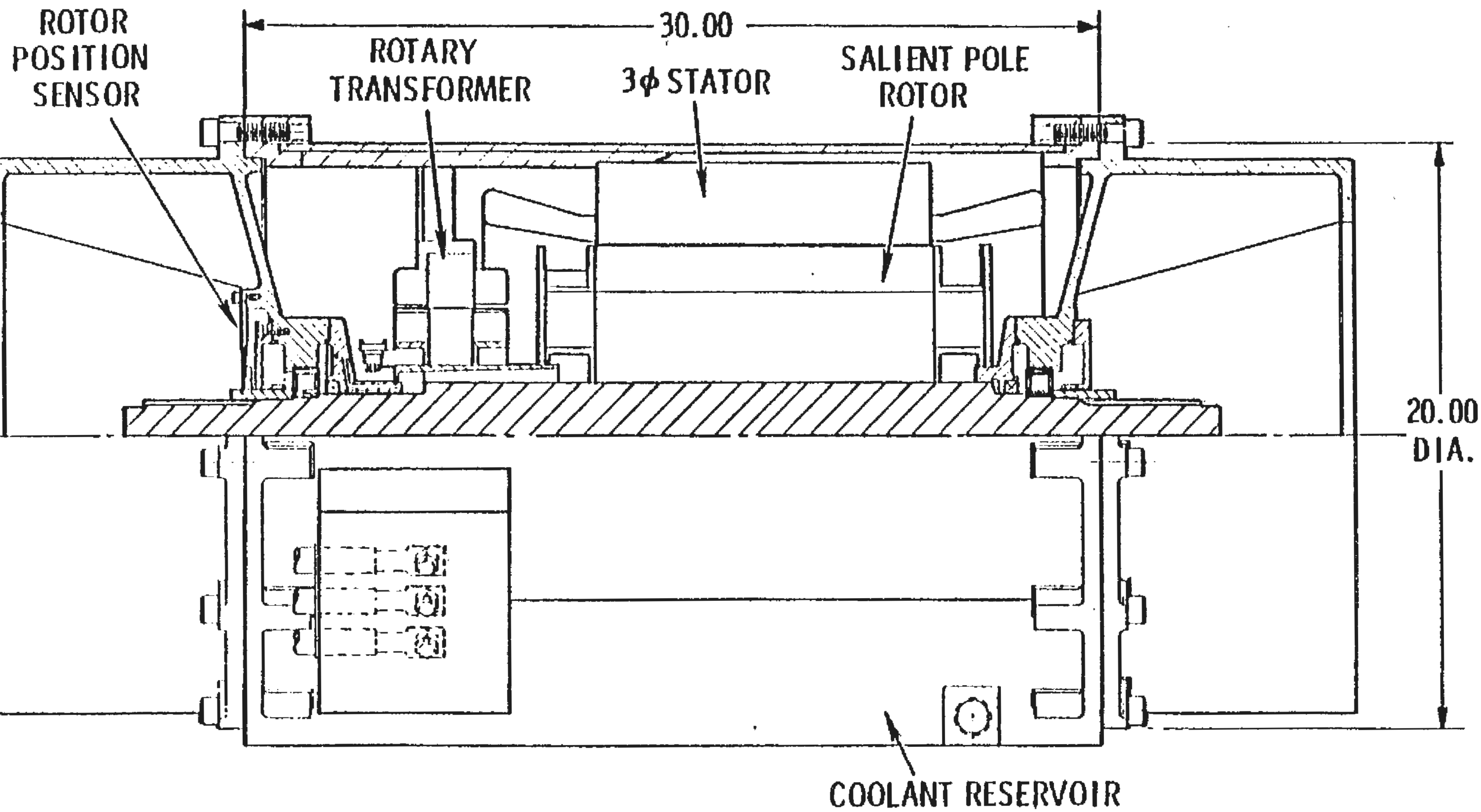


FIGURE 30

POWER CONVERTER ASSEMBLY PACKAGING

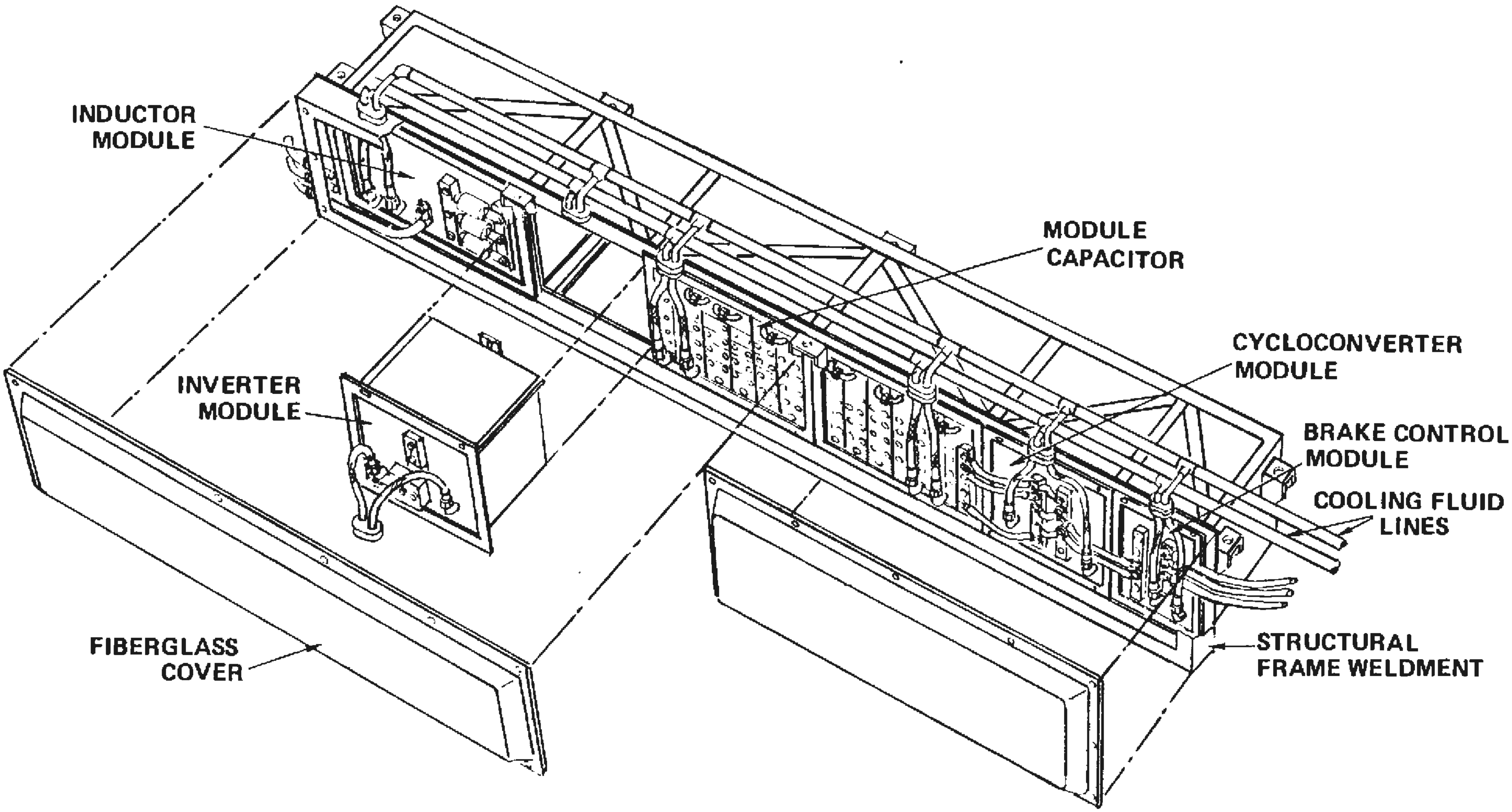


FIGURE 31

The cooling system for the self-synchronous propulsion is shown schematically in Figure 32,

Significant Progress

CDR's have been conducted on all major components and assemblies except the monitor panel (diagnostics). The manufacturing and/or procurement of these items is in process. The drawing status is 85% complete and remainder by 15 October.

Interface Definition - The interfaces (electrical power electrical signal, structural, and hydraulic) which exist between the self-synchronous propulsion system including the ASDP monitor panel, the SOAC, the synchronous brake system, and the improved ride quality monomotor truck are described and documented on Interface Log Sheets in accordance with procedures defined in Document No. UMTA-IT-06-0026-76-1.

Weight Status - The weight of the self-synchronous propulsion system and its components is shown in Figure 33.

Analyses and Test Performed - The thermal analysis methods are defined in Figure 34 and the thermal model employed is described in Figure 35.

The mechanical/structural stress analysis methods are defined in Figure 36.

The components to be tested are defined in Figure 37 and the Design Qualification Plan is described in Figure 38.

Future Events

The more significant activities planned include:

- Sign-off of ASDP-SOAC Integration Analysis Sheets (Ref. UMTA-IT-06-0026-76-1, "Vehicle Integration Plan").
- Completion of Engineering Analyses and Design of Both the Control Electronics and the ASDP Monitor Panel.
- Conducting of Integrated Test Program (Component, Subsystem, System Simulation, and Prime Hardware Acceptance Tests).
- Preparation of Reliability, Maintainability, and Safety Analyses Reports.
- Issuance of Operational and Maintenance Manuals.
- Providing of Spare Components and Assemblies.

COOLING SYSTEM SCHEMATIC

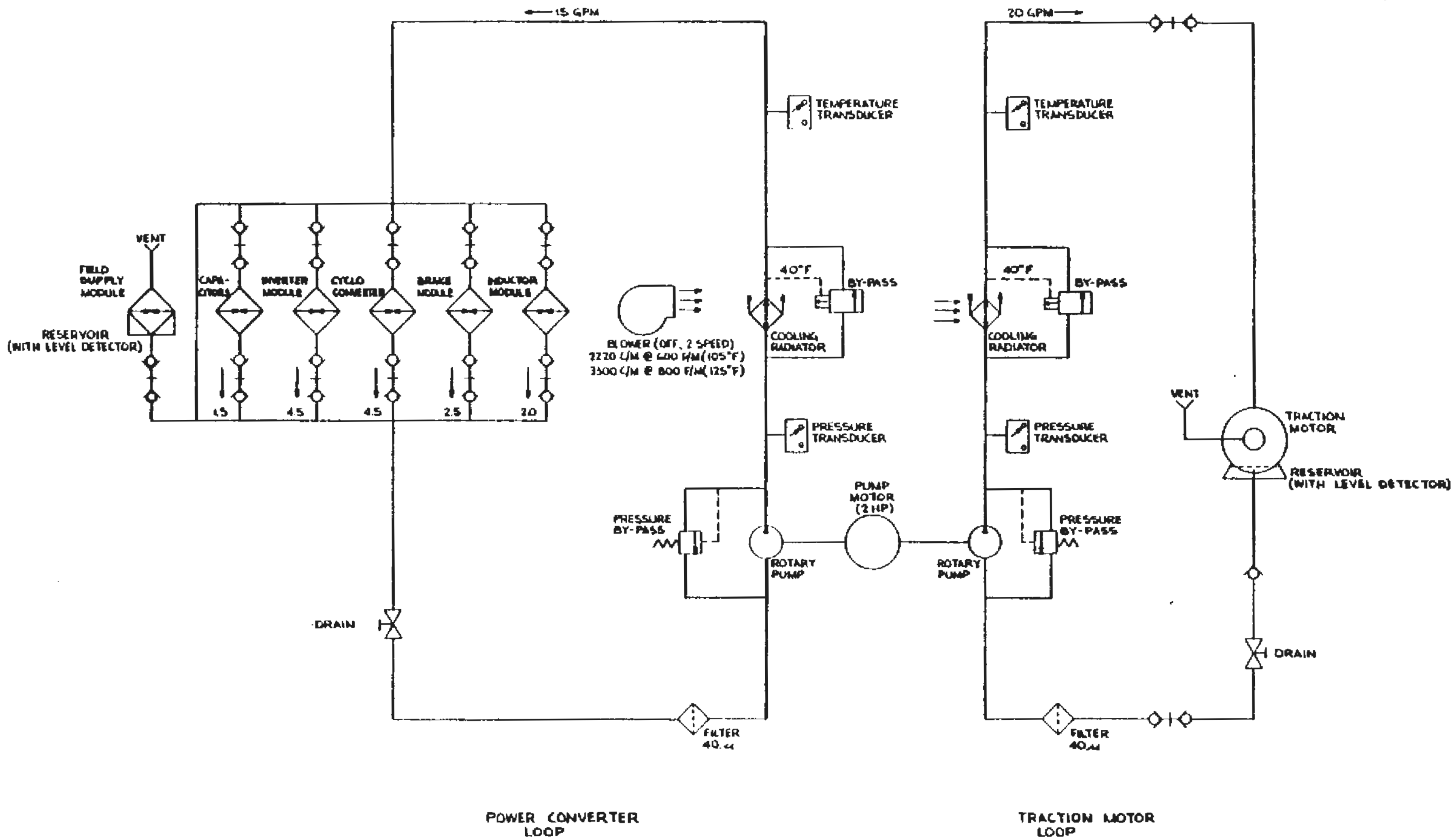


FIGURE 32

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ASDP WEIGHT STATEMENT

			CDR WT (WET)		CDR WT (DRY)	
ITEM	DESCRIPTION	QTY/ CAR	UNIT WT	TOTAL WT/CAR	UNIT WT	TOTAL WT/CAR
1	Traction Motor	2	1840	3680	1787	3574
2	Gear Drive & Axle Couplings	4	975	3900	957	3828
3	Motor/Gearbox Coupling	4	40	160	40	160
4	Groundbrush & Speed Sensor Assy.	8	10	80	10	80
	TOTAL TRUCK MOUNTED			7820		7642
5	Truck Connector Box	2	50	100	50	100
6	Power Converter Assembly	2	910	1820	717	1434
7	Resonating Inductor Module	2	625	1250	600	1200
8	Cooling System	2	410	820	394	788
9	Power Control Switchgear	2	230	460	230	460
10	Line Filter Inductor	1	780	780	780	780
11	Dynamic Brake Resistor	2	225	450	225	450
12	Electronic Control Unit	1	100	100	100	100
	TOTAL CAR MOUNTED			5780		5312
	TOTAL PROPULSION SYSTEM			13600		12954

FIGURE 33

THERMAL ANALYSIS METHODS

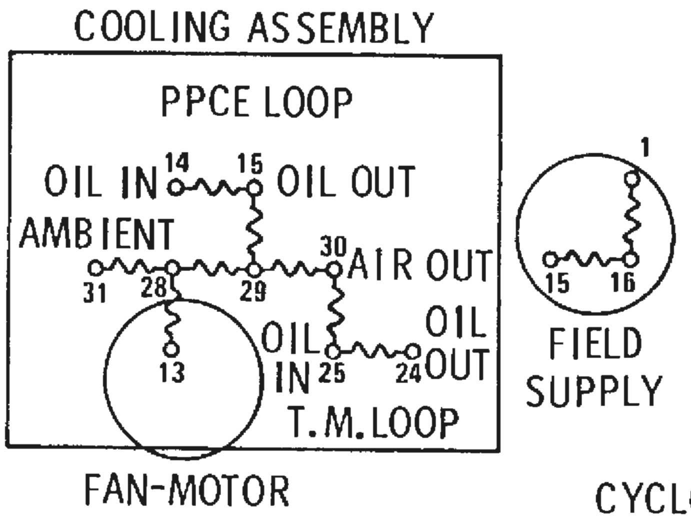
ANALYTICAL THERMAL MODELS

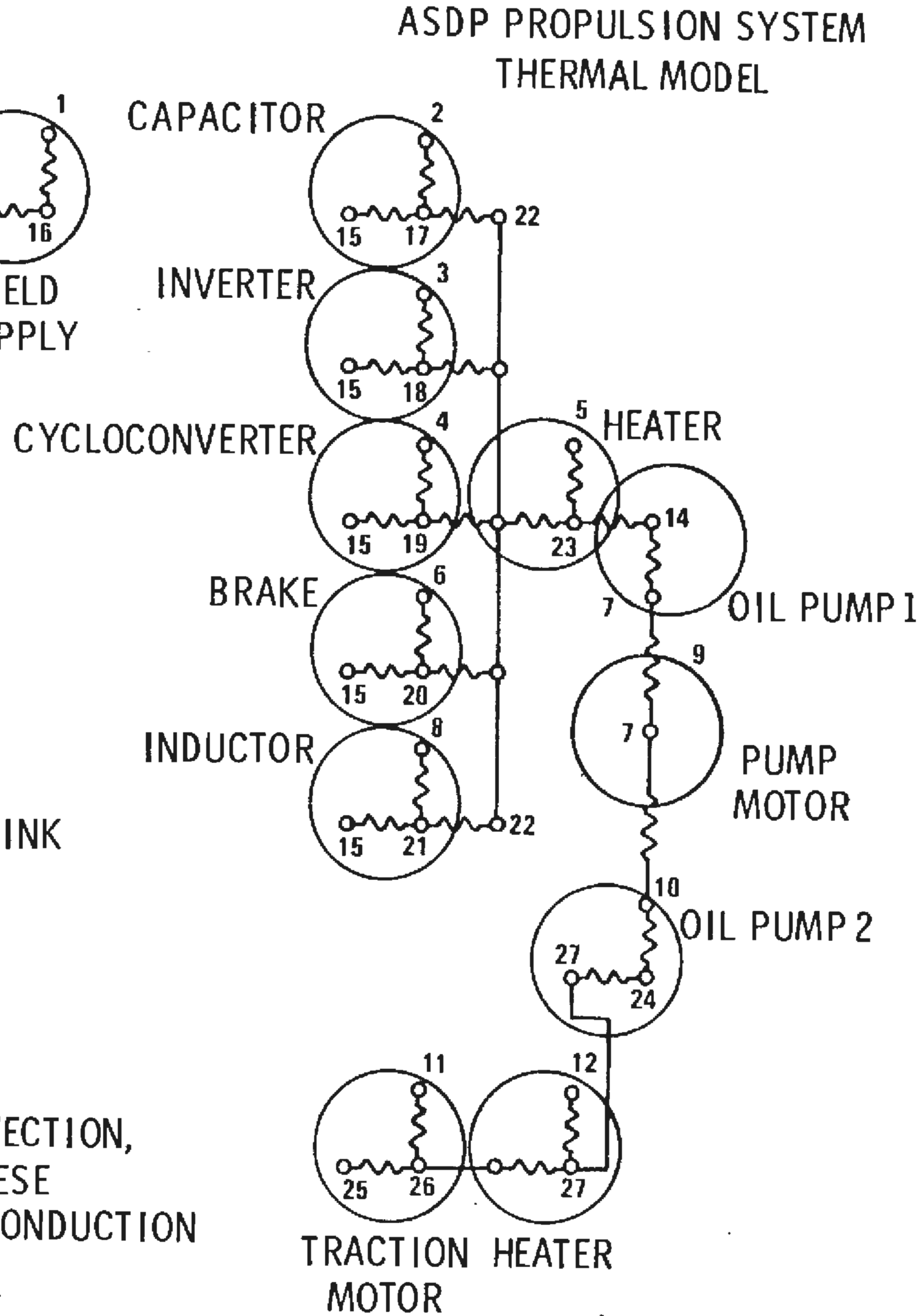
- Based on electrical-thermal analogy, E = IR   T = QR.
- Relate the three modes of heat transfer; convection, conduction and radiation.
- Solved by computer programs using matrix techniques for steady-state problems and numerical finite difference techniques for transient problems.
- Used to assess cooling performance of air and liquid-cooled modules.

THERMAL TESTING

- Determine thermal and flow performance of spiral groove heat sinks.
- Establish appropriate groove geometry for the selected coolant.
- Verify performance of liquid-cooled flow-through modules.
- Verify performance of coolant assembly radiators.

FIGURE 34





NODES	DESCRIPTION
1-13	MODULE BULK MASS
14-27	OIL NODES (14-23 PPCE LOOP, 24-27 TM LOOP)
28-30	COOLING AIR NODES
31	AMBIENT CONVECTION SINK
32	CAR STRUCTURE-CONDUCTION SINK
33	RADIATION SINK 1
34	RADIATION SINK 2

NOTE: ALL MODULE NODES ARE COUPLED TO CONVECTION, CONDUCTION AND RADIATION SINKS. THESE CONNECTIONS AND ALSO MODULE INTER-CONDUCTION CONNECTIONS NOT SHOWN FOR CLARITY.

FIGURE 35

MECHANICAL STRESS ANALYSIS METHODS EMPLOYED

CAR BODY EQUIPMENT

- Design layouts reviewed by stress analyst for structural integrity.
- Positive load paths established for all equipment.
- Stardyne finite element computer program utilized for highly redundant structures: power converter chassis, inverter module, cooling assembly.
- Conventional shear panel/box beam hand calculations: resonating inductor chassis, power control switchgear chassis.
- Visual inspection and review of simple assemblies: line filter inductor modules, power capacitor modules, truck connector box.

SUBCONTRACT AND VENDOR ITEMS

- Subcontractors required to supply stress data.
- Structural adequacy of commercial items verified by previous use in transit car applications.

FIGURE 36

TEST ARTICLES – SYSTEM LABORATORY TESTS

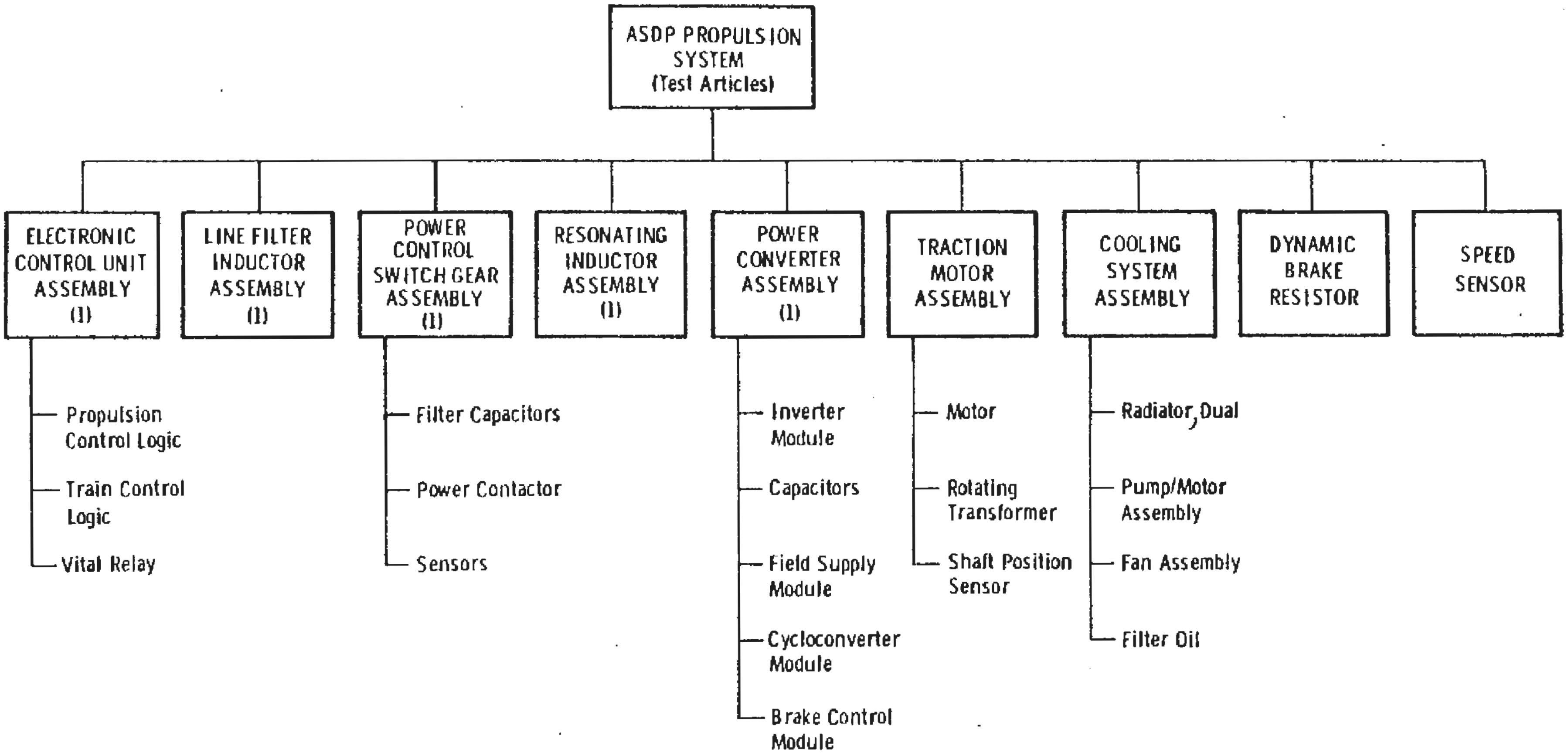


FIGURE 37

ASDP PROPULSION SYSTEM
COMPONENT AND SUBASSEMBLY QUALIFICATION

	Performance Characteristics	Thermal	Vibration and Shock	Acoustic Noise	Transients	Overspeed	EMI-RFI
Electronic Control Unit	SL	Sa	S	NA	NA	NA	VS
Power Control Switchgear	SL	SL	A	NA	SL	NA	VS
Propulsion Power Control Equipment	SL	SL	A	SL	SL	NA	VS
Inverter Module	SL	SL	Sa	Sa	SL	NA	VS
Traction Motor	SL	SL	A	Sa	SL	V	VS
Gear Drive and Coupling	V	V	S	V	NA	V	NA
Line Filter Inductor	SL	SL	A	NA	SL	NA	VS
Brake Resistor	SL	SL	S	NA	NA	NA	NA
Cooling Assembly	SL	SL	A	Sa	NA	NA	NA
Ground Brush	S	S	S	NA	S	S	NA
Speed Sensor	SL	SL	S	NA	NA	S	NA
Truck Connector Box	SL	SL	S	NA	SL	NA	NA
Motor -Gearbox Coupling	SL	SL	A	NA	NA	V	NA

VS - Vehicle System Tests
SL - Propulsion System Laboratory Tests

V - Vendor Tests
Sa - Subassembly Test

S - Similarity (Equipment used in Transit Car Environment)
A - Analysis
NA - Not Applicable

FIGURE 38

Improved Ride Quality Monomotor Truck

Technical Description

The improved ride quality monomotor truck (Figure 39) is designed to incorporate a monomotor propulsion unit plus disc (two per axle) brakes, and will interface with the SOAC vehicle with minimum modifications to the vehicle.

Pertinent Dimensions

Truck Wheel Base	7 feet 6 inches
Track Gauge	56-1/2 inches
Wheel Diameter (new, worn)	30 inches, 28 inches
Center-to-Center, Trucks	54 feet
Length of Car (over anticlimbers)	74 feet 8-1/2 inches
Width of Car (maximum)	9 feet 9 inches

The truck frame consists of three parts joined together through four limited compliancy elastomeric joints: two side frame/transom weld assemblies, each with two formed plates and seven castings, and a cast center plate. The bolster is a welded assembly of upper and lower formed plates, a center pivot tube and two anchor castings. It is attached to the carbody by anchor rods and to the truck frame by an integral pin on the center plate. Airsprings are mounted between the bolster and carbody with auxiliary air reservoirs slung beneath the bolster.

Traction will be reacted from the wheels through the journals to the side frames, through the centerplate to truck bolster, and then through the anchor rods to the carbody. The truck is designed to control wheel load reduction due to weight transfer from braking and acceleration to less than 7-1/2 percent.

A roll bar controls carbody roll, and, in this case, limits the roll to 1.5 degrees relative to the track under a lateral load of 0.1g.

The truck is equalized by rotation of one side frame with respect to the other. The rotation is about an axis through the pivot points at opposite ends of the transoms at an angle of approximately 30 degrees with respect to the lateral axis, approximately 7.5 inches above the plane of the axles. During equalization there is a minimum load change per wheel along with minimum relative movement within the gearbox axle drive couplings and of the brake actuators with respect to the brake discs.

The side bearers provide the vertical load path between the truck bolster and frame and allows the frame/axle assembly to swivel. Sliding occurs between a stainless steel plate on the top of the side frame and an anti-friction shoe on the underside of the bolster. The shoe is mounted to the bolster through an elastomeric pad which distributes the load when relative pitch occurs between the side frame and bolster.

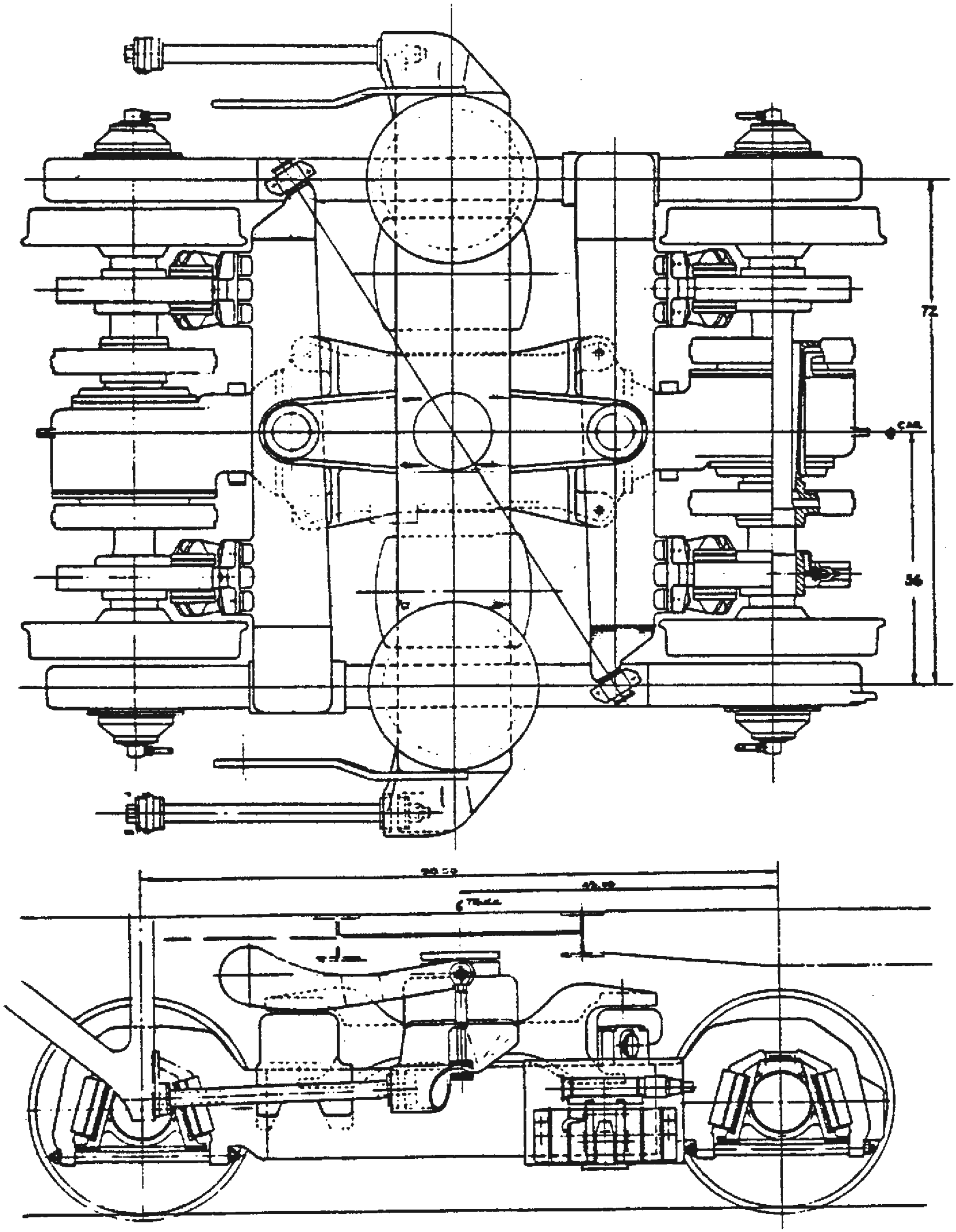


FIGURE 39

The cast journal housings adapt the primary rubber suspension assemblies to the journal bearings. The primary suspension is an elastomeric vee spring, which provides high frequency isolation of the truck from the axles and wheels, molded to steel backing plates. Two sets of primary springs are provided, with a two-to-one variation in vertical rate achieved by varying vee angle and elastomeric thickness.

The secondary suspension incorporated two rolling diaphragm type airsprings in each truck. The physical air volume of each spring is supplemented by a small reservoir connected to the spring through a short, 2-inch diameter tube. The small reservoir is contained within a larger (3900-cubic inch) reservoir and airflow between the two is restricted by an orifice to provide reduced effective volume and reduced damping at higher vibration frequencies. Each spring has a levelling valve with the two valves for the "B" end truck operated through torque tubes from near the car centerline.

Truck design including suspension was constrained by the requirement to accommodate the monomotor-gearbox drive plus the disc brake components while providing improved ride quality for the SOAC as defined in Figure 40. With the first carbody bending frequency of 7 to 8 Hz within the operating speed range, it is necessary to choose either a relatively low or high truck frame natural frequency. Since the soft primary suspension required for a low truck frame frequency would result in excessive relative motions between frame and axle, stiff primary springs were selected. The lower stiffness primary springs to be provided has a vertical rate per journal of 65,000 pounds per inch minimum and will result in a frame natural frequency in excess of 30 Hz. The second set of primary springs has a vertical rate of 140,000-150,000 pounds per inch and will be tested for effects on wayside vibration, noise and ride quality. Both primary spring sets are to have a lateral rate of 130,000 pounds per inch.

With the stiff primary suspension, ride quality is controlled by the secondary suspension. In addition to the auxiliary volumes incorporated in the airspring system, the spring housings are configured to provide a negative area change of -10 square inches per inch. These features result in a low natural frequency of 0.7 Hz corresponding to the effective vertical rate per spring of 1100-1200 pounds per inch. Due to the orifice in the auxiliary reservoir system, the spring rate increases to approximately 2500 pounds per inch above 4 Hz while damping reduces from 20% at 0.8 Hz to 2% at 8 Hz.

The rolling diaphragm airspring has a lateral spring rate of 1500 pounds per inch at 70 psi. Lateral damping is provided by two linear hydraulic dampers on each truck.

SOAC AND ASDP/ACT-1 RIDE QUALITY GOALS

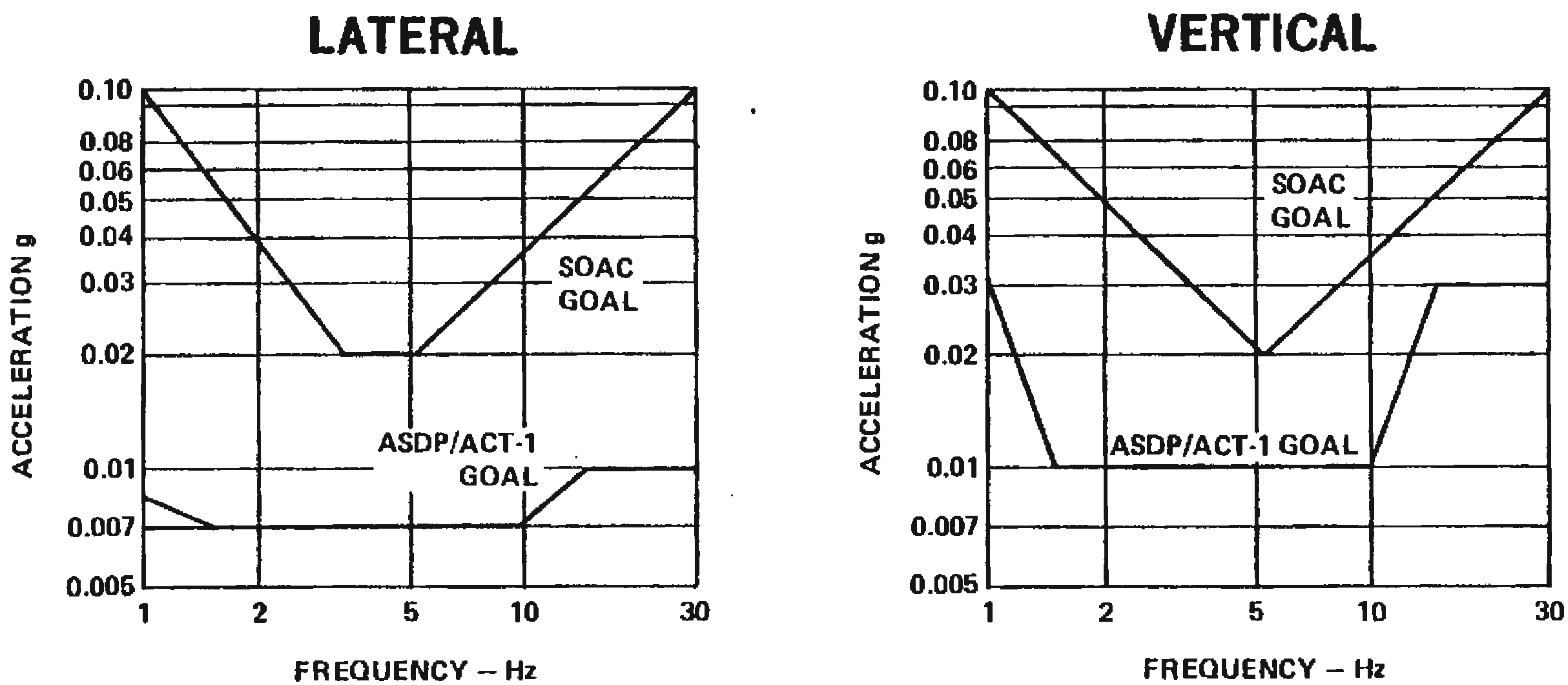


FIGURE 40

The truck design incorporates provisions for compatibility with the five demonstration cities. This involves two car floor heights, two third rail shoe lengths plus collector assembly height adjustment, two track trip lateral positions plus height adjustments and provisions for ATO coil mounting.

Major Components and Assemblies - The basic truck to be furnished by the truck contractor consists of five major assemblies: roll bar, bolster, frame/centerplate assembly and two axle assemblies including wheels. Major assemblies to be installed on the truck are:

- Monomotor and drive gearboxes rigidly mounted to the centerplate.
- Two brake actuator/caliper units mounted to each transom.
- Drive coupling hub and two brake discs pressed on each axle.
- Axle ground rubbing discs and brush assemblies at each end of each axle.
- Speed sensor toothed wheel and pickup at one end of each axle.

The truck contractor is The Budd Company: the primary suspension is supplied by Lord Manufacturing, the secondary suspension supplied by Firestone Company, the current collector supplied by Ohio Brass Company, and the wheels supplied by Standard Steel Company.

Significant Progress

CDR's have been conducted on all major components and assemblies. The manufacturing and/or procurement of these items is in progress. The drawing status is essentially 100% complete with only minor detailing remaining.

Interface Definition - The interfaces (electrical signal, structural, hydraulic, and pneumatic) which exist between the improved ride quality truck, the SOAC, the self-synchronous propulsion system including the ASDP monitor, and the synchronous brake system have been resolved and are being documented on Interface Log Sheets in accordance with procedures defined in Document No. UMTA-IT-06-0026-76-1. The truck specification, D239-10001-1, was updated to revision "B" and released as Report No. UMTA-IT-06-0026-75-2.

Weight Status - The weight of the improved ride quality monomotor truck and its components is shown in Figure 41.

MONOMOTOR TRUCK
WEIGHT STATEMENT

	PROPOSAL	1-16-76	2-27-76	4-30-76	5-31-76	7-13-76
Wheel	1,840	1,716	1,713	1,620	1,620	1,620
Axle	1,000	1,716	1,327	1,208	1,094	1,094
Journal Braking	400	400	400	518	762	833
Journal Housing	600	600	600	790	765	868
Main Frame	1,075	1,504	1,506	1,784	1,769	1,821
Primary Suspension	52	52	52	13	13	13
Secondary Suspension	240	840	313	296	301	314
Reservoir	140	402	400	202	202	202
Bolster	710	826	829	694	719	692
Lateral Dampers	86	86	86	65	65	22
Lateral Stop	40	40	40	40	40	20
Vertical Stop	30	30	30	30	30	36
Lifting Protection					121	105
Central Pivot Braking						
Centerplate Assembly	355	519	542	542	527	536
Leveling Valve	22	22	25	31	24	26
Height Adjustment	5	5				
Equalizing Valve	5	5	5	5	5	5
Load Weigh Provisions	5	5				
Monomotor & Drive	2,500	2,500	3,000	3,000	3,000	3,000
Brake Disc/Caliper	1,000	2,000	2,002	1,855	1,855	1,855
Vertical Damper						
Track Trip & Provisions	125	125	125	33	33	33
Third Rail Shoe Assembly	120	120	120	73	73	73
Groundbrush Mtg. Prov.	10	82	82	72	90	89
Plumbing Mtg. Prov.	30	30	30	30	30	30
Wiring Mtg. Rev.	60	60	60	60	60	60
Misc. & Contingencies	550	0	0	00	0	0
Sub Total	11,000	13,685	13,287	12,961	13,198	13,347
Anchor Rod Installation	--	--	88	77	78	84
Roll Bar	409	285	287	389	389	434
Total	11,409	13,970	13,662	13,427	13,665	13,865

FIGURE 41

<u>Analyses and Tests Performed</u> - Structural analyses were performed for the following specification fatigue, static, shock and crash loading combinations:

		Fatigue (1)	Fatigue (2)	Static	Shock	Crash
Car Body	• Vertical	1	±0.37g	2g	-	-
Accelerations	• Lateral	±0.10g	±0.40g	0.5g	-	(250,000 lb)
	• Longitudinal		±0.20g	0.55g	-	(250,000 lb)
Truck Assembly	• Vertical	1	±5g	7g	7g	-
Accelerations Except Axle	• Lateral	±5g	±0.40g	7g	7g	-
	• Longitudinal		±5g	7g	7g	-
Axle Assembly	• All Directions		±5g	7g	100g	-
Motor Torque (5.8 Gear Ratio)	Pound-Inches	±18,450		100,000	-	-
Braking Torque (per Axle)	Pound-Inches	±73,000		90,000	-	-

Stresses were calculated, including approximate stress concentration factors, and compared to the appropriate allowable stresses which were based on modified Goodman diagrams for fatigue, yield strength for static and shock accelerations, and ultimate strength for each of the crash loads. The results are summarized in the following table:

Part		Factors of Safety Material	Fatigue	Static	Crash
Center Plate	Main Section	(1)	1.23	1.10	2.94
Pivot Casting - Transom	Root Section	(1)	1.20	1.48	1.15
Female Casting - Pivot	Bolts		1.59	2.10	1.22
Transom	Large Weld Section	(2)	1.27	1.59 Center	1.80
Saddle Casting	Top Weld-Side Frame to Corner	(3)	1.26	2.10	1.13
Bolster	Top Weld-Center	(4)	1.49	Air Spring Failure 1.03	
Anchor Rod Casting	Weld Section	(3)	5.50	6.8	2.65
Side Frame	Weld Section	(3)	1.20	1.71	-
Pedestal Casting	Small End	(1)	1.12	1.73	-

Materials:
(1) ASTM A-352 Grade LC-2 Steel Casting
(2) Casting-to-casting weld
(3) Casting-to-NES 65 plate weld
(4) Plate-to-plate weld

Dynamic analyses have been performed on ride quality and hunting stability by Budd and on ride quality and truck vibration by Boeing. The ride quality results indicate substantial improvements, as shown in Figure 42, and that goals will only be exceeded slightly at the carbody first bending natural frequency. The hunting stability analysis showed positive stability up to 100 mph for both small truck swiveling angles (side bearers not sliding) and large angles, with wheel tread conicities of 1/7 and 1/10 in addition to the planned 1/20 conicity.

ASDP

RIDE QUALITY

SOAC
VS
PREDICTED ASDP

● MEASURED SOAC
O PREDICTED ASDP

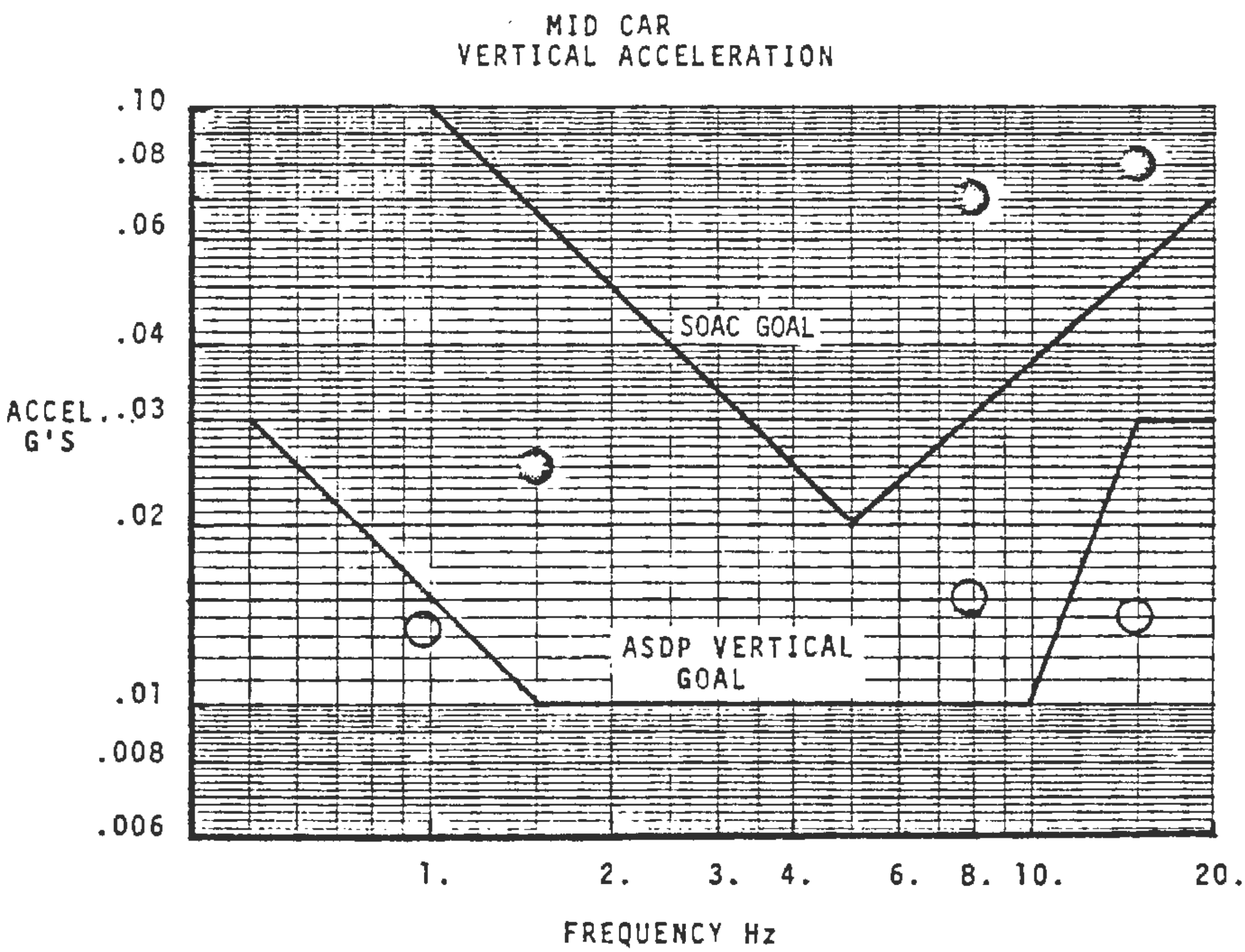


FIGURE 42

The Truck Equalization Analysis demonstrated that jacking one wheel 2 inches on level track under an empty car does not cause the reactions on any other wheel to change by more than 20%. The summary of the wheel load changes due to 2-inch elevation of wheel A (A and B wheels are on same axle; A diagonally opposite to C) follows:

Wheel	Load Change	% of Static Load
A	2094 lbs	19.0
B	-2094 lbs	19.0
C	639 lbs	5.8
D	- 639 lbs	5.8

Tests on various side bearer materials showed that a commonly used combination of Gatke anti-friction material on 304 stainless steel satisfied friction and wear requirements. Figure 43 shows the approximate upper and lower limits selected for the friction coefficient, based on truck "steerability" and stability, respectively, and illustrates the effect of unit load on friction coefficient which dictated the selection of design area. The requirement to pre-wear-in the side bearer to avoid excessive friction is illustrated on Figure 44. Tolerance of contamination is shown on Figure 45, which also indicates that wear is slow after an initial wear-in.

Future Events

The most significant activities planned include:

- Conduction of both Static and Fatigue Tests on the Test Truck.
- Fabrication and Acceptance Inspection of two carsets of trucks.
- Issuing of the updated Failure Modes Effects Analysis (FMEA).
- Updating the Weights Analysis, Material Specifications, and Truck Design Specifications
- Issuing the Spare Parts List, Support Equipment List, and Maintenance Manual

Synchronous Brake System

Technical Description of Design - The friction brake system for the ASDP-SOAC vehicle is to be supplied by WABCO and features synchronous brake control.

Synchronous brake control refers to the ability to control the brake pressure in a proportional or analog manner to closely follow the available adhesion on slippery rails - or to "synchronize" brake control with the rails. Figure 46 illustrates how synchronous control differs from the present "on-off" type of slide control.

SIDE BEARER MATERIAL - EFFECT OF UNIT LOAD

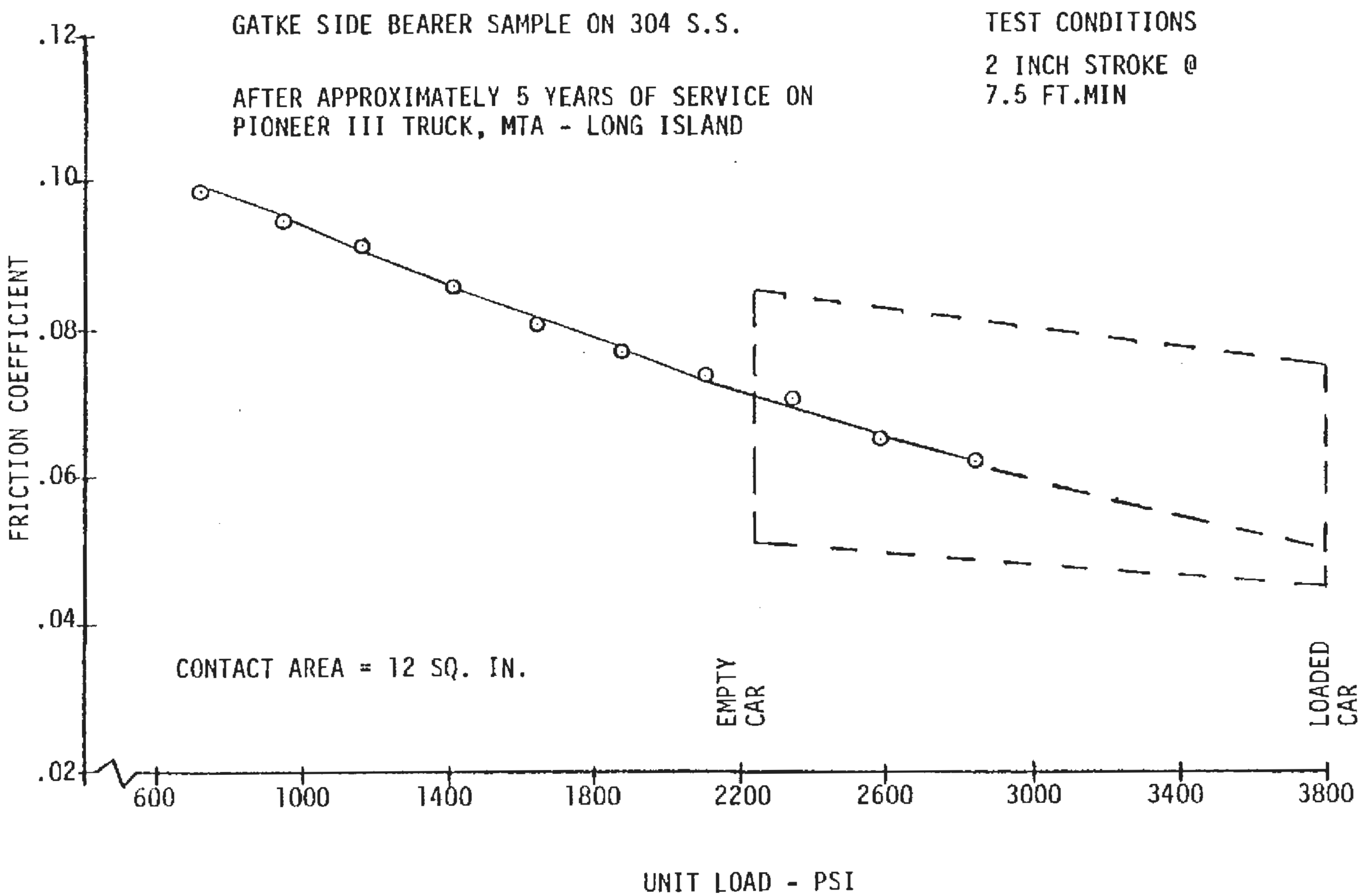


FIGURE 43

SIDE BEARER FRICTION & WEAR TEST

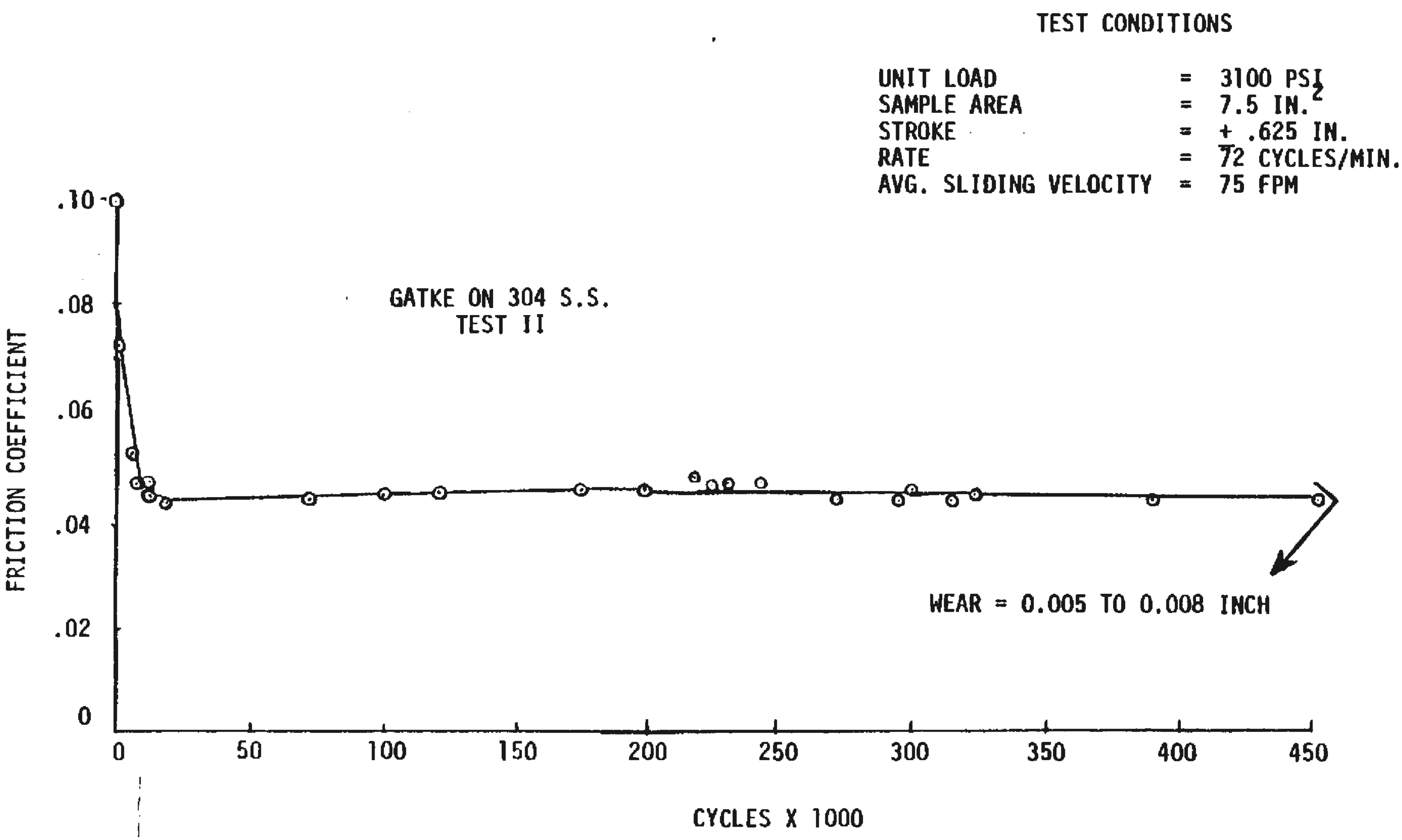


FIGURE 44

SIDE BEARER FRICTION & WEAR WITH CONTAMINATION

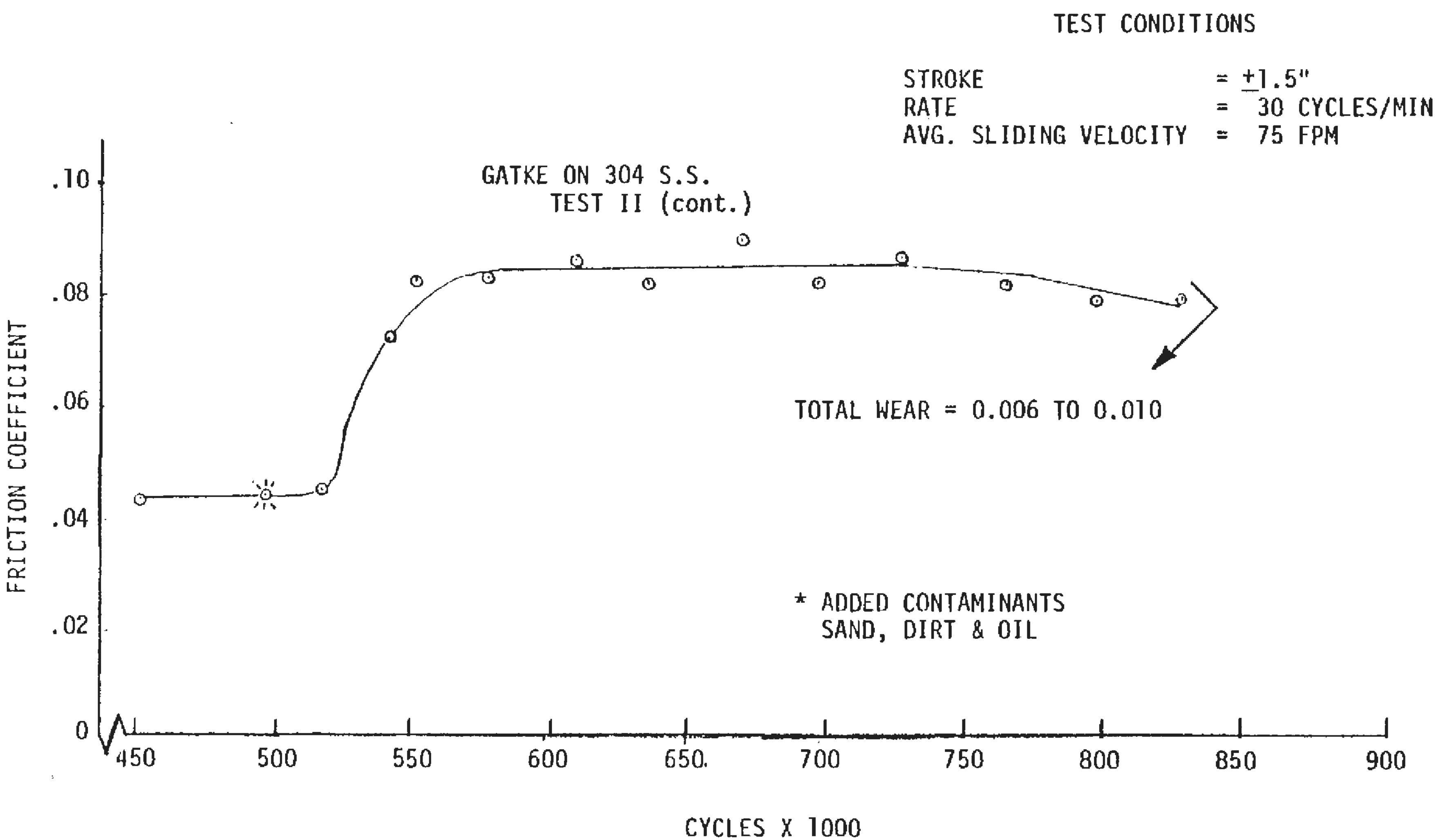
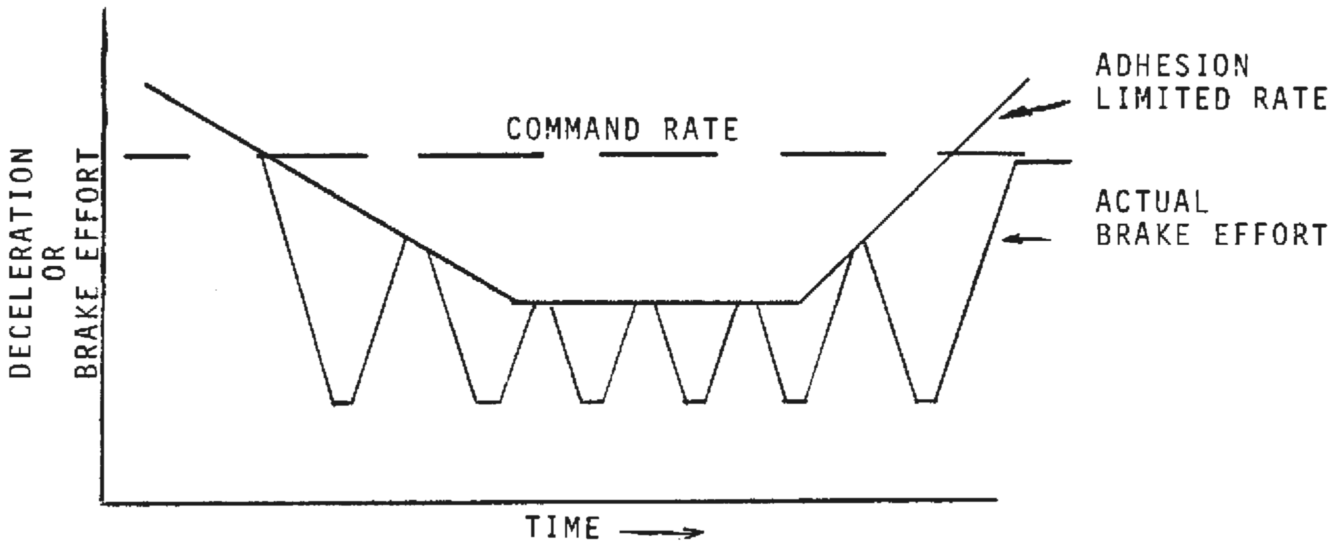


FIGURE 45

WHEEL SLIDE CONTROL SYSTEMS

ON-OFF CONTROL



SYNCHRONOUS CONTROL

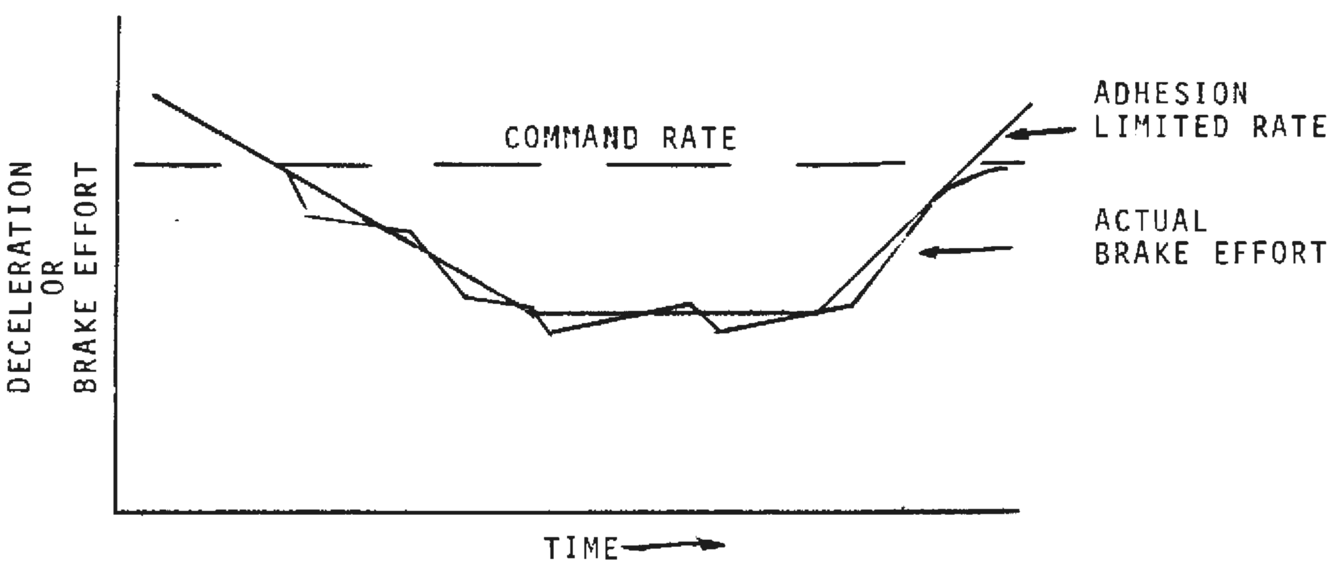


FIGURE 46

The benefits of the WABCO synchronous brake system are: high efficiency (95%) during slides and accurate control of braking rate and stopping distances.

The WABCO brake system features air as the control medium, fast response wheel slip valves, axle acceleration feedback, electronic control with increased sensitivity for faster response, an integral air over oil brake actuator, and two split discs per axle.

Figure 47 is a block diagram of the WABCO synchronous brake system. As the block diagram illustrates, the synchronous brake system controls the brakes on an individual truck basis.

Major Components and Assemblies - Major functional items in the system are: the electronic control unit, the two pneumatic control units, the wheel slip valves, the disc brake units, and the parking brake unit. The brake contractor is Westinghouse Air Brake Company: the disc and hub supplied by Pont-A-Masson (France).

The electronic control unit is the logic unit translating the inputs from the P-signal, electric brake effort and axle speeds into air pressure commands and wheel slip valve operation commands. The wheel slip valves provide apply, lap (allows neither an application nor release), release functions for rapid, high gain wheel slip control. These valves have significantly faster response than existing decelostats or dump valves. The advantage of the lap position in the wheel slip valve is that during a slide the brake cylinder pressure need only be reduced to the level necessary to correct the slide and then the valve is lapped off to hold that pressure until the wheel re-accelerates to speed and the pressure is reapplied. Without the lap position, air must continually be exhausted until the wheel has re-accelerated and then the pressure is reapplied (but from a much lower pressure) thus requiring more time.

The disc brake units consist of the actuator, the tong assembly and the disc. The integral air-over-oil actuator is shown in Figure 48. In order to eliminate leak sources, this unit has no external oil lines or connections. Pressure levels in the actuator are; 90 psig air pressure and 900 psig oil pressure. It also incorporates an infinite slack adjuster and is designed for zero clearance (pad to disc) operation and with minimum air volume to reduce response time. The zero clearance operation, which is obtained by a spring inside the unit that maintains an approximate 60 lb. force against the disc at all times, also eliminates the need for a snow brake mode. The disc is a cast iron split disc with bell shaped hub that mounts the disc to the axle. The bell shape of the hub permits radial expansion of the disc at high temperatures without prohibitive material stresses. The disc is a development of a split disc design that is in service in France. To meet the braking requirements of the Synthetic Transit Route, two discs per axle are required.

SYNCHRONOUS BRAKE SYSTEM BLOCK DIAGRAM

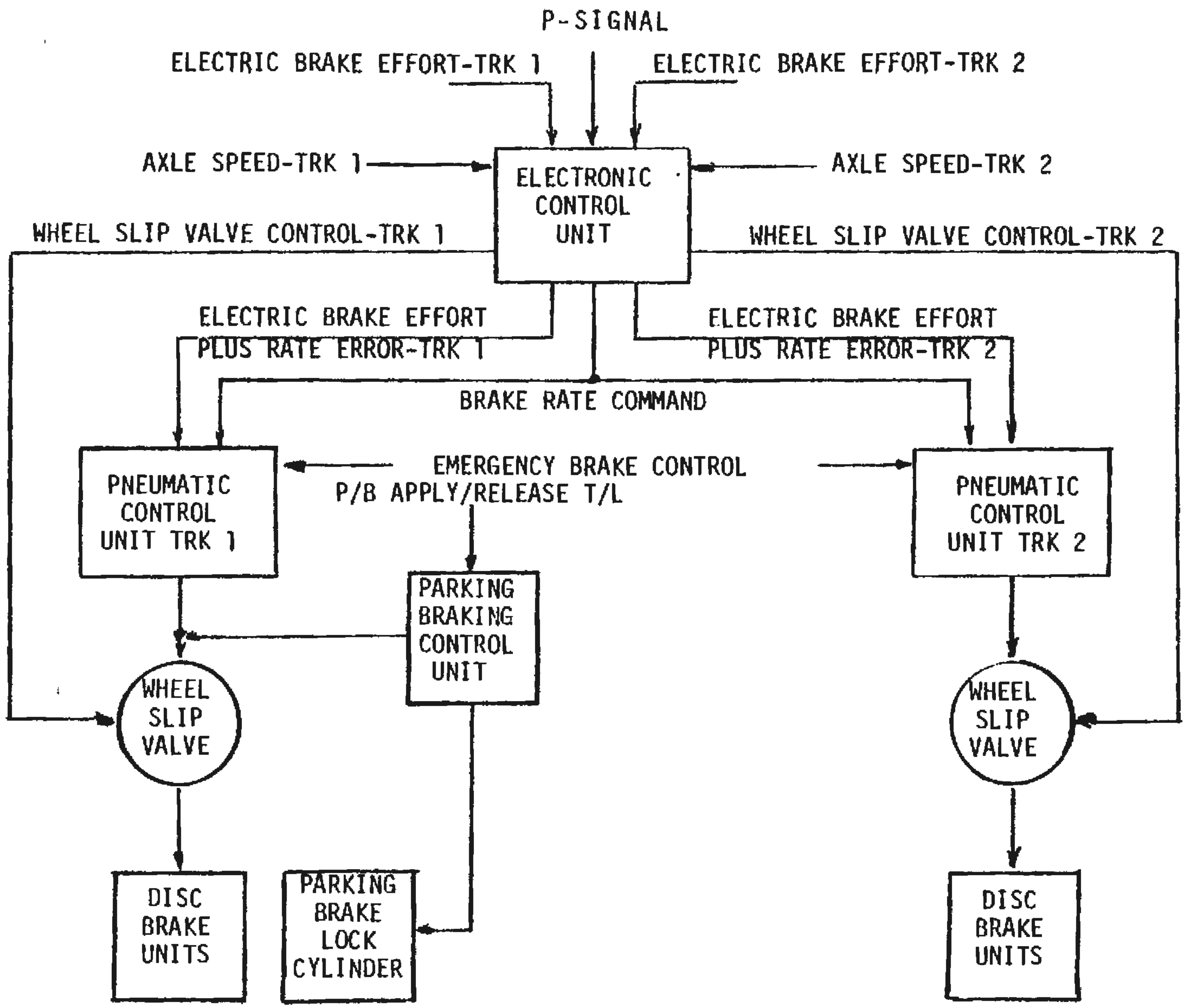


FIGURE 47

ACTUATOR ASSEMBLY

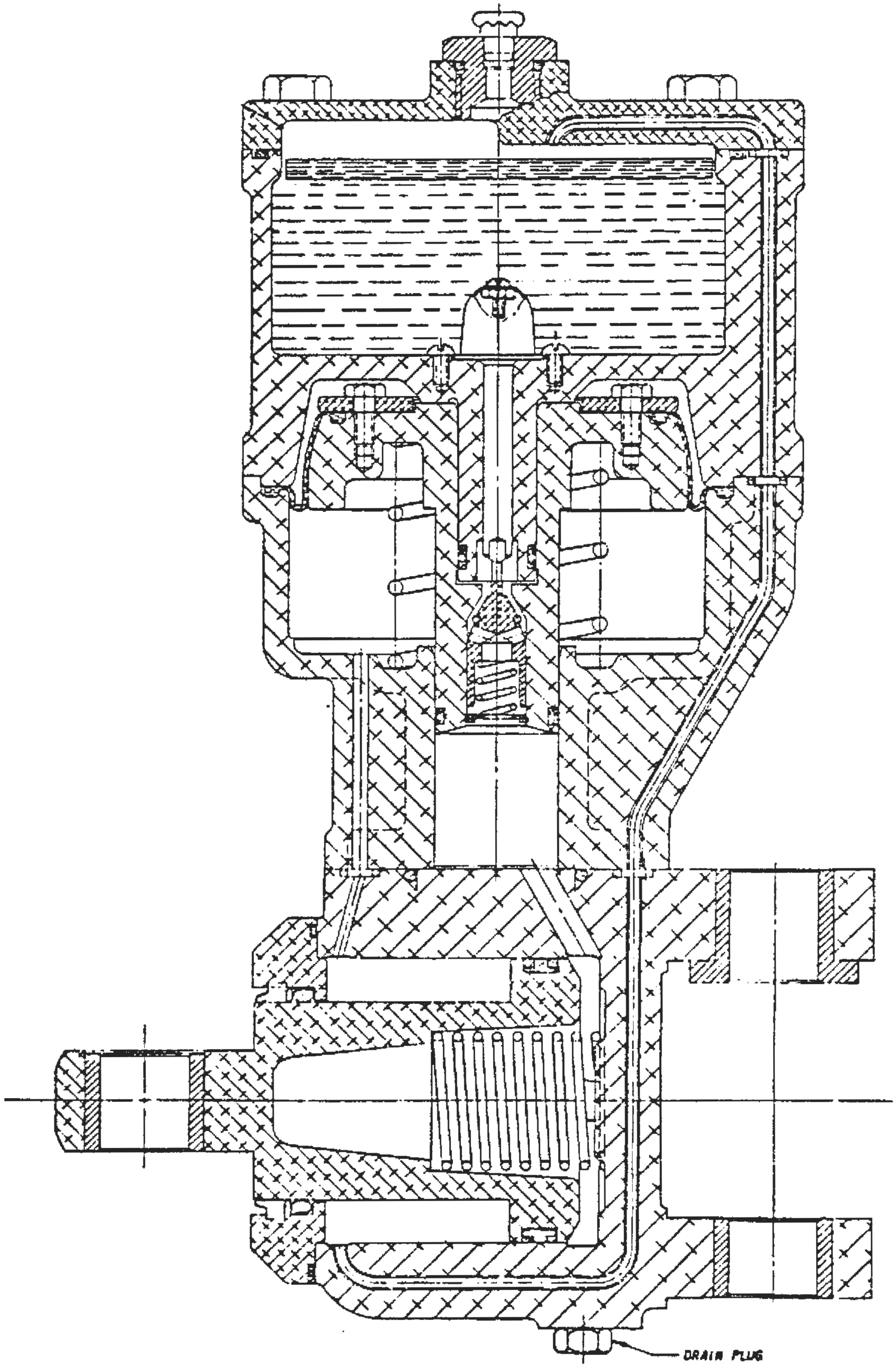


FIGURE 48

The parking brake control unit is a packaged unit complete with fittings and internal piping so that it can be installed or replaced as a unit with ease. It is comprised of a hand pump, pressure release valve, selector valve, and a pressure switch. The control unit is located in the operating cab (one per car) with connecting tubing and hoses to two brake units on the truck system equipped with the parking brake locking device. The locking device has a limit switch that is actuated by the movement of the lock and thus positively indicates the apply or release condition of the unit.

The control configuration differs significantly from a typical pneumatic brake system in two ways: (1) the synchronous brake system control is closed loop through the use of differentiated axle speed feedback for brake rate control and modulation during slides, and (2) the wheel slip valves differ from traditional dump valves or decelostats by having, in addition to the normal apply and exhaust modes, a lap mode which "locks in" or holds the brake cylinder pressure at its present pressure - thus limiting the pressure drop necessary to correct a slide and greatly speeding up system response. (See Figures 49 and 50.)

The following discussion is an overall functional description of the WABCO synchronous brake system.

Overall braking effort is controlled in a closed loop manner such that any inefficiencies or inherent non-linearities of the disc brake units are negated through rate feedback and frictional braking pressure modulation, to maintain constant friction retardation during a blanded brake or all-friction braking stop.

The electronic control unit senses wheel speed by using frequency signals from each of the two magnetic pickup and gear assemblies, on one axle of each of the two trucks. The unit develops internal voltage speed signals proportional to the input frequency. The voltage speed signals are electronically differentiated to provide analog rate voltage signals which are directly proportional to actual effective car deceleration braking rate.

The actual train rate voltage signal is compared against the desired train braking rate (P-wire brake command). The result is a train braking rate "error" signal.

The rate error signals are combined with the incoming regenerative braking effort signals (one per truck) from the propulsion equipment.

The end result is the formulation of two (one per truck) composite signals proportional to the summation of rate error and the effective regenerative braking effort on a per-truck basis. These signals represent that portion of the overall braking rate requirement which is excessive to friction brake requirement. After amplification, they are fed to the service portions on the pneumatic brake application units on each truck.

SERVOTROL UNIT

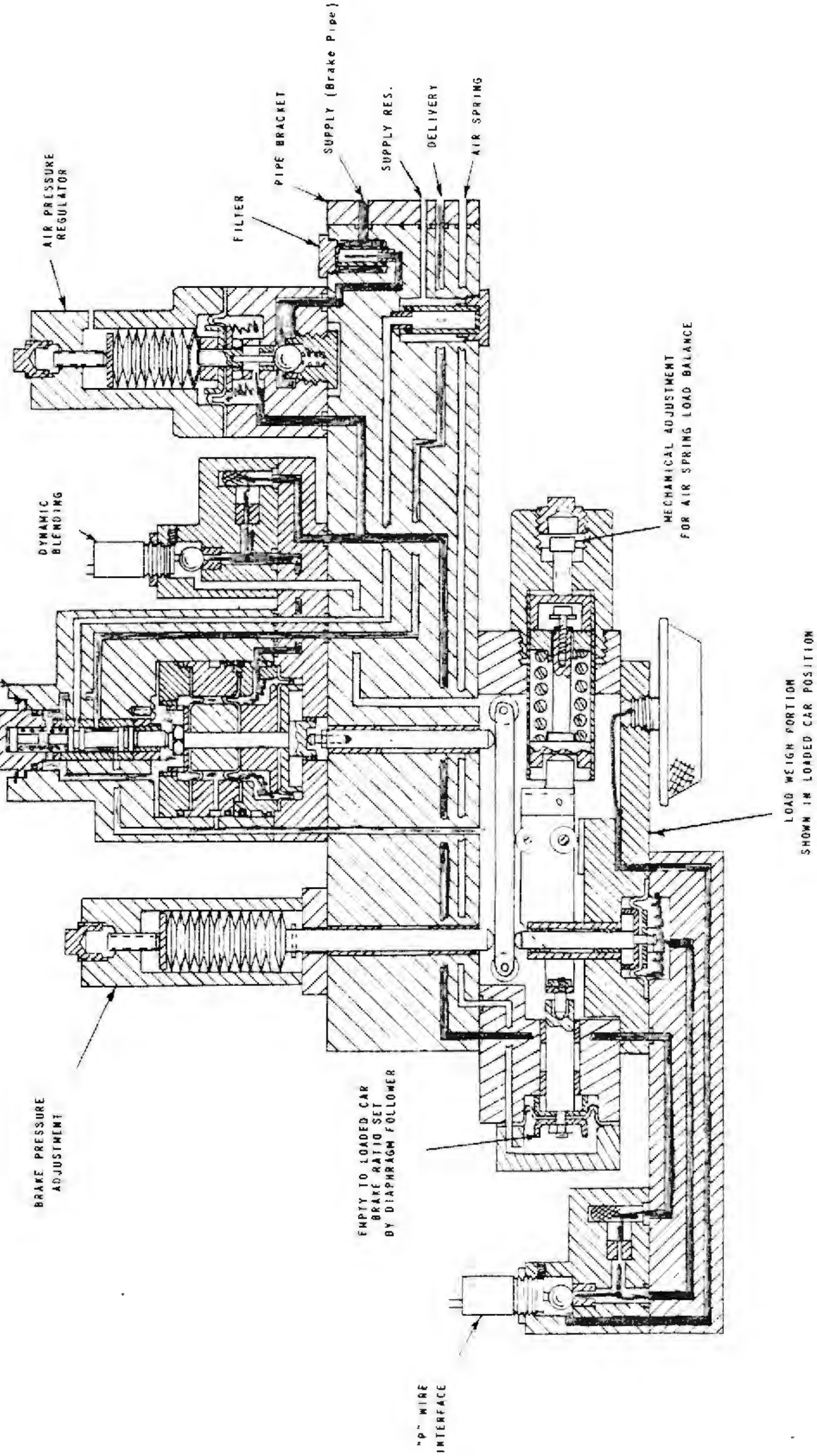


FIGURE 49

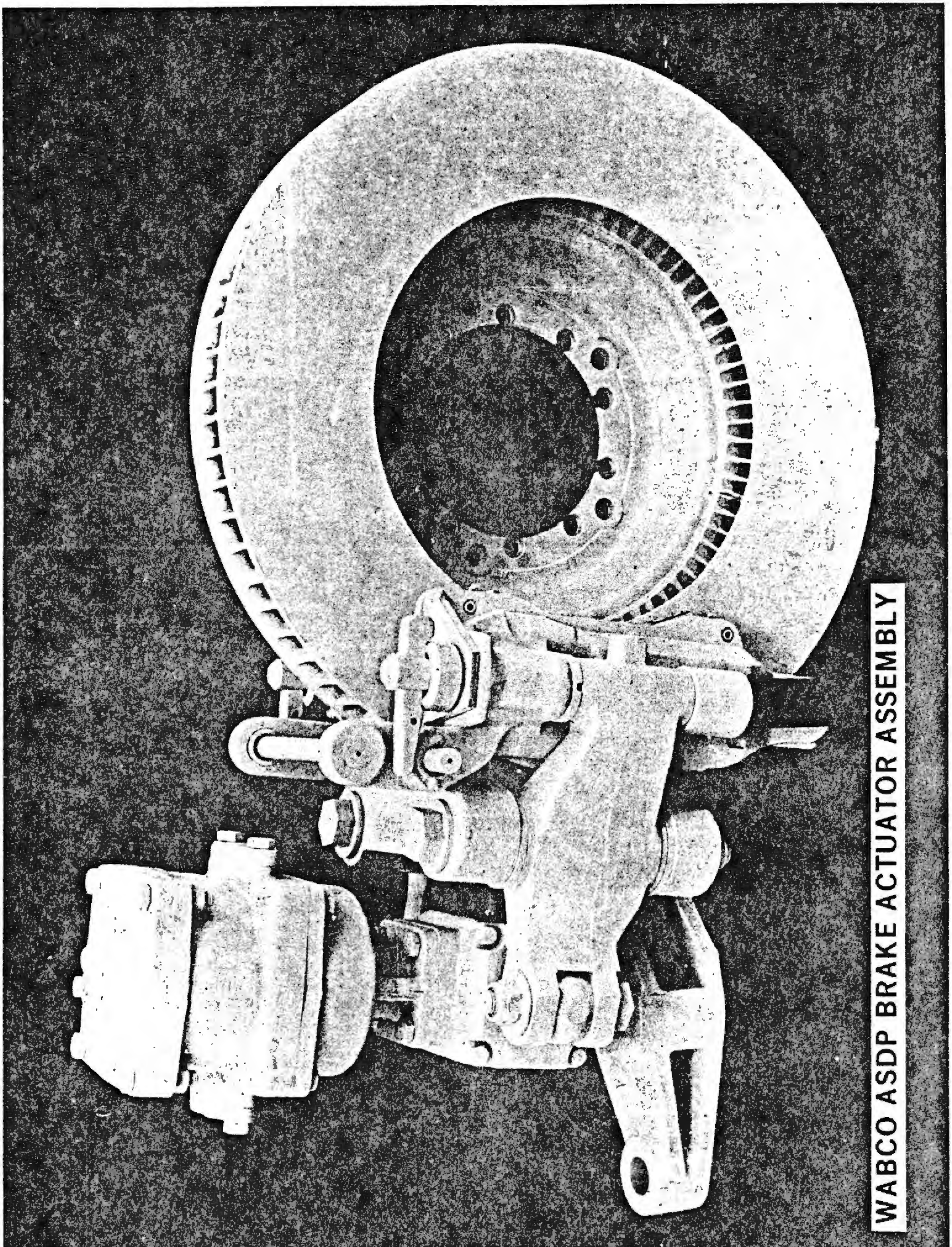


FIGURE 50

The incoming jerk limited braking rate signal (Delco modified P-wire) is amplified and fed directly to each of the pneumatic brake application service portions.

A comparison is performed by the service portions between the overall braking rate signal (P-wire), the composite non-friction braking rate and the pneumatic car weight signals. Through establishment of the difference between the two rate signals and compensating for the car weight, the service portions deliver the required braking pressures.

The braking pressures are delivered to the disc brake units through the synchronous brake slip-slide control valves. The disc brake units develop the required frictional braking effort and hence complete the loop. The actual braking rate is continuously sensed by the wheel pickups, the electronic control unit interprets any rate deviations from the required, and the pneumatic friction brake components perform the desired modulation.

During the braking cycle, the closed loop synchronous brake system inherently corrects against loss of wheel-to-rail adhesion by reducing the friction braking level consistent to that which available wheel-to-rail adhesion will support.

When adhesion is initially lost, causing excessive wheel-axle deceleration to occur, the rate comparison portion of the electronics will cause the rate error signal to quickly assume a high magnitude.

After signal combination, the higher composite signal magnitude will cause the pneumatic brake application unit to reduce disc brake unit pressure.

When the rate error signal reduces, indicating regain of wheel-to-rail adhesion, the service portion permits the re-application of normal braking pressure.

The net result is a synchronous, closed loop, friction braking level consistent with the incoming retardation signal (P-wire), modified to lower braking levels as required to meet available adhesion.

In addition to the wheel slip correction inherent within the main closed loop synchronous brake control, a high gain wheel slip control loop is provided to further improve wheel slip control.

Both individual axle velocity and rate signals are fed to detectors which are calibrated to trip at specific signal level thresholds.

Rates or velocity differences exceeding the threshold values trigger the detectors. Detector operation causes energization of the wheel slip valves (two per truck), which locally reduce the disc brake unit air pressure.

Reduction in braking effort followed by a subsequent lowering of velocity difference or rate signals, indicating partial or full regain of wheel rotation, will cause the detectors to modulate the wheel slip valves to lap or full reapplication conditions.

A regenerative brake inhibit output (dynamic knockout) is also provided.

The safety lockout network limits friction and regenerative braking slip-slide control correction to a maximum of three seconds. Any braking slip-slide correction exceeding three seconds will terminate the correction by inhibiting outputs of the detectors.

All emergency brake applications will lock out the friction brake slip-slide correction system by opening the wheel slip valve circuits.

The system emergency brake is integrally separate from the service synchronous brake system, and operationally serves as a backup to the service brake.

The emergency brake is controlled by a normally energized electrical trainline and a normally fully charged pneumatic brake pipe running the length of the train. Interruption of electrical continuity of the trainline wire causes de-energization of normally energized electrical magnet valves in the emergency portion of one of the pneumatic brake units on each car, thus causing local venting of brake pipe air on each car. Whether initiated electrically or directly (i.e., trip cock), venting of the emergency brake pipe air causes the emergency sensing valves in the emergency portions of each brake application unit to deliver pressure directly to the truck brake units through the wheel slip valves.

The pressure delivered will be consistent with that required for an emergency braking rate corrected for car weight as sensed on a per-truck basis by the car's pneumatic load weighing system.

An electrical output signal from the synchronous brake electronic control unit relay interlock inhibits the recharge of brake pipe following initiation of an emergency application until the train has come to a stop, as detected by the zero speed detector.

A parking brake is provided on each car which may be remotely applied and released from the controlling cab. Operation is by two trainline wires, application and release. On each car, one set of parking brake control details is provided on one of the brake application units. The parking brake control, in response to the parking brake trainline control wires, delivers the proper air pressure to two brake units on one truck applying, locking, or releasing brake on both axles of the truck.

The manual parking brake unit provides the same function on each car, even though there may not be electrical power or air pressure available on the car.

Electrical parking brake applied signals are provided to trainline wires for purpose of providing train parking brake lamp indications in the cab.

Significant Progress

CDR's have been conducted on all major components and assemblies except the electronic control unit. The manufacturing and/or procurement of these items is in progress. The drawing status is essentially 100% complete except for the electronic control unit, which is 55% complete.

Interface Definition - The interfaces which exist between the synchronous brake system on the SOAC, the improved ride quality monomotor truck, and the self-synchronous propulsion, including the ASDP monitor panel, are being resolved and documented on Interface Log Sheets in accordance with procedures defined in Document No. UMTA-IT-06-0026-76-1.

Slip-slide control interface between the synchronous brake system and the self-synchronous propulsion system has been resolved by having three modes of control that are selectable by minor modifications that are being incorporated. The three modes are: 1) WABCO has 100% control; 2) Delco has 100% control, and 3) control is transferred between WABCO and Delco, with the authority transfer being primarily a function of car speed. The need for this special interface, that would not be required on production cars, results because both WABCO and Delco have slip-slide control requirements in their specifications, which must be tested and have service experience.

Weight Status - The weight of the synchronous brake system and its components is shown in Figure 51.

Analyses and Tests Performed - The ASDP brake subcontractor, WABCO, performed development tests on discs and pneumatic controls to provide test confirmation of production methods and productions of disc temperature and control response times. The following results were obtained.

Disc Tests - Pont-A-Mousson, WABCO's ASDP disc vendor located in France, modified an existing disc such that it closely resembled the ASDP disc. This experimental disc was the same in O.D., I.D., width and weight. Differences existed in the number of fins, the thickness of the braking faces and it was a one piece disc, not split as the ASDP disc. This disc was run through a dynomometer test program at Pont-A-Mousson late in April. The test program consisted of measuring heating and cooling rates, coefficient of friction at various speed and temperature conditions. Also, the synthetic transit route was simulated on the dynomometer and the discs performance checked. These tests confirmed the predicted temperatures and demonstrated that the disc could perform at the expected temperatures.

ASDP BRAKE SYSTEM

Weight Statement

No.	Item	No./Car	Estimated Weight Each	Estimated Weight Per Car
Truck Mounted Details				
1	Disc with Axle Mounted Hub	8	253	2024
2	Disc Brake Unit - Non-Parking Brake	6	187	1122
3	Disc Brake Unit - Parking Brake	2	231	462
4	Magnetic Pick-Up with Connector	2	.25	.5
	Sub Total - Truck Mounted Details			3608.5
	Weight Goal			3796
	Amount Current is Below Goal - 4.9%			
Car Mounted Details				
5	Parking Brake Unit	1	68	68
6	C-1 Vapolex Dryer	1	64	64
7	Electronic Control Unit	1	60	60
8	J-1 Pneu.Operating Unit (with B.P.Control)	1	159	159
9	J-1-A Pneumatic Operating Unit	1	148	148
10	Slip/Slide Valve	4	3.5	14
11	3/4" Check Valve	2	3	6
12	24-C Double Check Valve 2 - Parking Brake 1 - Leveling Valve	3	2.5	7.5
13	Cut-Out Cock (Ball-Vented)	6	3	18
14	Cut-Out Cock (with Position Switch)	2	5.5	11
15	Pressure Switch 1 - Brake Pipe 2 - Brake On (Replace Existing) 1 - Low Main Reservoir	4	4	16
16	F-1 Safety Valve	1	.25	.25
17	Test Fitting (6 with Choke)	10	.25	2.5
	Sub Total - Car Mounted Details			574.25
	Weight Goal			496
	Amount Current is Above Goal - 15.7%			

Total Brake System
Weight Goal
(Per Par. 3.5 of Spec. D239-10002-1)
Amount Current is Below Goal - 2.5%

FIGURE 51

Pneumatic Controls - WABCO assembled a preliminary half-car pneumatic system in their laboratory. This system used existing control valves that are similar to the ASDP equipment. This test rig was used to measure transient and frequency responses. The resulting data was then used in the slip-slide simulation model that is used to establish the electronic control parameters.

Future Events

The more significant activities planned include:

- Completion of System Simulation Modelling Studies
- Final System Weight Reduction Effort
- Issuing of Reliability Analyses (including FMEA) and Safety Analyses (including Fault Trees)
- Interface Solidification
- Completion of Dynamometer Testing of Split-Disc
- Final Design and CDR on Electronic Control Unit Emphasizing Rate Control Portion
- Conduction of System CDR
- Performing Prototype and Systems Tests
- Recommendation of Spare Parts Lists
- Publishing of Operational and Maintenance Manuals
- Manufacture and Test the System

SOAC Integration

Technical Description of Modifications - Boeing Vertol as System Manager for the Advanced Subsystem Development Program (ASDP) has reviewed and analyzed the designs generated by the contractors for the ASDP subsystems (self-synchronous propulsion system, improved ride quality monomotor truck, and synchronous brake system) to assure that this equipment is being developed in a manner than, when incorporated into the vehicle, will result in proper functioning of the ASDP-SOAC. Technical direction, as required to achieve ASDP requirements, is being given by Boeing Vertol to the ASDP subsystem contractors.

The hardware modifications to the SOAC, which will be made at Boeing Vertol, includes: removal of existing propulsion equipment, trucks, and certain brake system components; minor modification to the undercar structure; modification to the motorman's cab; relocation of certain undercar equipment; changes to piping and electrical cabling; installation of ASDP subsystem components; and fabrication and installation of new inter-component electrical cabling.

Significant Progress

Interface Definition - The procedures described in Document No. UMTA-IT-06-0026-76-1, "ASDP Vehicle Integration Plan", Boeing Document No. D239-10007-1) are being followed to resolve and define the interfaces (electrical power, electrical signal, hydraulic, and pneumatic) which exist between the SOAC, the self-synchronous propulsion system including the ASDP monitor panel, the improved ride quality monomotor truck, and the synchronous brake system. Details of these interfaces are being documented on the Interface Log Sheets required by the ASDP Vehicle Integration Plan.

Weight Status - The weight economies suggested by the original proposals for the advanced subsystems have not been realized. Substantial weight growth has been experienced in both the truck mounted propulsion components and the truck frame.

	Weight (lbs) per Truck	
Over Weight Components	Orig. Proposal	Current Weights
Delco Truck Items		
Motor Assembly	950	1840
Gearbox and Coupler	1450	2048
Budd Truck Components	7500	8926

Although motor growth has been substantial, the weight is still significantly lighter than conventional motors, 39% lighter than the ACT-1 motors, for example.

Cost and schedule considerations led to the procurement of existing configuration gearboxes and couplings, and although cast aluminum is used for the gear box casings, it is not as weight effective as the material suggests when full consideration of the fatigue loading and stiffness requirements are made.

The change in the improved ride quality monomotor truck primary spring configuration to a chevron type introduced heavy journal housings and side frame pedestal castings because of adherence to traditional practice of generous fabrication thickness with accompanying large stress margins for non critical areas.

Reduction of weight, based on knowledge gained in the test program, could be achieved for a production vehicle. However, substantial reductions would require requalification testing.

The self-synchronous propulsion system car body mounted equipment and the synchronous brake system components are relatively close to their contract weight goals.

Comparison between the weights of ASDP vehicles and the existing SOAC vehicles, based on latest estimates for both is as follows:

	Car No. 1 (Low Density)	Car No. 2 (High Density)
SOAC Empty Weight (AWO)	88,071	88,831
ASDP Empty Weight (AWO)	91,171	91,931

Analyses and Tests Performed - Identification has been made of the equipment which must be removed from the SOAC in preparation for installation of the ASDP subsystems. Layouts and drawings are being prepared to define the modifications of the motorman's cab and undercar structure that are required to install the ASDP subsystems (self-synchronous propulsion system including the ASDP monitor panel, improved ride quality monomotor truck, and synchronous brake system). These documents provide vendor supplied ASDP subsystems with the SOAC; pertinent data developed is defined by the Interface Log Sheets in accordance with the Vehicle Integration Plan.

Engineering analyses and trade-off studies are part of the review process Boeing Vertol is conducting on designs generated by the ASDP subsystem contractors. Both formal design reviews and informal meetings have been held with the ASDP subsystem contractors and action items developed to resolve areas of concern.

Future Events - After the 2-car SOAC train has completed its extended demonstration on the Port Authority Transit Authority's (PATCO) Lindenwold Line, it will be taken to the Boeing Vertol Philadelphia facility for vehicle modification and installation of the ASDP subsystems.

The SOAC trucks and bolsters will be removed and the improved ride quality trucks and bolsters installed. Boeing Vertol will assemble the improved ride quality monomotor trucks including the pressing of wheels on axles and the installation of both hydraulic and pneumatic piping and electrical cabling.

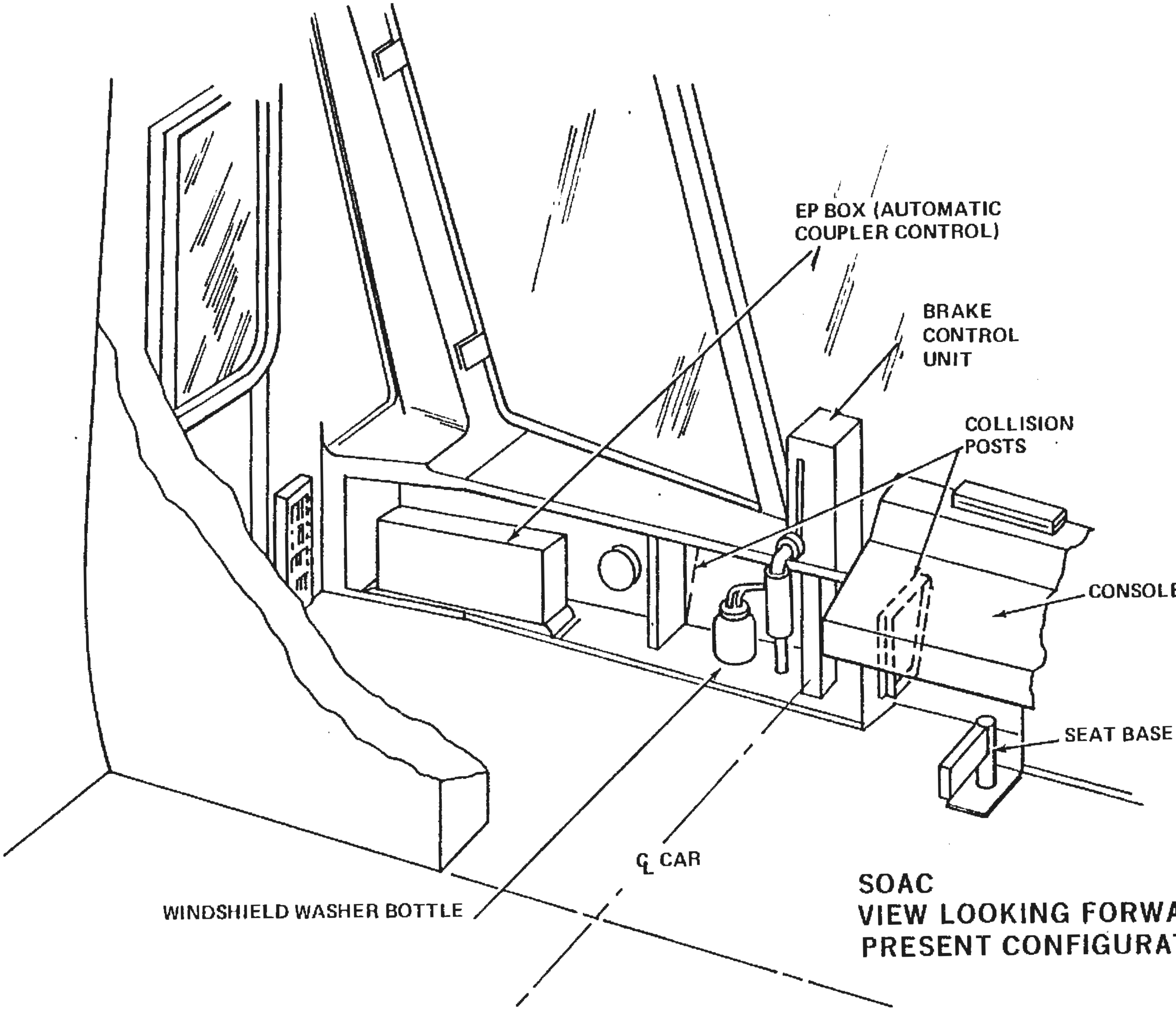
The undercar SOAC propulsion control and brake equipment will be removed. Some of the other undercar equipment will be relocated with minor undercar structure, wiring, and piping changes made accordingly. Changes will be made to the motorman's cab; they include rework of the collision post, windshield corner support, control console, and motorman's seat installation.

The underfloor components of both the ASDP self-synchronous propulsion system and the ASDP synchronous brake system will be installed; and structural analyses made of all ASDP subsystem equipment installations to assure structural integrity of the ASDP-SOAC.

The motorman's cab ASDP equipment (parking brake control, propulsion system ECU, and ASDP monitor panel) will be installed. (See Figures 52 and 53.)

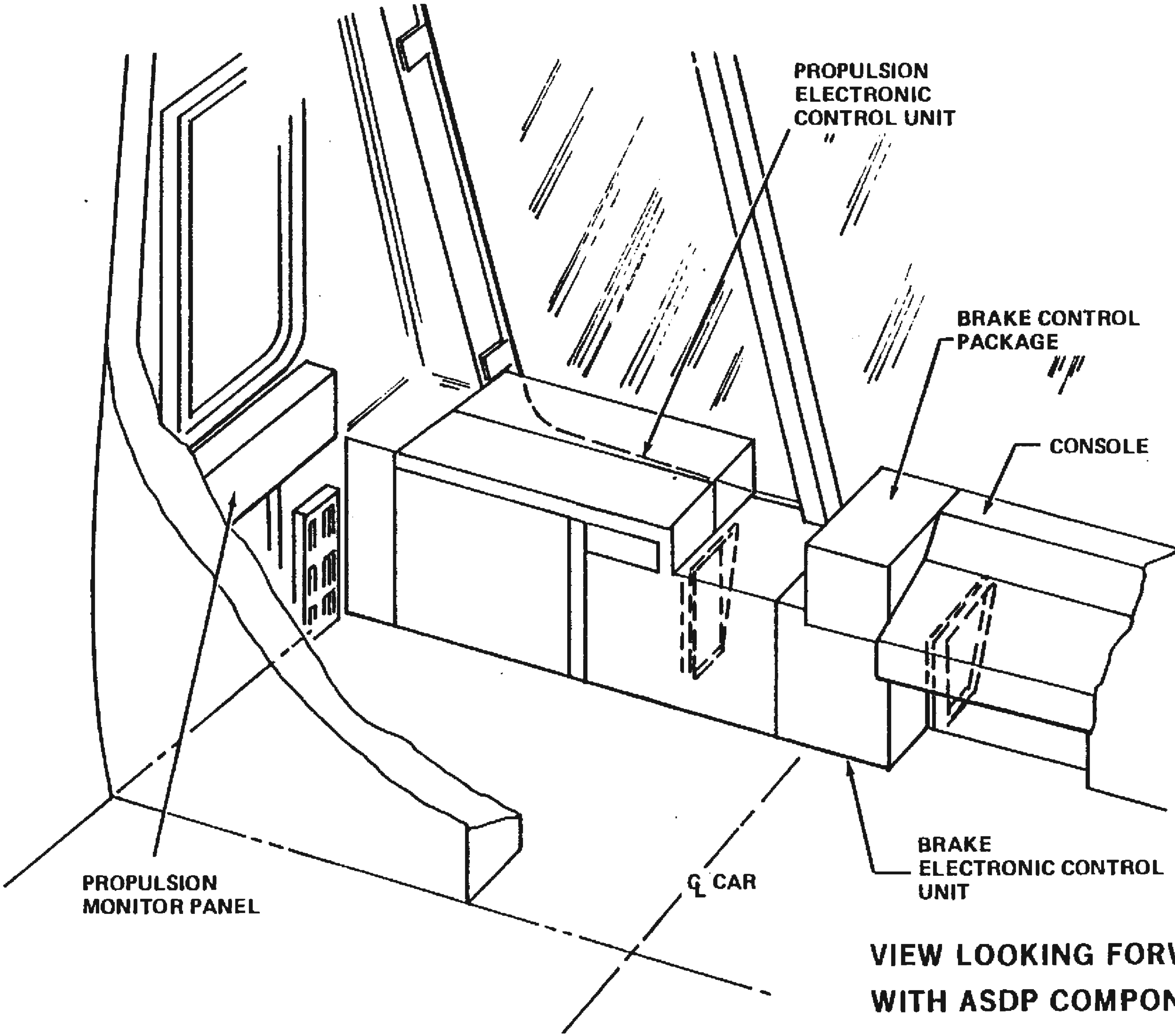
Electrical loads and electromagnetic compatibility (EMC) analyses will be performed. Electrical cabling/wiring drawings which incorporate the ASDP subsystem equipments into the SOAC will be prepared. Boeing Vertol will fabricate, install, and check out the electrical cabling required to interconnect the ASDP subsystem components into the SOAC.

The Boeing Vertol Quality Assurance Plan will be in effect during these modifications to the SOAC and the installation of the ASDP equipment. After completion of these tasks the ASDP-SOAC will be functionally tested on the Boeing Vertol test track prior to shipment to the UMTA-Transit Test Track, Pueblo, Colorado.



SOAC
VIEW LOOKING FORWARD
PRESENT CONFIGURATION

FIGURE 52



VIEW LOOKING FORWARD
WITH ASDP COMPONENTS

FIGURE 53