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Support and Power Plant Documentation for the Gas Turbine Powered Bus Demonstration Program

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Indianapolis, IN 46206

March 1982

Final Report for Period 1 January 1980 through 30 September 1981

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Cleveland, OH 44135
Under Contract DEN 3-187

for
U.S. DEPARTMENT OF ENERGY
Conservation and Solar Applications
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16. Abstract

The operational experience obtained for the GT404-4 gas turbine engines in the Intercity and Intracity Bus Demonstration Programs is described for the period January 1980 through September 1981. Support for the engines and automatic transmissions involved in this program provided engineering and field service, spare parts and tools, training, and factory overhauls. The Greyhound (intercity) coaches accumulated 183,054 mi (294,595 km) and 5154 hr of total operation. The Baltimore Transit (intracity) coaches accumulated 40,567 mi (65,285 km) and 1840 hr of total operation. In service, the turbine-powered Greyhound and Transit coaches achieved approximately 25% and 40% lower fuel mileage, respectively, than did the production diesel-powered coaches. The gas turbine engine will require the advanced ceramic development currently being sponsored by the DOE and NASA to achieve fuel economy equivalent not only to that of today's diesel engines but also to the projected fuel economy of the advanced diesel engines of the 1990s. Sufficient experience was not achieved with the coaches prior to the start of service to identify and eliminate many of the problems associated with the startup of new equipment. Because of these problems, the mean miles between incident were unacceptably low. The future gas turbine system should be developed sufficiently to establish satisfactory durability prior to evaluation in revenue service. Commercialization of the gas turbine bus engine remains a viable goal for the future.

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I. SUMMARY

Detroit Diesel Allison (DDA), Division of General Motors Corporation, has completed contractual requirements for support of the Gas Turbine Powered Bus Demonstration Programs under Contract DEN3-187 from NASA Lewis Research Center. The contract covered the period from 1 January 1980 through 30 September 1981.

The Demonstration Programs were planned to occur in three phases. During Phase I, the suitability of the gas turbine engine for intercity and intracity service would be demonstrated and an operational baseline with the all-metal engine established. During Phases II and III, introduction of ceramic technology from the DOE/NASA Ceramic Applications in Turbine Engines (CATE) program would demonstrate improved performance of the engine. Due to funding cutbacks, however, Phases II and III will not occur.

In Phase I of the Demonstration Program, four Greyhound intercity coaches and four RTS II transit (intracity) coaches, powered by GT404-4 gas turbine engines, were operated in representative service environments. Valuable experience was obtained through operation of the transit coaches. Although the previous GT404 engine models had been subjected to considerable intercity operation, no prior engine experience existed in the transit service.

This report covers the operational experience obtained for the GT404-4 engines in the intercity and intracity service environments through the support contract period of performance.

OBJECTIVE

The objective of this project was to provide personnel, spare parts, tools, training, and facilities as required to keep the gas turbine engines and the automatic transmissions operational throughout the duration of the Intercity and Intracity Bus Demonstration Programs.

The support project consisted of the following major tasks:

- o provide engineering and field service for the engines, transmissions, and vehicle interface systems
- o provide spare parts and special tools required for overhaul and repair
- o provide operation, maintenance, and driver training
- o provide factory overhauls

DISCUSSION OF RESULTS

- o The Greyhound coaches operating in the Intercity Bus Demonstration Program accumulated 183,054 mi (294,595 km) and 5154 hr of total operation. Of the total, 170,610 mi (274,568 km) and 4692 hr were logged in service. The service miles achieved were considerably lower than the 450,000 mi (724,205 km) service mileage anticipated for accumulation during the period. That is due to the startup problems experienced.

- o The Baltimore Transit coaches operating in the Intracity Bus Demonstration Program accumulated 40,567 mi (65,285 km) and 1840 hr of total operation. Of the total, 19,660 mi (31,639 km) and 1096 hr were logged in service during the 3-month service period. The number of service hours achieved

was lower than the anticipated accumulation of 1500 hr for the period because of startup problems experienced. Baltimore city operation had been planned for 1 yr of service with 6000 hr accumulated during the period, but lack of funding ended the program prematurely.

- Driver and passenger reactions to the gas turbine coach were generally favorable when the vehicle operated without incident (after acceleration and braking improvements were made). However, both drivers and passengers were annoyed when delayed by any failure and the gas turbine system was usually blamed. The lack of engine noise and vibration, which resulted in a quiet and less fatiguing ride, and the lack of exhaust smoke and odor were features most often referred to by the drivers and passengers. The drivers also liked the road performance of the turbine, most often noting the superior hill climbing ability with the engine.

- The fuel average achieved with the Greyhound turbine-powered coach in intercity service was 4.26 mpg. Diesel coach fleet average in similar service is 5.66 mpg.

- The fuel average achieved with the Baltimore turbine-powered transit coach in city service was 2.7 mpg. Diesel coach fleet average in similar service is 4.3 mpg.

- The mean miles between incident experienced in Greyhound intercity service were 4265 mi for the engine, 21,326 mi for the transmission, and 5170 mi for the coach. The mean miles between incident in Baltimore transit service were 2107 mi for the engine, 6322 mi for the transmission, and 862 mi for the coach. Although anticipated performance was not established at the start of the demonstration programs, these results are considered to be unacceptably low because of the large number of startup problems experienced.

- Analysis of the braking requirements in the transit driving cycle indicates that the necessary vehicle stopping times require significant assistance from the engine, turbine or diesel, but that most of the power required to stop must be absorbed by the brakes. Transit experience has shown that a vehicle retarder is required to extend brake life.

- The bus duty cycle profiles obtained during revenue service revealed that the Baltimore transit operation was 3 to 7 times more severe to the GT404-4 engine gas path rotating components than was operation on the Greyhound intercity express run.

CONCLUSIONS

- Sufficient experience was not achieved with the coaches prior to the start of service to identify and eliminate many of the problems associated with the startup of new equipment. Vehicle mileage accumulated with the previous model GT404-3 engine prior to the start of DDA-sponsored field evaluation was nearly 5 times greater than comparable experience available to the GT404-4 engine at the start of service in the bus programs. Because of startup problems, only about 40% of the anticipated mileage in Greyhound service and 70% of the anticipated hours in Baltimore city service were accomplished. Although the program did not accomplish the operational miles and hours anticipated and was ended prematurely for lack of funding, a great deal of valuable experience was obtained. Critical knowledge gained in such areas as duty cycles, vehicle acceleration and braking, inlet filtration during winter driving, and coach systems interface will be useful in the design and development of future gas turbine systems.

- In-service fuel mileage achieved with the turbine-powered Greyhound and Transit coaches was approximately 25% and 40% lower, respectively, than with the production diesel-powered coaches. These comparisons are within 3% of computer predictions using the simulated operating profiles. The bus programs had been planned to occur in three phases, with ceramic technology from the DOE/NASA CATE program introduced in the latter phases to demonstrate improved performance. Due to funding cutbacks, Phases II and III did not occur. In view of the growing importance of fuel consumption, the gas turbine will be required to demonstrate fuel economy not only equivalent to that of today's diesel engines but also to the projected fuel economy of the advanced diesel engines of the 1990s. It is anticipated that the necessary improvements in fuel consumption can be obtained through the use of advanced ceramic development currently being sponsored by the DOE and NASA.

- The bus duty cycle profiles obtained for the Greyhound intercity and Baltimore city runs revealed that transit operation represents a significantly more severe service environment for the GT404-4 engine. Since the GT404-4 vehicular engine design has been established through engine experience on the intercity express type duty cycle, transit operation exceeds some of the original design criteria for the engine.

- Because of the problems associated with the introduction of new systems, the mean miles between incident were unacceptably low. This made it difficult and costly to properly evaluate the suitability of the gas turbine for coach operation. It is recommended that, in the future, the gas turbine system be subjected to sufficient development in each specific application to establish satisfactory durability prior to evaluation in the revenue service environments. The bus programs have established the basis for formulating future demonstration programs with the gas turbine engine and commercialization of the gas turbine bus engine remains a viable goal for the future.

II. INTRODUCTION

The Allison GT404 engine is a highly regenerative, low pressure ratio, two-shaft, industrial gas turbine engine designed for heavy-duty vehicular and stationary applications. The GT404 series of gas turbine engines has been under active development at DDA since 1970. Similarly, the HT740CT and V730CT transmissions have evolved from a long line of transmission developments with initial production in 1971 on the HT740D diesel truck transmission and the V730D diesel coach model in 1975. These production units were modified to adapt these proven designs for use with the GT404 gas turbine engine.

In addition to extensive dynamometer testing, the engine and transmission have been subjected to a variety of service environments through field evaluation programs funded jointly by DDA and the users. Some of these applications included heavy-duty highway trucks, intercity coaches, generator sets, air compressors, and marine and stationary industrial power plants. The 280 hp (209 kW) GT404-1 and GT404-2 engines accumulated nearly 1,000,000 truck miles (1,609,000 km) over 900,000 coach miles (1,448,000 km) and over 16,000 hr in marine and stationary power operation. More recently, the 300 hp (224 kW) GT404-3 and 390 hp (291 kW) GT505-3 engines in truck and coach applications accumulated over 1,132,000 mi (1,822,000 km) whereas marine and stationary power applications logged more than 5100 hr operating in service. Over 32,500 hr of engine operation were accumulated for all applications during the GT404/GT505-3 field evaluation program.

In 1970, DDA provided the first gas turbine engine/automatic transmission power package for the Greyhound coach application. The power plant was the 280 hp (209 kW) prototype for the GT404 engine, and the transmission was the prototype HT740T. Since that time, nearly 1,300,000 mi (2,092,000 km) of Greyhound intercity operation have been accumulated with previous GT404 engine models and HT740CT transmissions. Although operation of an advanced-design transit coach with an early GT404 engine model provided limited experience in a prototype environment, no previous GT404 engine and V730CT transmission experience existed in transit revenue service.

The gas turbine engine offers a number of potential advantages to the transportation industry and to the bus riding public. Long life, the elimination of the water cooling system, and the virtual vibration-free operation of the engine will increase reliability, reduce overall vehicle maintenance, and improve driver efficiency. The engine offers excellent cold weather starting, multifuel capability, and excellent torque characteristics for improved vehicle performance. The engine is substantially quieter than the diesel engines presently in use and is more environmentally acceptable due to lower exhaust emissions. These factors, combined with the virtual vibration-free operation of the basic engine, will provide passengers with a more comfortable and less tiring ride, thus diverting automobile ridership to buses.

The Intercity and Intracity Bus Demonstration Programs were initiated to accelerate acceptance of the gas turbine engine by the transportation industry and to provide necessary input for further development and commercialization. These programs would subject the gas turbine engine to operation in the intercity and transit revenue service environments. The operational data obtained with the engines in these service environments would evaluate such criteria as performance, driveability, reliability, maintainability, and fuel economy.

The demonstration programs were structured so that advanced ceramic components under development in the DOE/NASA CATE program could be introduced into the engines for demonstration of the continuing improvements in fuel efficiency achievable with these engine configurations.

The gas turbine engines and automatic transmissions for use in the buses involved in the Intercity and Intracity Bus Demonstration Programs were provided by DDA under separate contract to the DOE. DDA procured the hardware and assembled and delivered 11 GT404-4 industrial gas turbine engines and five HT740CT and six V730CT automatic transmissions. The engine/transmission build program is discussed in Appendix A of this report.

DDA provided engineering support to the bus conversion facilities for integration of the gas turbine power packages in the production Motor Coach Industries Model MC-8 Greyhound intercity coaches and General Motors Corporation RTS II model transit coaches involved in the demonstration programs. This support was provided by DDA under separate contracts to the Jet Propulsion Laboratory and Booz.Allen and Hamilton. A general description of the Greyhound coach and Baltimore Transit coach installation features is presented in Appendix B of this report.

The objectives of this project for support of the GT404-4 gas turbine engines and the automatic transmissions involved in the Intercity and Intracity Bus Demonstration Programs included the following:

- o provide engineering and field service for the engines, transmissions, and vehicle interface systems
- o provide spare parts and special tools required for overhaul and repair
- o provide operation, maintenance, and driver training
- o provide factory overhauls

A summary of contractual work performed by DDA in support of the Intercity and Intracity Bus Demonstration Programs is listed below.

- o Contract DE-AC02-78 CS54867. Department of Energy dated 28 August 1978 to procure and deliver 11 engines and transmissions.

- o Contract KU-681939. Jet Propulsion Laboratory dated 2 February 1979 to provide integration support to Motor Coach Industries for Greyhound coaches.

- o Contract 2611-002-CO-104-01. Booz.Allen and Hamilton dated 6 February 1979 to provide integration support to Modern Engineering for Baltimore Transit coaches.

- o Contract DEN 3-187. NASA Lewis Research Center dated 6 February 1980 to provide labor, spare parts, and tools to keep coach engines and transmissions operational.

III. BUS DEMONSTRATION PROGRAMS SUPPORT PROJECT

OBJECTIVE

The objective of the Support for the Gas Turbine Powered Bus Demonstration Program under NASA Contract DEN3-187 was to provide engineering and field service support for the gas turbine engines and automatic transmissions involved in the Intercity and Intracity Bus Demonstration Programs. The period of performance of this total support effort was the period commencing 1 January 1980 and extending through 30 September 1981. Funds from the U.S. Department of Energy, Office of Transportation Programs, were used to sponsor this project.

Figure 1 shows the operational structure for the Bus Demonstration Programs, of which the support project was a part, and the interface of the various government agencies and contractors involved. Funding for the Intercity Bus Program was provided by the U.S. Department of Energy in a cooperative effort with Greyhound Lines, Inc. The Intracity Bus Program was jointly funded by the Urban Mass Transportation Administration of the U.S. Department of Transportation and the U.S. Department of Energy. The Demonstration Programs were intended to collect, evaluate, and disseminate information on gas turbine performance, reliability, driveability, and public reaction in actual fleet bus operation and through this effort to accelerate development and commercialization of the engine for transportation applications.

All of the work performed under this contract was in support of the Bus Demonstration Programs. These included the following:

- Greyhound Lines Program. This program consisted of four intercity coaches operating in revenue service between selected city pairs with a cumulative mileage objective of 450,000 mi (724,205 km) for the service period. Five engine/transmission power packages were provided to this program.

- Baltimore Transit Program. This program consisted of four intracity coaches operating in revenue service in Baltimore, Maryland, with a cumulative hour objective of 6000 hr for 1 yr on city service runs. Due to budgetary restraints, however, transit coach operation in the program terminated three months after the start of city service. Six engine/transmission power packages were provided to this program.

- Test Track Program. This program consisted of one of the Baltimore Transit Program coaches operating at the Transportation Research Center of Ohio (TRC) test track prior to entering revenue service with a cumulative mileage objective of 10,000 miles (16,100 km).

SCOPE OF WORK

Within the scope of this project, DDA was required to provide engineering and field service support, inspection and overhaul, repair and modification, personnel training, and spare parts and special tools for the engines and transmissions. DDA was also required to maintain records for each engine and transmission involved in the demonstration programs in order to document accurately the continuous history of each unit. During the performance of these tasks, DDA coordinated the associated efforts with NASA Lewis Project Office personnel.

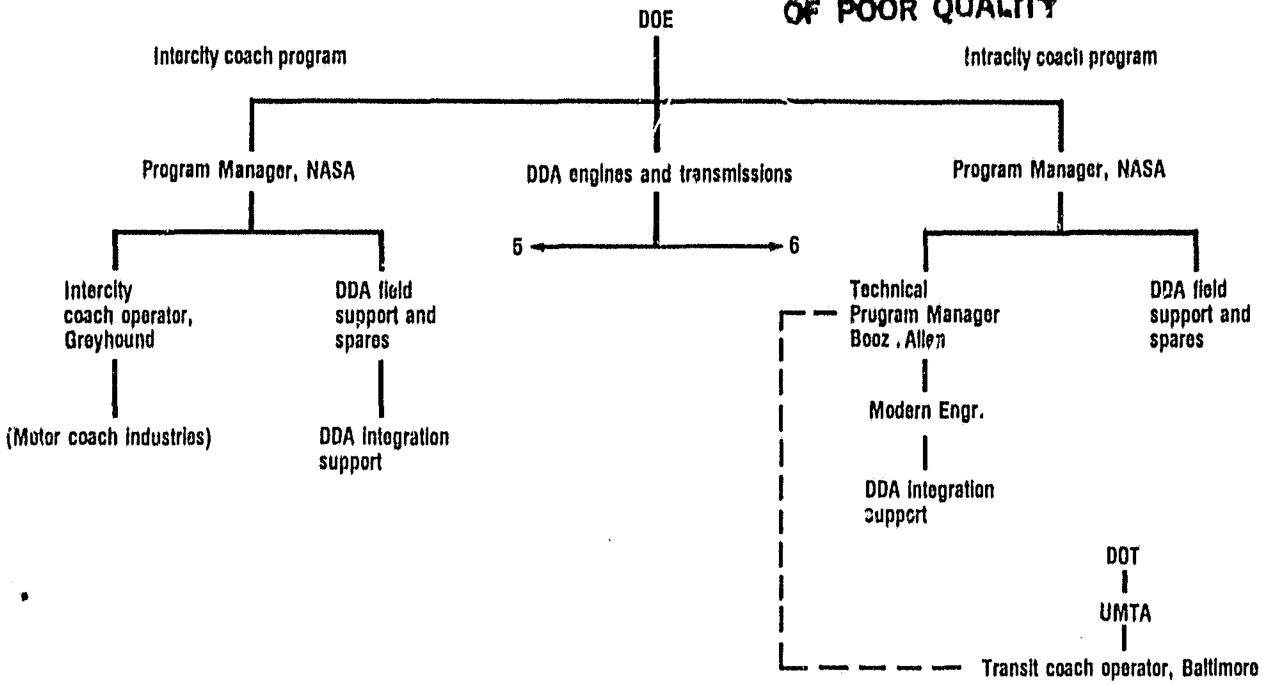

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Figure 1. Intercity/Intracity Bus Demonstration Programs organization.

The support project consisted of the following major tasks:

- o provide qualified engineering and field service personnel to assist in the operation, maintenance, and repair required to keep the engines, transmissions, and vehicle interface systems operational throughout the duration of the Bus Demonstration Programs (Coordination of all aspects of the project was included under this task. When deemed appropriate by DDA, engine and transmission repairs were performed in the field using either garage personnel or DDA Distributor personnel and facilities.)

- o provide factory personnel and facilities to repair or update engines and transmissions returned from the field (This task included teardown, inspection, parts rework or replacement, rebuild, and acceptance test.)

- o provide spare parts and special tools required for overhaul and repair of the engines and transmissions

- o conduct training programs for the bus operators and maintenance personnel on the operation and maintenance of the engines and transmissions

- o prepare monthly Technical Progress Reports and monthly Financial Reports, organize program coordination meetings, prepare and present written and oral reports on progress and problems and a program summary at a Contractors' Coordination Meeting, and prepare a final report for the program

Coordination

During the performance of this support contract, DDA coordinated all aspects of the project with NASA Lewis Project Office personnel.

DDA maintained almost daily communication with personnel from the Greyhound, Baltimore Transit, and test track operating facilities to obtain coach status, identify problems, and provide support and parts required to keep the engines and transmissions operational. In addition, DDA maintained regular communication with NASA Lewis, Greyhound, Baltimore Transit, and Booz.Allen and Hamilton for the purpose of keeping their personnel current on program status and problem situations.

Table I lists the major coordination meetings for the bus programs held during the support project period of performance involving representatives from DDA, DOE, DOT, NASA Lewis, Booz.Allen and Hamilton, Greyhound, and Baltimore Transit. In addition, a number of informal planning meetings were held throughout the project.

Table I.
Summary of coordination meetings:
Intercity/Intracity Bus Programs

Date	Location	Subject(s)
16 January 1980	DDA	Current problems, Greyhound service experience, and future plans
29 January 1980	DDA	Life cycle cost study for transit coach and transit coach program status
22 February 1980	DDA	Greyhound program status and future plans
25 March 1980	DDA	Engineering test results on Greyhound coach 5994 and current transmission problems
10 April 1980	NASA Lewis	Engine control system, design concepts, quality control, and current controls problems
16 July 1980	DDA	Failure investigation of gasifier quill shaft bump stop on Greyhound engine S/N T5
5 August 1980	DOT	Transit coach program status and future plans

Table I. (cont)

Date	Location	Subject(s)
7 August 1980	DDA	Greyhound coach operation, engine and transmission status, and coach performance
19 August 1980	TRC test track	Transit coach performance and vehicle configuration for transit service
26-27 August 1980	DDA	Quality assurance review
26 September 1980	DDA	Failure investigation of development engine compressor, casting problem, and compressor replacement plan for coach engines
14 November 1980	Greyhound (Chicago)	Coach operation and maintenance
24 November 1980	DOT	Transit coach readiness for Baltimore service
4 December 1980	Greyhound (Phoenix)	Greyhound engine, transmission, and vehicle problems, program status, and future Greyhound and transit requirements
24 March 1981	DOT	Initiation of transit coach service in Baltimore
27 March 1981	Baltimore Transit	Operation and maintenance support
30 June 1981	Greyhound (Phoenix)	Program status, recent operating experience and engine problems, and completion of the program

DDA submitted a Technical Progress Letter Report and a Financial Management Report for each accounting month of contract performance.

Training

Table II lists the engine, transmission, and coach training and familiarization activities which were conducted by DDA in support of the Bus Demonstration Programs. Additional training was provided to the Baltimore Transit personnel on transit coach installation features and coach operation by Modern Engineering, Booz.Allen and Hamilton, and DDA. Engine service information dealing with revised or added maintenance procedures and special installation features was provided periodically to the Greyhound and Baltimore Transit facilities.

The training provided the Greyhound and Baltimore Transit garage personnel with the experience necessary to perform routine service and maintenance and to assist in troubleshooting and repair.

Table II.
Summary of training and familiarization activities.

Date	Location	Description
26-28 June 1979	DDA training headquarters	Greyhound personnel--engine and transmission familiarization, operation, and maintenance
10-12 July 1979	DDA training headquarters	Greyhound personnel--Engine and transmission familiarization, operation, and maintenance
*21-25 April 1980	MTA garage--Baltimore	Baltimore Transit personnel --engine familiarization, operation and maintenance, including burner, regenerator, and accessory and external component removals
29-30 April 1980	Greyhound garage--Chicago	Greyhound personnel--engine and transmission familiarization, coach installation features, maintenance and troubleshooting procedures, and driver instructions
13-14 May 1980	Greyhound garage--Louisville	Greyhound personnel--engine and transmission familiarization, coach installation features, maintenance and troubleshooting procedures, and driver instructions

*Two sessions were originally planned for the Baltimore Transit garage to accommodate 12-15 persons (6-8 persons each session). However, the size of the group was reduced and only one session was required.

Table II. (cont)

Date	Location	Description
20-21 May 1980	Greyhound garage--Indianapolis	Greyhound personnel--engine and transmission familiarization, coach installation features, maintenance and troubleshooting procedures, and driver instructions
3 March 1981	MTA garage--Baltimore	Baltimore Transit personnel--engine and transmission maintenance requirements, program communication procedures, and spare parts and tools availability

IV. GAS TURBINE INTERCITY BUS DEMONSTRATION PROGRAM

SCHEDULE

Figure 2 shows the Gas Turbine Intercity Bus Demonstration Program schedule. Phase I of the Intercity Bus Demonstration Program involved the operation of four gas turbine powered Motor Coach Industries Model MC-8 Greyhound coaches in revenue service between selected city pairs.

DDA procured the hardware and assembled and delivered five GT404-4 gas turbine engines and HT740CT automatic transmissions to Greyhound Lines, Inc., under separate contract to the U.S. Department of Energy (see Appendix A). These power packages were installed in the four coaches (one power package was retained as a spare).

Coach 5992 was tested, was delivered, and commenced revenue service on schedule. The delays (approximately one to two months) experienced in completing and delivering the remaining three coaches were attributed to the following:

- o return of the engine electronic control assemblies to the vendor for improved (faster) power transfer clutch lockup and road speed governor response (Faster response of the power transfer clutch improved vehicle performance while the road speed governor modification reduced hysteresis and improved repeatability in the governing mode.)

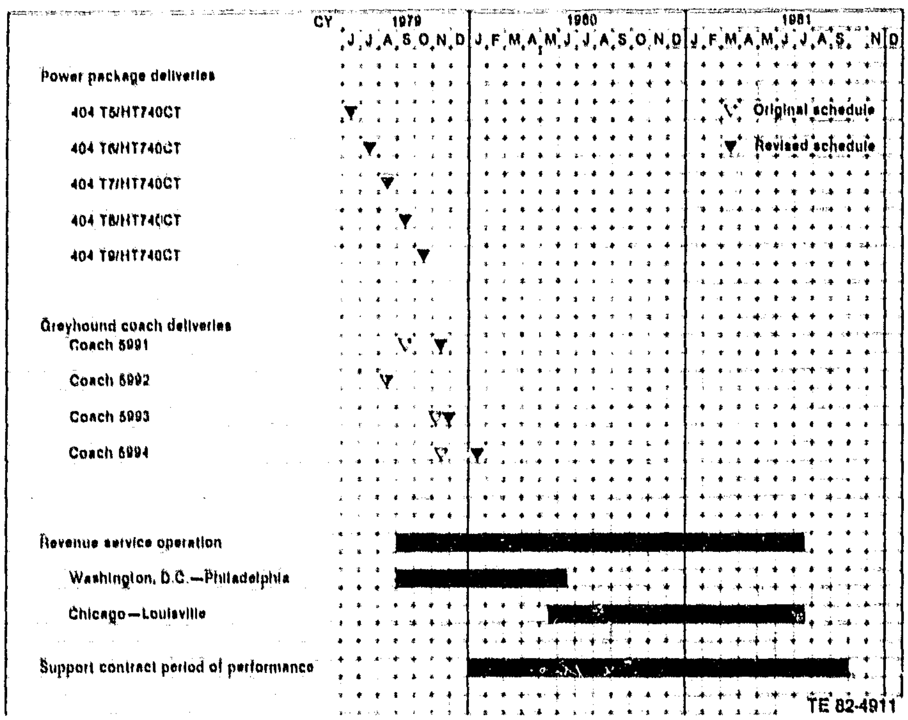

Figure 2. Gas Turbine Intercity Bus Demonstration Program schedule (Phase I).

- return of the HT740CT transmissions to DDA for incorporation of first gear start (see Appendix A) and to inspect for and correct fluid coupling seal leakage (Seal damage and subsequent leakage resulted from improper surface finish, which did not meet design requirements, on the mating coupling shaft.)

- return of the alternator drive assemblies to DDA for modifications to ensure proper tightening and locking of the drive shaft locknut (see Greyhound Service Operation--Other Engine Problems later in this section)

- late delivery of materials required by the coach conversion facility to complete the installations

Operation of the first coach in revenue service began on 30 August 1979 on the Washington, DC, to Philadelphia run. The route structure between Washington, DC, and Philadelphia covered an average 140 mi (225 km), and this high-density area provided for a large number of stops. In order to broaden the operational experience, the coaches were moved to Chicago in mid-1980 for operation on the Chicago to Louisville run. This run of slightly over 300 mi (483 km) provided an express run with only a few stops and a local return run with additional stops in the schedule. The coaches remained on this route until the program was completed on 13 July 1981.

GREYHOUND SERVICE OPERATION

Figure 3 shows the total service miles accumulated by the four GT404-4 powered Greyhound coaches for each of the revenue operating months of the Intercity Bus Demonstration Program. The service period for each of the coaches is also shown. Greyhound revenue service operation was initiated on 30 August 1979 with the introduction of coach 5992 on the Washington, DC, to Philadelphia run. DDA was under contract to the Jet Propulsion Laboratory at that time for Greyhound coach integration support, and funds from the contract provided limited field service support. By the end of CY 1979, three coaches were released to revenue operation in Washington, DC. The support contract with NASA Lewis was received by DDA in February 1980 and procurement of spare parts was initiated. At the start of the support project, DDA established a task force of cognizant personnel to investigate engine problems that had been experienced by Greyhound during the first 5 months of operation and to implement appropriate corrective action. This committee also coordinated activities related to transmission and vehicle problems. In mid-1980, the fleet was moved to Chicago for operation on the Chicago to Louisville runs, where the coaches remained until program completion on 13 July 1981. Four coaches operated in the program until December 1980 when budgetary restraints necessitated a reduction from four to two coaches.

Total service mileage accumulated by the Greyhound coaches was 170,610 mi (274,568 km). This is considerably lower than the anticipated accumulation of 450,000 service miles (724,205 km) during the period and is due to the startup problems experienced.

Three major engine problems and two coach operational problems were experienced during the Greyhound program. These problems, as shown in Figure 3, are located in the service period affected and involved deficiencies that required immediate corrective action that necessitated the suspension of coach operation while implementing the required changes.

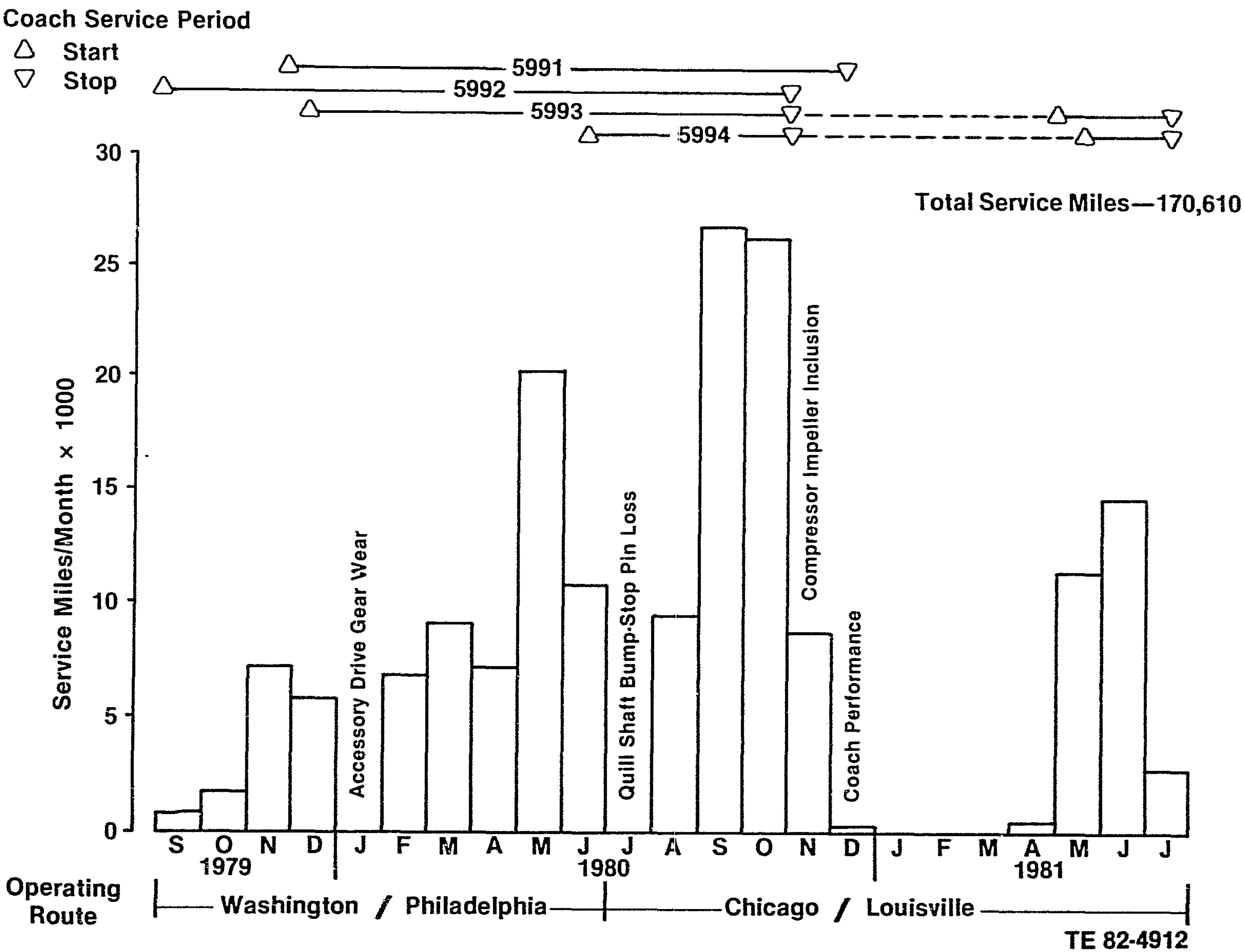

Figure 3. Greyhound service operation.

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The engine, transmission, and coach operational problems experienced during Greyhound service operation are discussed later in this section. The chronological histories of the GT404-4 engines and HT740CT transmissions involved in the Greyhound program are presented in Appendix C.

GREYHOUND SERVICE EXPERIENCE

The total service experience with the four GT404-4 powered Greyhound coaches operating on the Washington, DC, to Philadelphia and Chicago to Louisville runs is segmented into four operating periods, as shown in Figure 4. These periods profile, as a percentage of available service days, the coach operating days and the service days lost due to incidents which prevented the coach from starting a scheduled revenue run or completing a run in progress.

Through the total service period, the coaches were operational an average 36.8% of the available service days. Lost service time due to engine related incidents was an average 48.2% of the available service days. The overall engine performance shows the negative influences of the major engine problems and resultant utilization of the spare engine early in the program on operating days lost from service. Taken together, the three major engine problems experienced during Greyhound service operation accounted for nearly 60% of the total service days lost due to all engine incidents.

Coach performance during the final operating period in the program, April-July 1981, was significantly improved from the earlier periods, reflecting the absence of major engine difficulties and the accumulation of service experience. The coaches were operational 68.9% of available days, which is more than double the average coach operation for the previous periods.

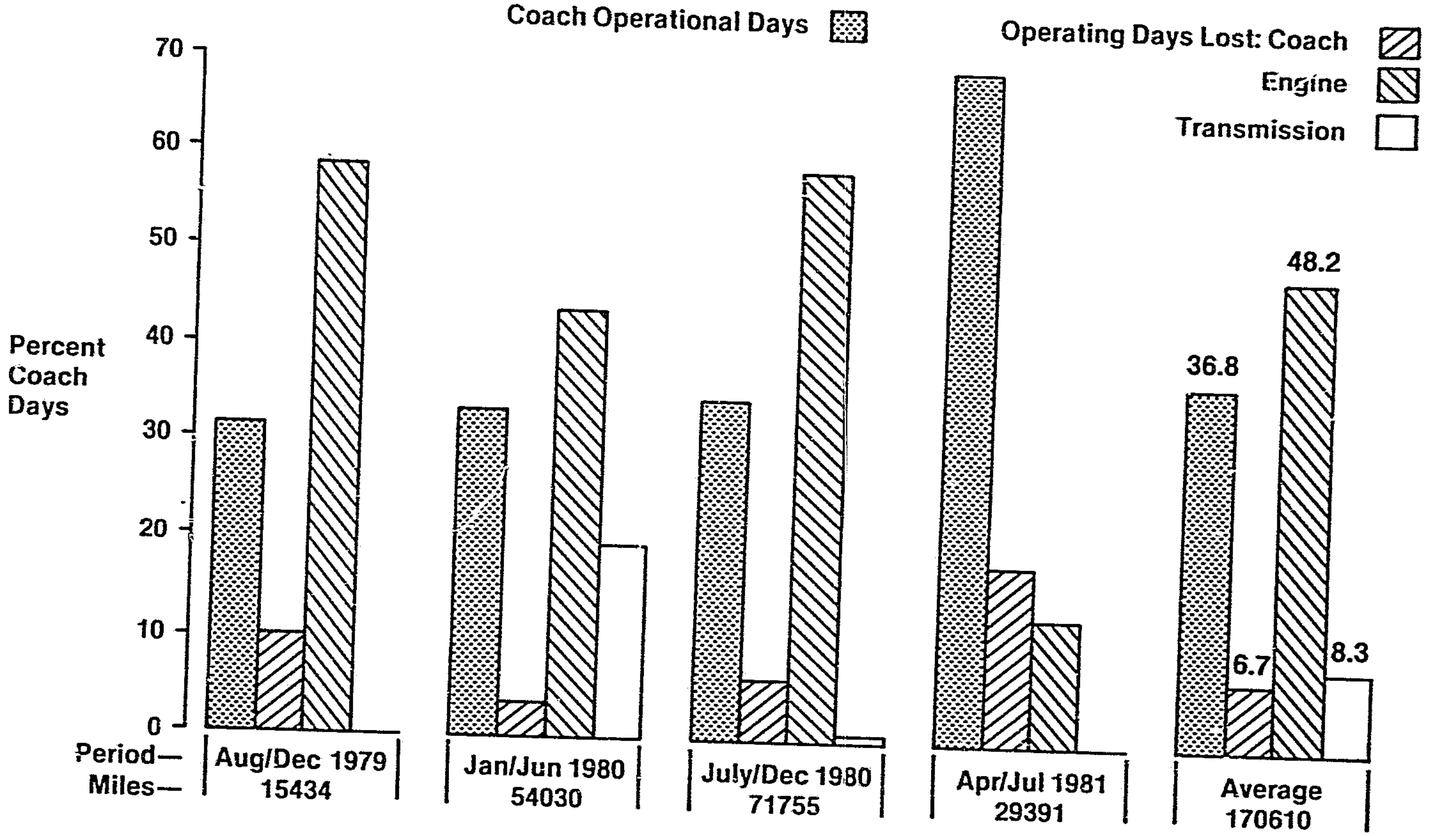
The number of incidents attributable to the engine, transmission, and coach and the mean miles between incidents for the service period are also shown in Figure 4. Major coach problems involved driveline alignment, alternator and oil cooler fan motor malfunctions, and engine intake duct blockage due to leaf ingestion.

The fuel average achieved with the GT404-4 engine in the composite service environment of local runs (state highways with numerous stops) and express runs (interstate highway with few stops) was 4.26 mpg. Diesel fleet average in similar service is 5.66 mpg.

Many favorable comments on the engine were received from drivers and passengers during the program. Features often referred to were the smooth and quiet ride and the good road performance, particularly when climbing very steep hills. The bus was described as "a truly well-engineered piece of equipment."

GREYHOUND SERVICE OPERATION--MAJOR ENGINE PROBLEMS

The three major engine problems experienced during Greyhound service operation involved design and quality originated deficiencies as noted below. Taken together, the three major engine problems accounted for nearly 60% of the total service days lost due to all engine incidents in the Greyhound program.



Number of Incidents	Aug/Dec 1979	Jan/Jun 1980	July/Dec 1980	Apr/Jul 1981	Total	Mean Mile/Incident
Coach	3	6	13	11	33	5170
Engine	9	11	14	6	40	4265
Transmission	0	7	1	0	8	21326
Powerplant (Engine + Transmission)					48	3554

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Figure 4. Greyhound service experience.

- Design

  - Accessory Drive Gear Wear. The Greyhound accessory loads exceeded the design capability of the gear, necessitating the change from cast iron to steel accessory gears in all of the Greyhound engines.

- Quality

  - Quill Shaft Bump-Stop Pin Loss. The orientation pin size and fit in the bump-stop assemblies did not meet design requirements, which necessitated the inspection of all coach engines and replacement of bump-stop pins.

  - Compressor Impeller Inclusion. A subsurface casting defect was formed by the collection of alloy additives that could not be identified by X-ray inspection. Impeller replacement with filtered casting parts was required on all coach engines.

Accessory Drive Gear Wear--Design Deficiency

One major engine problem originating from a design deficiency surfaced early in the program. The failure of the accessory drive gear in the Greyhound engine power turbine gear train was attributed to insufficient load-carrying capacity of the gear.

The Greyhound engine power turbine gear train is shown schematically in Figure 5. The power turbine driven accessories are identified in Figure 5 as the coach electrical system's 24-V alternator, direct driven via a 1:2.895 step-up gearbox from the No. 1 accessory drive gear, and the air conditioning (Freon) compressor, pulley driven with 1:0.526 speed reduction from the No. 4 accessory drive gear. At peak accessory load conditions, the alternator imposes 17 hp (12.7 kW) at the No. 1 gear drive and the Freon compressor imposes 20.3 hp (15.1 kW) at the No. 4 gear drive. Power flow is from the power turbine rotor (pinion gear) through the No. 2 accessory drive gear and to the coach accessory drives.

Heavy wear occurred on the cast iron No. 2 accessory gear teeth (Figure 6) at the mesh with the power turbine accessory drive gear after 3870 mi (6228 km) of operation on Greyhound engine S/N T5. This mesh experiences the highest tooth loading of the accessory drive gears, a calculated hertz stress of 112,800 psi (777.7 MPa) from the impact of combined peak accessory loads and the relative diameters of the gears.

As in the GT404-3 engine design, pearlitic malleable cast iron accessory gears were used in the GT404-4 engine. Casting porosity at the surface significantly reduced the load-carrying capacity of the gear, which resulted in wear and subsequent fatigue failure at the tooth root. In order to avoid an expensive and time-consuming redesign effort, case-hardened SAE 8620 steel gears were substituted for the cast iron gears in all of the Greyhound engines. Since the accessory gear problem occurred early in the Greyhound program, the steel accessory drive gears were subsequently subjected to considerable field operation without further incident.

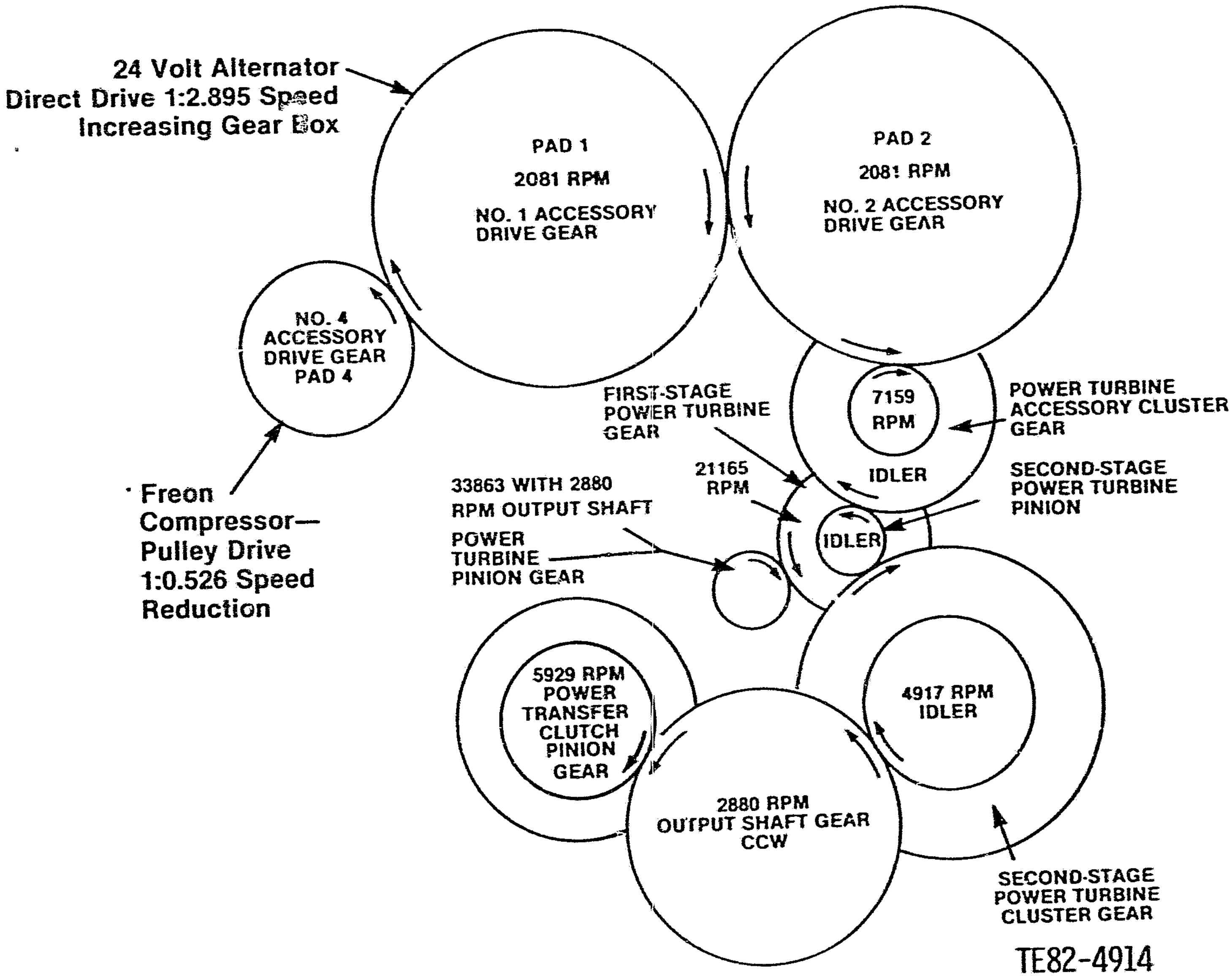

Figure 5. Greyhound engine power turbine gear train schematic.

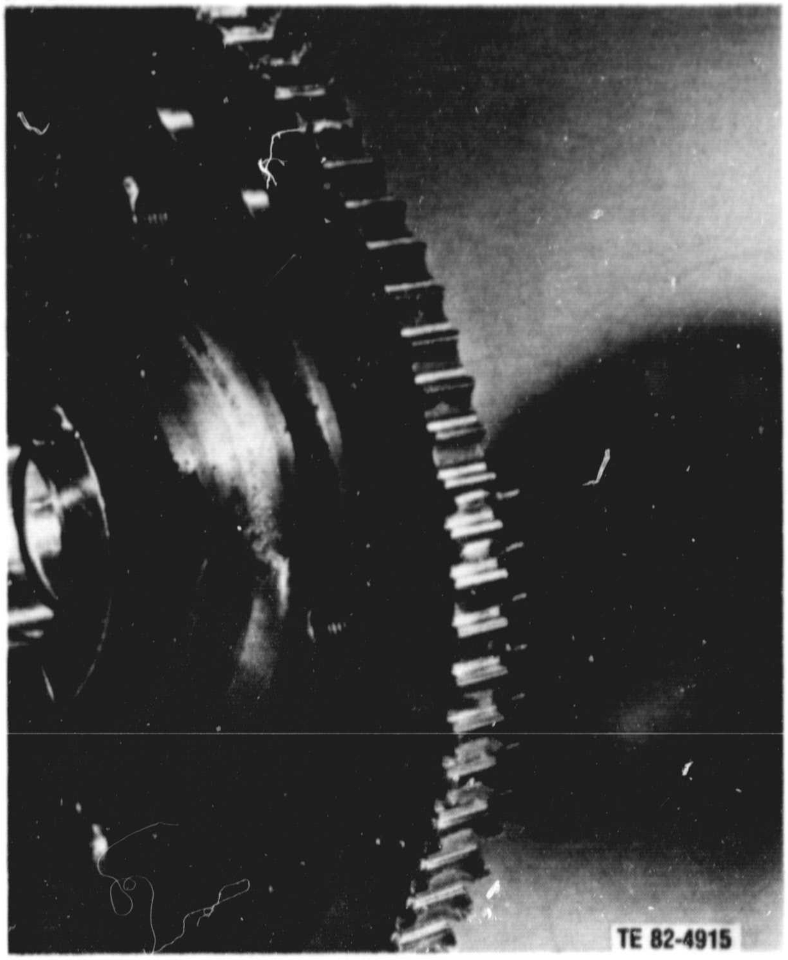

Figure 6. Failed accessory drive gear from Greyhound engine S/N T5 (149 total engine hours).

Loss of Quill Shaft Bump-Stop Orientation Pins--Quality Deficiency

The first of two major engine problems originating from a quality deficiency involved the loss of the orientation pins in the quill shaft bump-stop assembly.

The quill shaft bump-stop assembly is located along the gasifier main shafting and is shown in the engine cross section (see Figure 7). A failure occurred after 16,740 mi (26,940 km) of Greyhound operation on engine S/N T5 and was initiated by the loss of the bump-stop orientation pins, which permitted the bump-stop assembly to creep circumferentially, reorienting itself to create a significant lubrication leak from the bump-stop outer diameter to the gearbox cavity. This leak essentially terminated the supply of pressure oil to the bump-stop bushing and greatly reduced the oil supply pressure in the passages that provide lubrication to the power turbine pinion gear mesh and the power turbine bearings. Figures 8 through 10 show the failed bump-stop assembly and gasifier quill shaft.

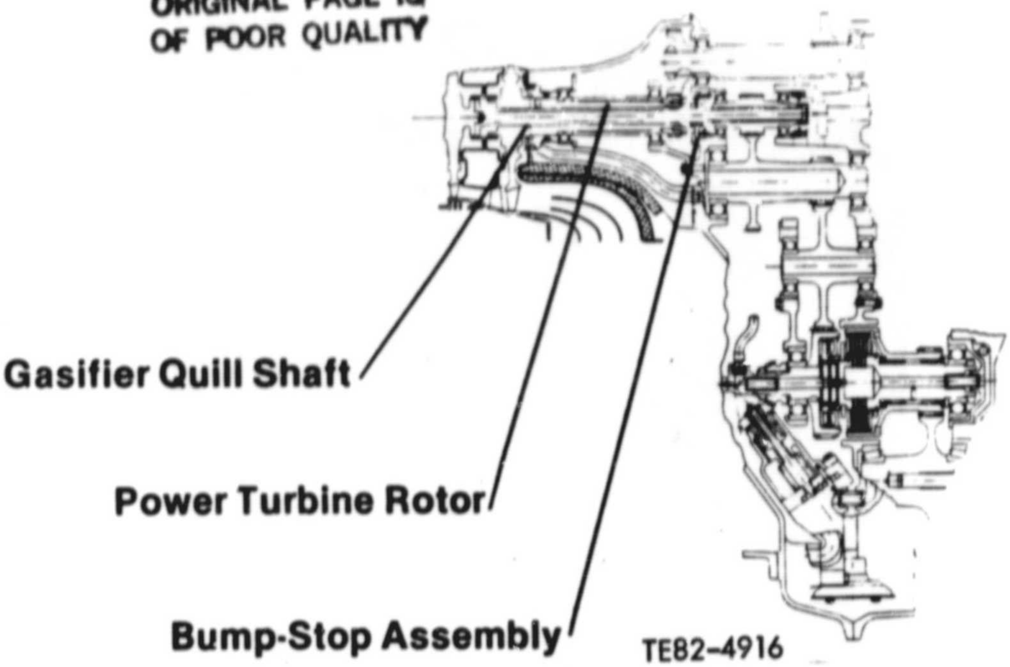

Figure 7. GT404-4 engine cross section showing gasifier quill shaft and bump stop.

The quill shaft provides the mechanical connection between the gasifier rotor system and the gasifier gear train. The dynamic modes with major quill shaft bending are positioned outside the engine operating regime with acceptable margin. Thus, the quill shaft passes through a bending critical speed during engine starting and thereafter operates in a supercritical mode with the quill shaft mass center on the rotational center. Shaft inversion (phase change) occurs during the transition from subcritical to supercritical operation and to restore the gasifier quill shaft to stable supercritical operation after a disturbance such as throttle position change, initiation of dynamic braking, or change from power transfer to free shaft operation moves the shaft mass center off the rotational center. Loss of supply oil to the bump-stop bushing terminated the ability of the bump-stop to provide viscous damping to the quill shaft at the critical bending frequency and the viscous force required to promote shaft inversion without large shaft deflections. The quill shaft therefore achieved excessive deflection, exceeding the yield strength of the shaft, contacting the bore of the counterrotating power turbine rotor, and progressing to failure of the quill shaft and power turbine shaft.

The failure sequence described for engine S/N T5 during this incident would produce failure within a very short engine operating time. This indicates that the use of engine vibration pickups to monitor vertical and lateral movements and, therefore, dynamic response of the engine rotor systems while operating in the coach would not have provided adequate warning to avert engine damage.

The pins lost from the bump-stop assembly were found to be totally undamaged (Figure 9), which indicated that they were disengaged prior to any of the failure events. Dimensional inspection disclosed that the pins were undersize and a review of the manufacturing history of the bump-stop assemblies used in

Figure 8. Gearbox front housing from Greyhound engine S/N T5 showing misoriented bump stop and pins missing (508 total engine hours).

the coach engines suggested that all pins were suspect. Factory inspection of the coach engines revealed that all of the bump-stop assemblies contained undersize pins. Table III shows the results of these inspections. In the case of one of the operational Greyhound engines, one of the pins had fallen into the gearbox but with no damage to the engine. Proper pins were provided for all of the coach engines and no further incident occurred.

As a result of this quality problem, DDA instituted 100% inspection on vendor parts (parts fabricated in house are subjected to a large number of inspections performed throughout the manufacturing process). Additional inspection was also implemented during assembly of the engine, and vendor certification on part quality was reinforced.

DDA Technical Data Report No. AD0000-383, which discusses investigation and analysis of the gasifer quill shaft bump-stop assembly failure on Greyhound engine S/N T5, was provided to the NASA Lewis Vehicle Systems Project Office on 31 July 1980.

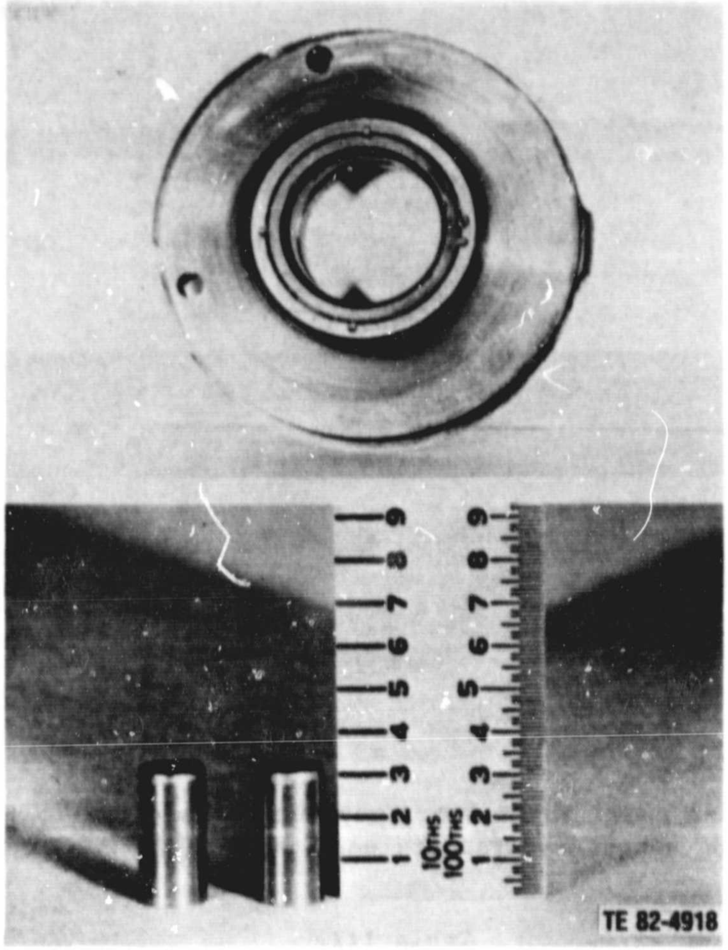

Figure 9. Bump-stop assembly and undamaged orientation pins from Greyhound engine S/N T5 (508 total engine hours).

Compressor Impeller Subsurface Inclusion--Quality Deficiency

The last of the major engine problems experienced during Greyhound service operation involved a quality deficiency in the compressor impeller casting.

A failure of a compressor impeller was encountered after 27,240 mi (43,839 km) of Greyhound operation on engine S/N T9 and resulted from a subsurface inclusion in the casting. The compressor impeller failure is shown in Figures 11 and 12.

The material of the GT404-4 engine compressor impeller is cast aluminum 201 (KO-1). Investigation revealed that failure occurred in fatigue which initiated at a subsurface film type casting defect. The inclusion was found to contain increased amounts of base metal alloying elements. Due to the compact structure of the inclusion and subsurface location, the routine nondestructive inspections of X-ray and fluorescent penetrant inspection (Zyglo) failed to identify the defect. The alloys, added to the molten aluminum for enrichment, did not disperse completely and collected to form the subject inclusion.

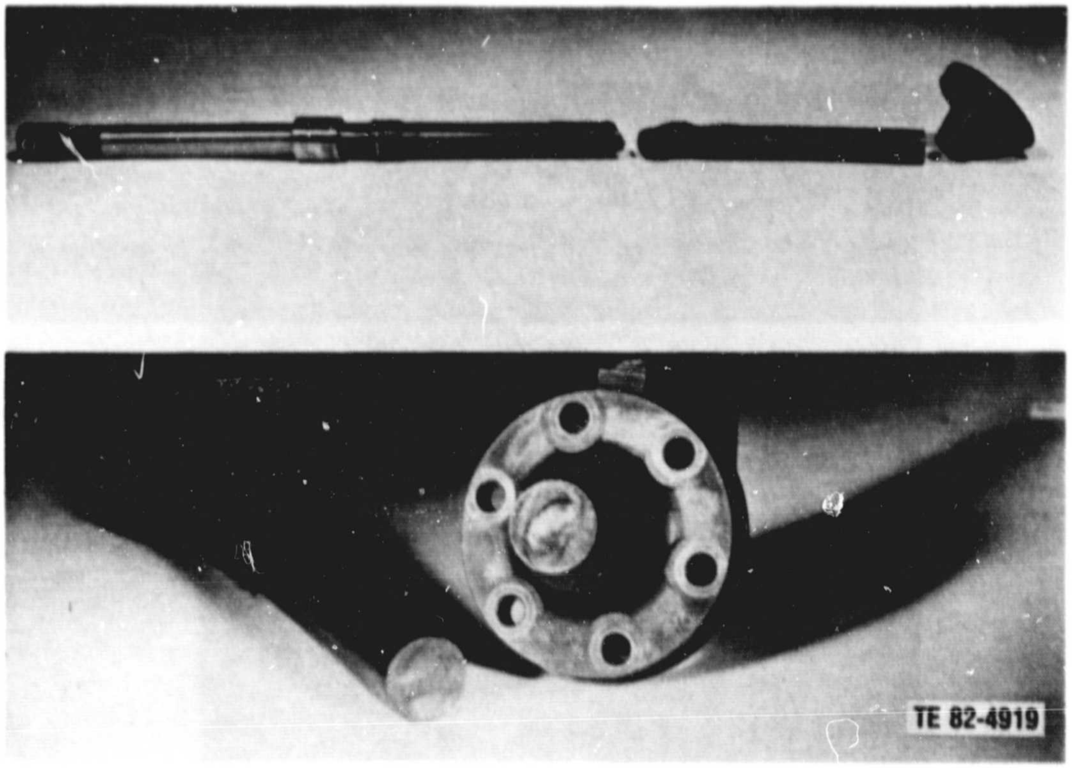

Figure 10. Gasifier quill shaft from Greyhound engine S/N T5 showing central rubbing failure and secondary fracture near flange (508 total engine hours).

Table III.
Coach engine bump-stop inspection results.

Print limits--hole dia = 0.1528/0.1513 in. (3.881/3.843 mm),
pin dia = 0.1535/0.1530 in. (3.899/3.886 mm)

Engine number	Hole dia 1		Hole dia 2		Pin dia 1		Pin dia 2		Inspection date
T5	0.1526	(3.876)	0.1526	(3.876)	0.1525	(3.874)	0.1525	(3.874)	6/24/80
T14	0.1526	(3.876)	0.1527	(3.879)	0.1525	(3.874)	0.1525	(3.874)	7/2/80
T15	0.1527	(3.879)	0.1526	(3.876)	0.1525	(3.874)	0.1525	(3.874)	7/7/80
T10	0.1520	(3.861)	0.1520	(3.861)	0.1525	(3.874)	0.1524	(3.871)	7/8/80
T8	0.1525	(3.874)	0.1520	(3.861)	0.1526	(3.876)	0.1526	(3.876)	7/16/80
T13	0.1523	(3.868)	0.1523	(3.868)	0.1523	(3.868)	0.1525	(3.874)	7/17/80
T6	0.1525	(3.874)	0.1525	(3.874)	0.1520	(3.861)	0.1520	(3.861)	7/24/80
T12	0.1523	(3.868)	0.1522	(3.866)	0.1526	(3.876)	0.1525	(3.874)	7/30/80
T9	0.1520	(3.861)	0.1520	(3.861)	0.1522	(3.866)	0.1522	(3.866)	8/19/80
T11	0.1525	(3.874)	0.1525	(3.874)	0.1525	(3.874)	0.1525	(3.874)	10/21/80

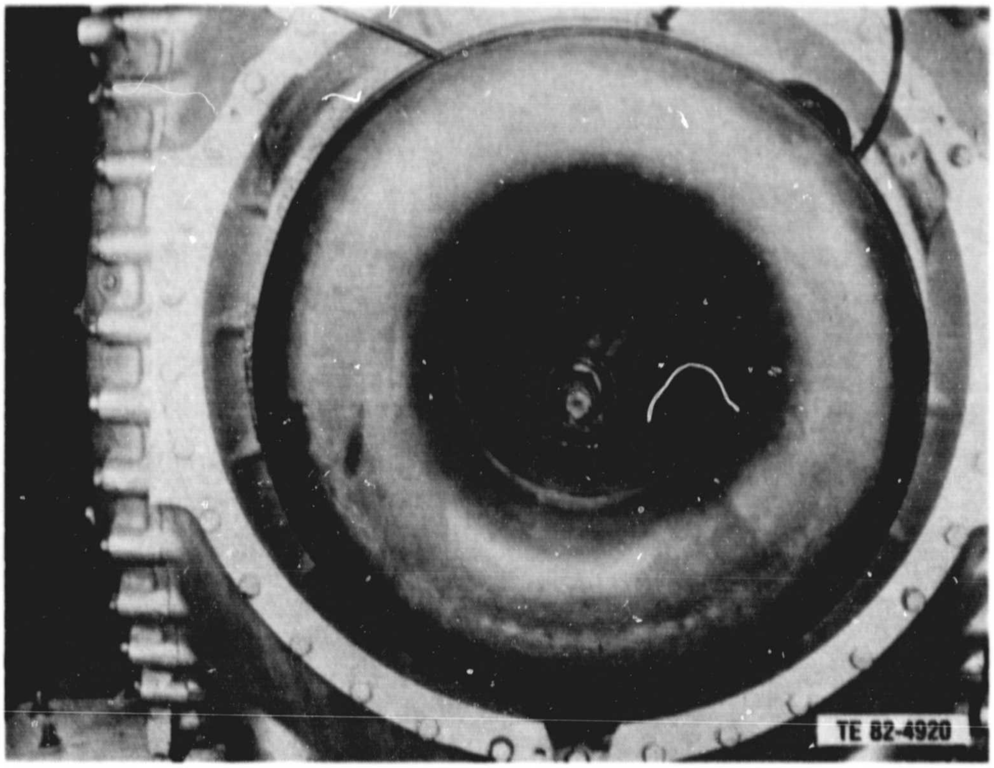

Figure 11. View of Greyhound engine S/N T9 inlet showing failure of compressor impeller (768 total engine hours).

Techniques normally used to fill porosity and other voids in the impeller casting, such as the hot isostatic pressure process in which the finished casting is heated to a plastic condition and subjected to a high pressure environment, would not be effective for this type of defect.

The inclusion problem was corrected by filtering the alloy-enriched molten aluminum during the pouring operation. Both ceramic and fiber screen filters were evaluated and found to be effective in diluting the alloy concentrations in the aluminum prior to entering the mold, thus preventing the formation of inclusions in the finished casting. This was verified by inspection sampling of a number of finished castings. The procedure involves machining through the casting in small increments with Zyglo inspection of the machined face after each cut. No discrepancies were found and filtering was added to the casting process.

Effort continues to identify improved nondestructive inspection techniques to detect this type of subsurface fault. Destructive inspection sampling which involves one casting per batch was instituted to monitor casting quality.

In order to expedite compressor impeller replacement on all of the coach engines, special tooling was designed and fabricated to allow proper removal and installation of the parts without engine removal from the coach. Figure 13 shows the tooling being used on a Greyhound engine installed in the coach.

The filtered casting compressor impellers were installed on all of the coach engines and no subsequent impeller failures were encountered.

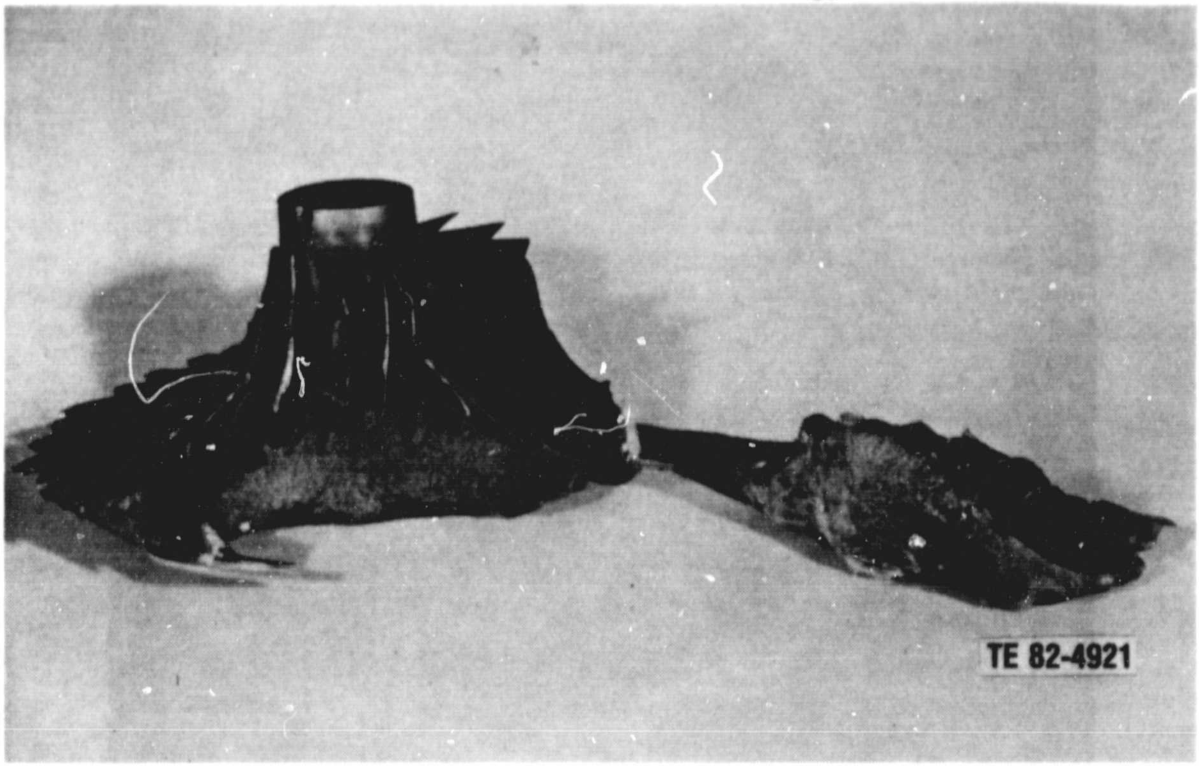

Figure 12. Failed compressor impeller from Greyhound engine S/N T9 (768 total engine hours).

GREYHOUND SERVICE OPERATION--OTHER ENGINE PROBLEMS

Other engine problems experienced during Greyhound service operation are summarized as follows (most of these problems were quality related and many were experienced early in revenue service operation):

- Engine assembly
  - assembly nuts not properly torqued (quality)
  - bearing outer race omitted during field assembly (quality)
- Regenerator system
  - metal regenerator inboard seal crossarm oxidation (quality)
- Control system
  - wiring errors and rework damage in electronic components (quality)
  - fuel valve balance piston breakage (design)
- Gas path
  - turbine inlet duct cracking (design)

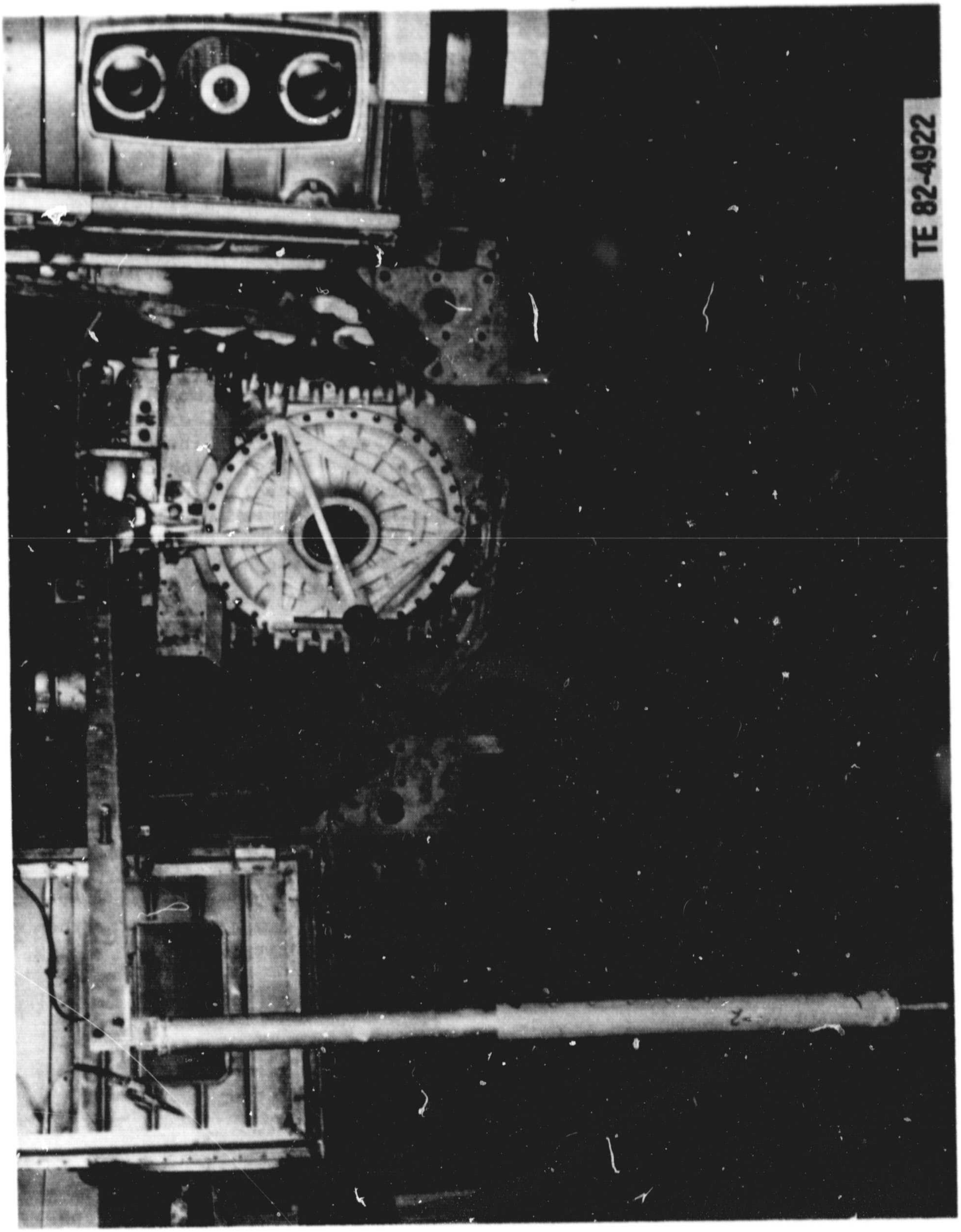

Figure 13. Engine compressor impeller replacement tooling.

Assembly Nuts not Properly Torqued--Quality Deficiencies

Four incidents experienced with engines operating in Greyhound service have been attributed to assembly nuts not properly torqued.

Two incidents involved the oil pump drive gear locking nut, which loosened during engine operation causing a loss of pump drive and resultant loss of oil pressure. Figure 14 shows the oil pump and drive in the engine gearbox cross section. Considerable engine test experience without similar incident suggested that the locknut, which clamps the drive gear and provides friction drive to the oil pump, had not been torqued properly. No damage was sustained by the engines and field repair involved reinstallation of the locknut with design torque applied. No further problems occurred. The friction drive for the gear was later replaced with a key between the gear and shaft for positive drive, but no change was found to be necessary in the locking technique for the nut.

One incident involved the alternator drive assembly, shown in Figure 15, which attaches to the Greyhound engine gear housing drive pad and provides flange drive for the Greyhound coach system's 24-V alternator. In this instance, the assembly locknut loosened and disengaged from the drive shaft, which caused gear failure in the drive. Inspection of the other Greyhound engine assemblies revealed that the locknuts were only finger tight, suggesting that the failed assembly had operated with a similar deficiency. Design changes were incorporated to improve bearing life and the assembly drawing was revised to clarify the required locking torque value for the nut and add thread locking compound.

Nut loosening was suspected as the principal cause for an incident involving the first-stage power turbine gear and pinion (see Figure 16), which resulted in power turbine rotor system failure. Investigation revealed the gear loosened on the shaft pilot, causing misalignment of the gear tooth mesh with the power turbine pinion. This resulted in progressive chipping of the pinion gear teeth until complete tooth failure occurred. Since it could not be verified that improper torque on the gear shaft locking nut caused the incident, a design change was instituted. The gear (and pinion) pilot fit was tightened to eliminate minute movement of the gear at the pilot which, over a long period of time, would result in wear and fretting to progressive loosening. Analysis determined that the nut torque used was adequate to ensure proper clamping of the gear. Most of the coach engines operated through the demonstration period without this design change and no further problem was experienced.

Bearing Outer Race Omitted during Field Assembly--Quality Deficiency

During field assembly of a Greyhound engine gearbox, a bearing outer race was omitted (see Figure 17). The deficiency was not noted as the build progressed and subsequent operation of the engine during coach road testing resulted in gearbox damage.

In response to these engine assembly problems, inspection check-off sheets were developed for the various assembly sections of the engine. This provided verification that various critical operations, such as proper nut torques and bearings in proper position, were accomplished.

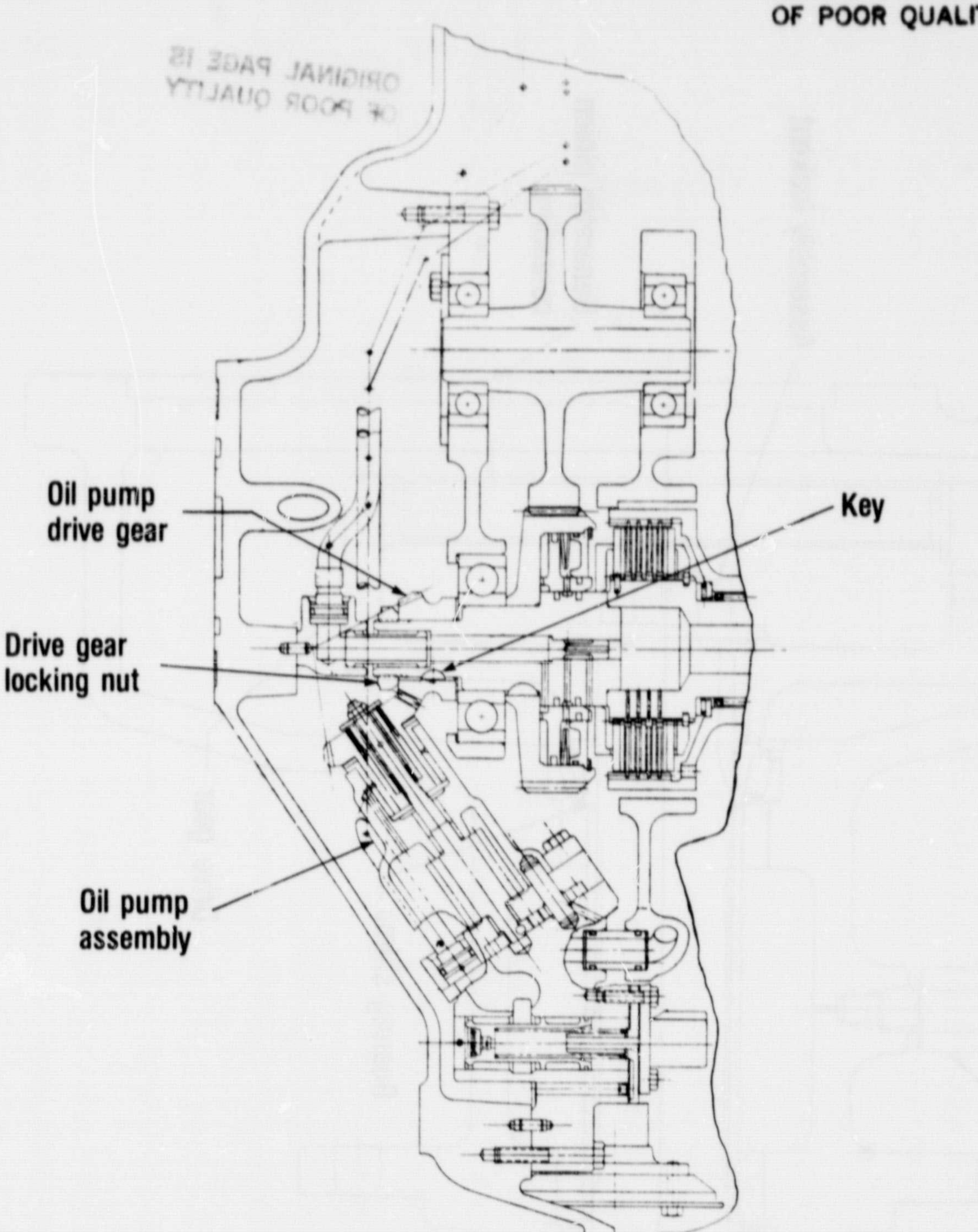

Figure 14. GT404-4 engine gearbox cross section showing oil pump and drive.

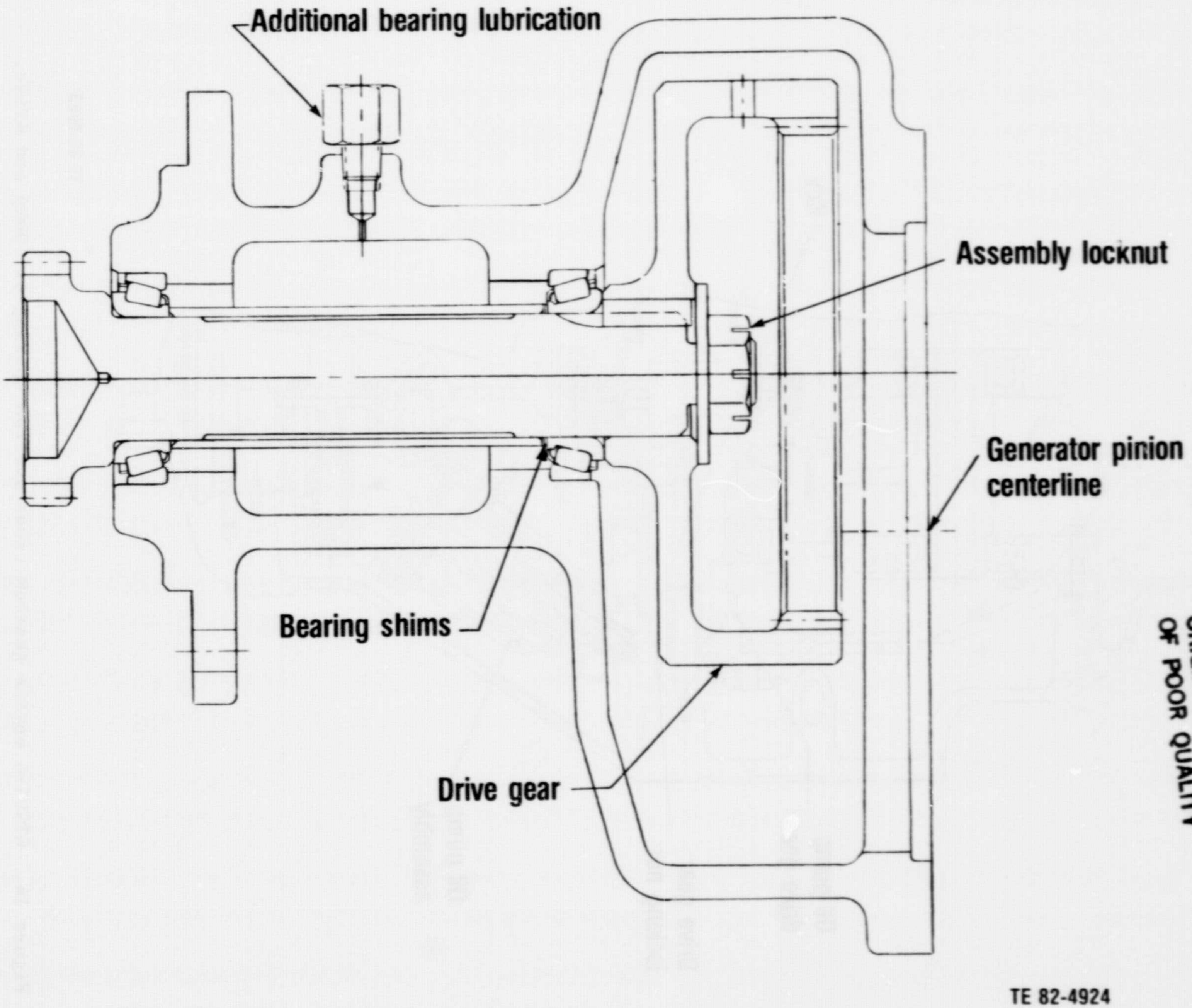

Figure 15. Greyhound alternator drive assembly.

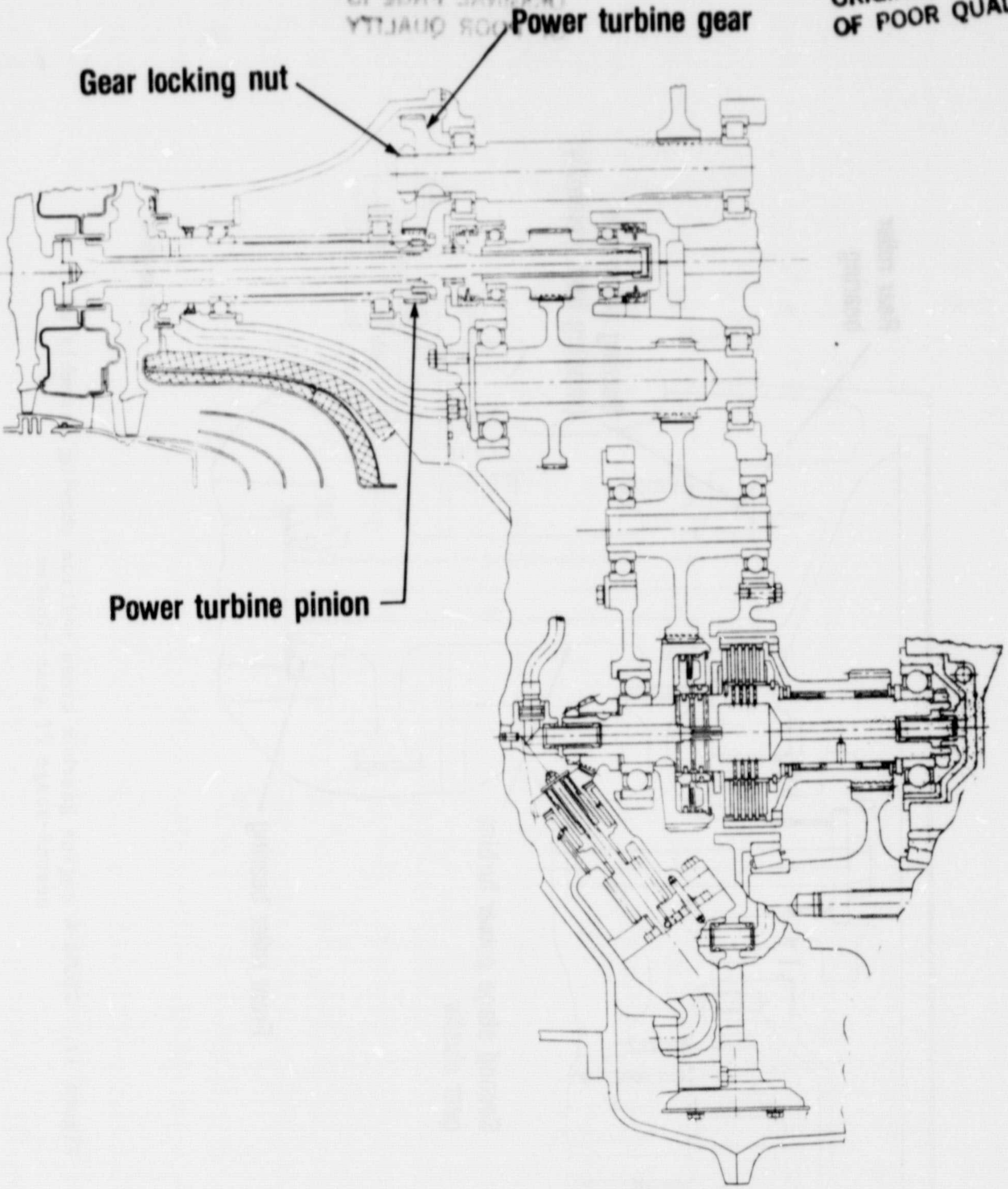

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Figure 16. GT404-4 engine cross section showing power turbine pinion and gear.

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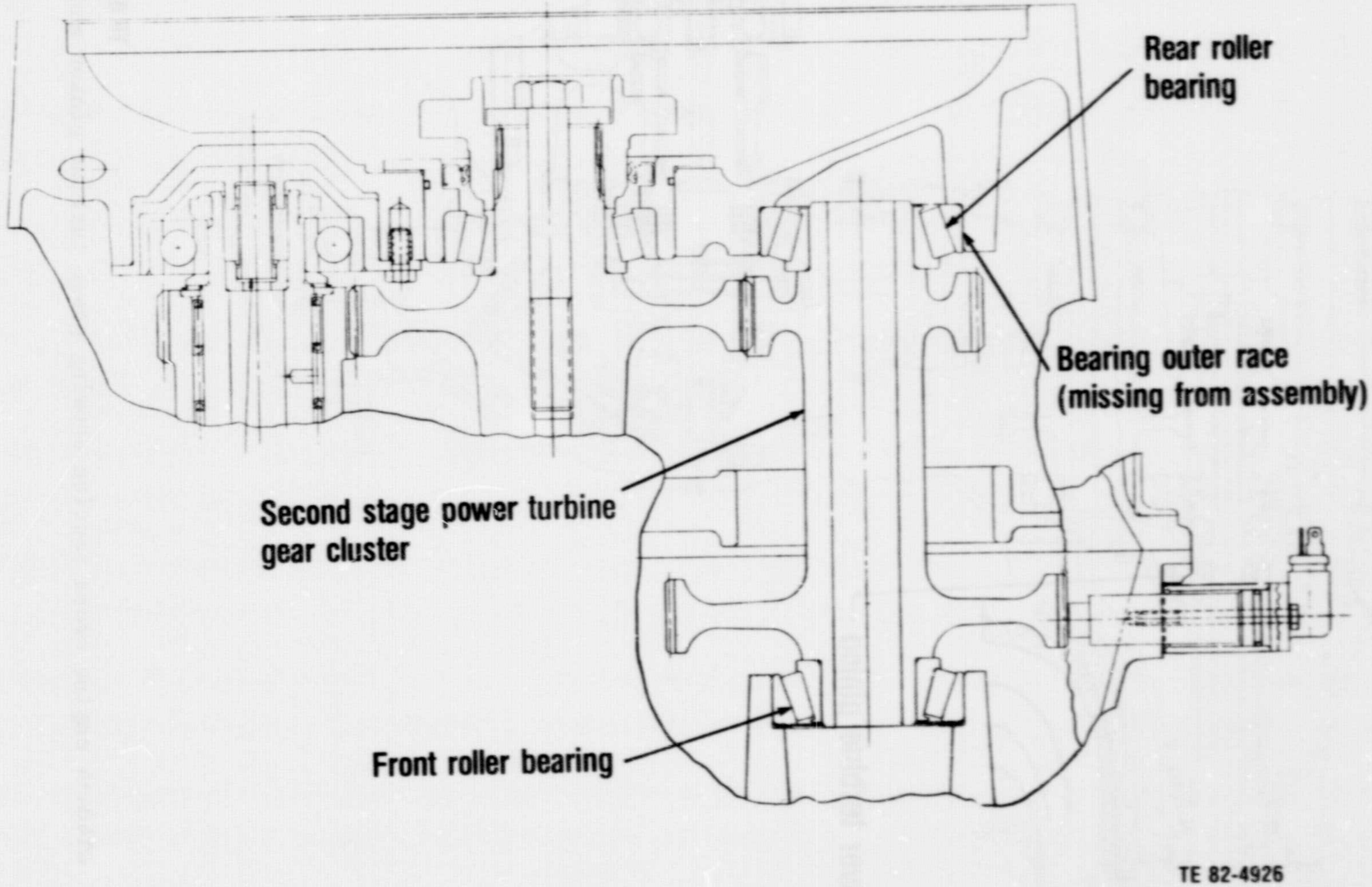

Figure 17. GT404-4 engine gearbox cross section showing assembly of second-stage PT gear cluster.

Metal Regenerator Inboard Seal Crossarm Oxidation--Quality Deficiency

The only regenerator problem experienced in Greyhound coach operation occurred early in the program and involved oxidation of the inboard seal crossarm wearface (see Figure 18). The crossarm wear surface on the metal regenerator inboard seal is composed of a metal mesh filled with a wearface material. Several metals, including chrome, are applied electrochemically in the process used to form the mesh. In the few instances where oxidation occurred, it was found that the chrome content was below the level required for oxidation resistance.

The plating process was changed from electrochemical to chrome packing and satisfactory control of chrome content, both quantity and uniformity, was achieved.

Wiring Errors and Rework Damage in Electronic Components--Quality Deficiencies

Problems associated with the electronic components in the engine control system were quality related.

The electronic control assembly, which provides control of fuel management, power transfer, and the shutdown functions, experienced circuit board damage in areas adjacent to reworks which were periodically performed to implement product improvements. This damage, when undetected during the field rework, caused control malfunctions during subsequent coach operation. Only one instance of control component replacement in all of the coach engine controls was necessary during the program. That involved an electrolytic capacitor in the start circuit that was upgraded to improve quality.

The few problems experienced with the T6 shutdown control, which provides protection for the metal regenerator disks used on the Greyhound coach engines, resulted from errors in rework wiring and improper connections.

Reworks and subsequent inspections of these electronic controls were improved through use of magnification during the rework operations. In addition, cyclic temperature testing and engine checkout were routinely performed on the controls after rework to identify problems in workmanship and component performance.

Fuel Valve Balance Piston Breakage--Design Deficiency

The only design deficiency experienced in the engine control system during coach operation involved the fuel metering valve.

The fuel metering valve, shown schematically in Figure 19, experienced failure of the pressure balance piston, which resulted in an overtemperature condition during engine starting. The shutdown function in the control was active during the incidents and prevented engine damage. The pressure balance piston is incorporated in the valve to stabilize the torque motor involved in the fuel metering function. Investigation revealed that fracture of the balance piston was due to pressure pulses being introduced from the relief valve operation. Over a period of time, the resultant piston chatter created fatigue cracking of the steel piston and, finally, breakage. The ball type relief valve was replaced by a piston relief valve with a damping orifice incorporated to elim-

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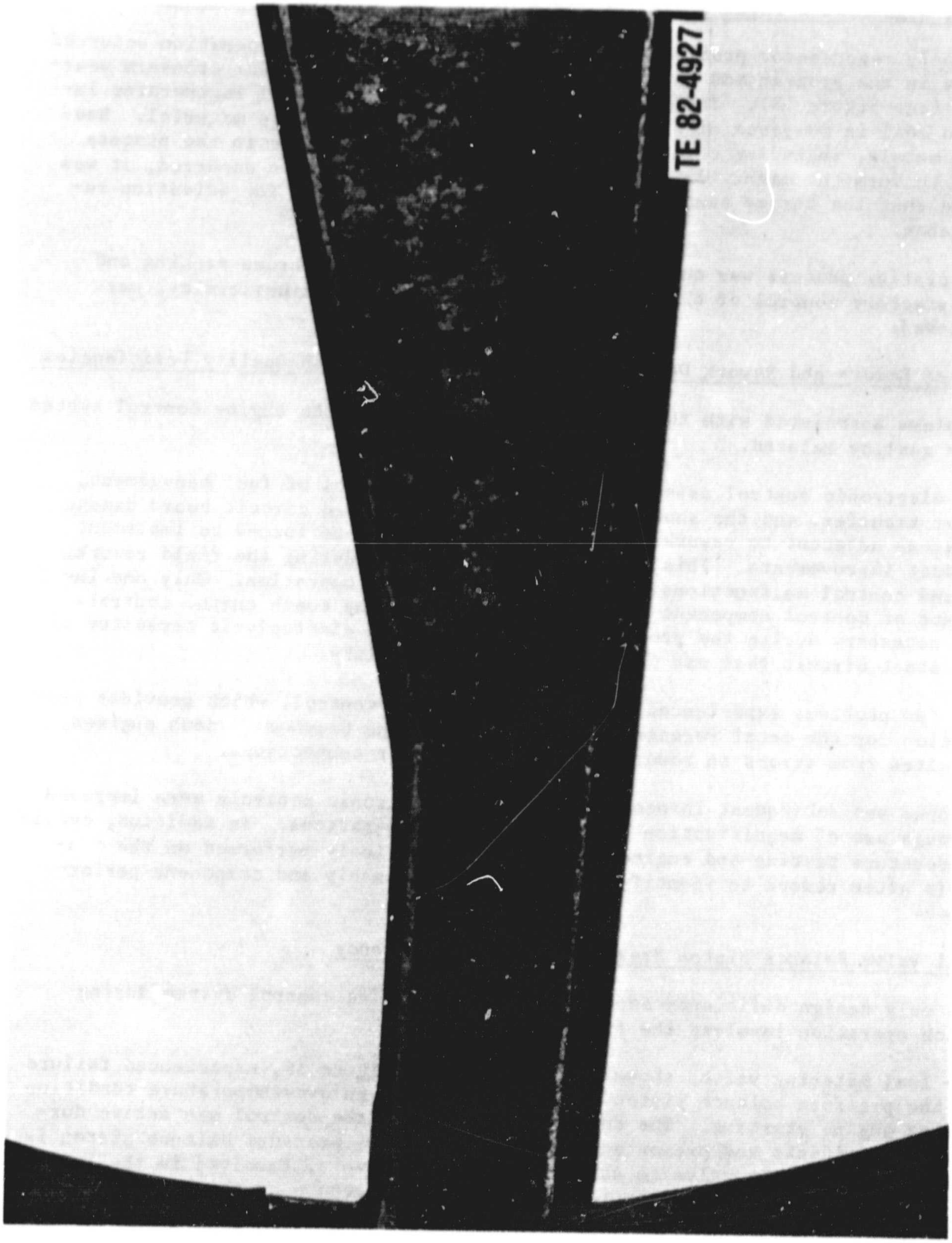

Figure 18. Metal regenerator inboard seal crossarm showing oxidation.

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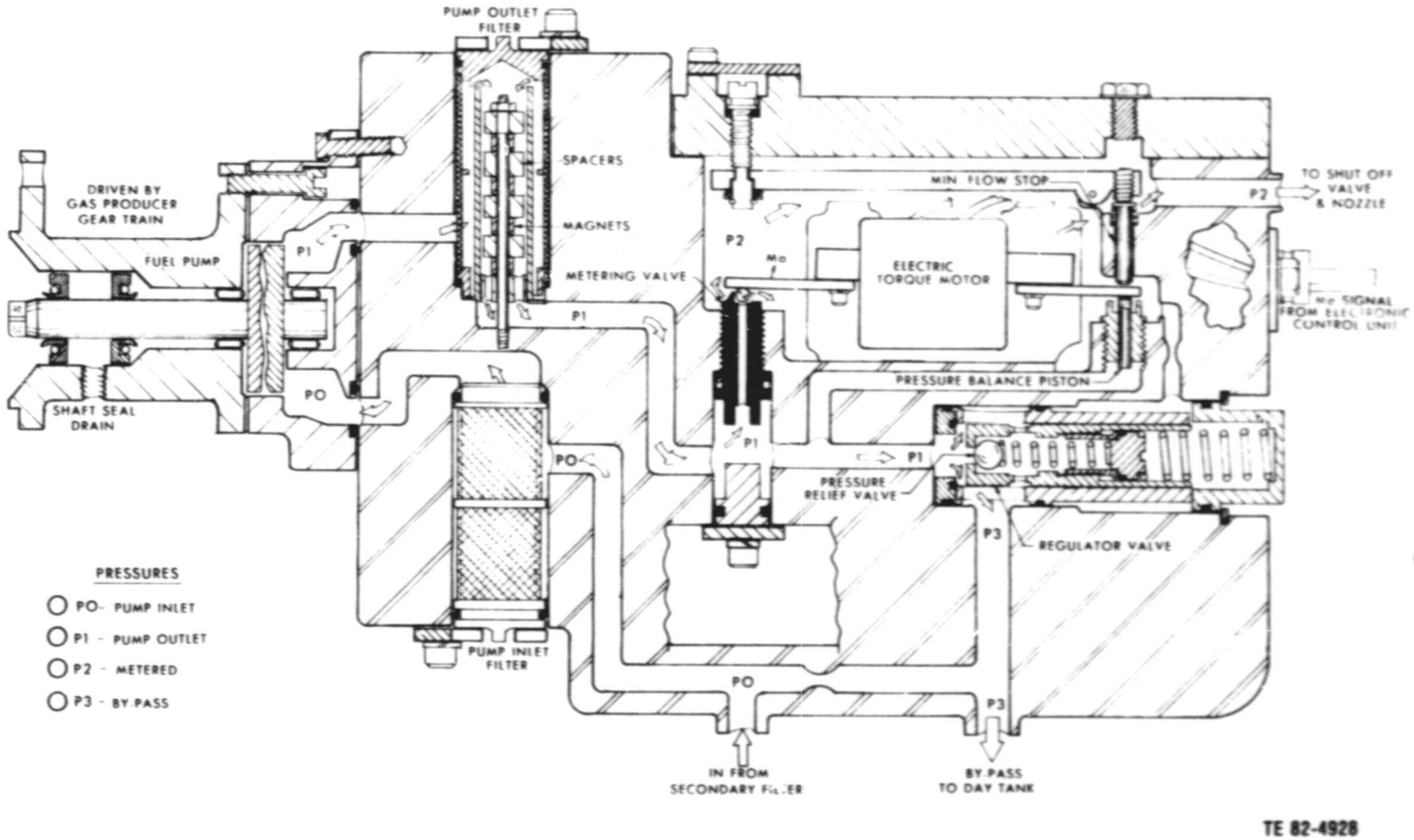

Figure 19. Fuel metering valve schematic.

inate the pressure pulse problem. All of the coach engine fuel valves required this modification, and after rework no further problems were experienced.

Turbine Inlet Duct Cracking--Design Deficiency

The turbine inlet duct, located in the gas path and shown in the engine general arrangement cross section (Figure 20), experienced cracking on the outlet outer sheet metal during Greyhound operation. This design deficiency resulted from local distress caused by temperature erosion and thermal distress.

The design was modified to change the material of the outer sheet metal from Hastelloy X to Haynes 188 and add a temperature resistant spray coat (Metco 202) to the gas side surface. A later change provided for the separation of the outlet outer sheet metal from the duct with retention such that movements of the piece could be accommodated. All of the coach engines were modified to incorporate these changes. Although field experience for evaluation was limited, no problems occurred through the remainder of the program.

GREYHOUND ENGINE UPDATE CONFIGURATION

Table IV shows the Greyhound coach engine update status at the completion of the Intercity Bus Demonstration Program. The updates listed were those which had been identified and recommended for coach engine modification during the period of performance of the support contract. These modifications corrected deficiencies identified through field operation and development testing of the engine. Because of funding limitations, many of the coach engines could not be upgraded or maintained to the desired configuration.

GREYHOUND SERVICE OPERATION--COACH OPERATIONAL PROBLEMS

The two major coach operational problems experienced during Greyhound service involved slow initial acceleration and insufficient instantaneous braking (the engine provides excellent downhill braking capability). Design changes made to the GT404-4 engine adversely affected braking and acceleration performance from that achieved with the GT404-3 engine. The change to a continuous combustion cycle, together with the higher engine cycle temperature, resulted in more stored heat energy and slower heat dissipation during deceleration. The new design of gas path rotating components increased the rotor system moment of inertia, which resulted in slower acceleration.

Vehicle Acceleration and Braking

Two major coach operational problems experienced during Greyhound service involved slow initial acceleration and insufficient instantaneous braking.

During Greyhound service operation, complaints were received periodically from the drivers concerning slow initial response of the bus during acceleration from rest and the lack of braking (as perceived in that driving environment, the normal coastdowns experienced on relatively flat interstate highways to accommodate necessary changes in traffic conditions).

Although some changes were implemented while maintaining service availability of the coaches, driver concerns for lack of vehicle control on wet and icy pavement continued. Service operation was suspended in early December 1980

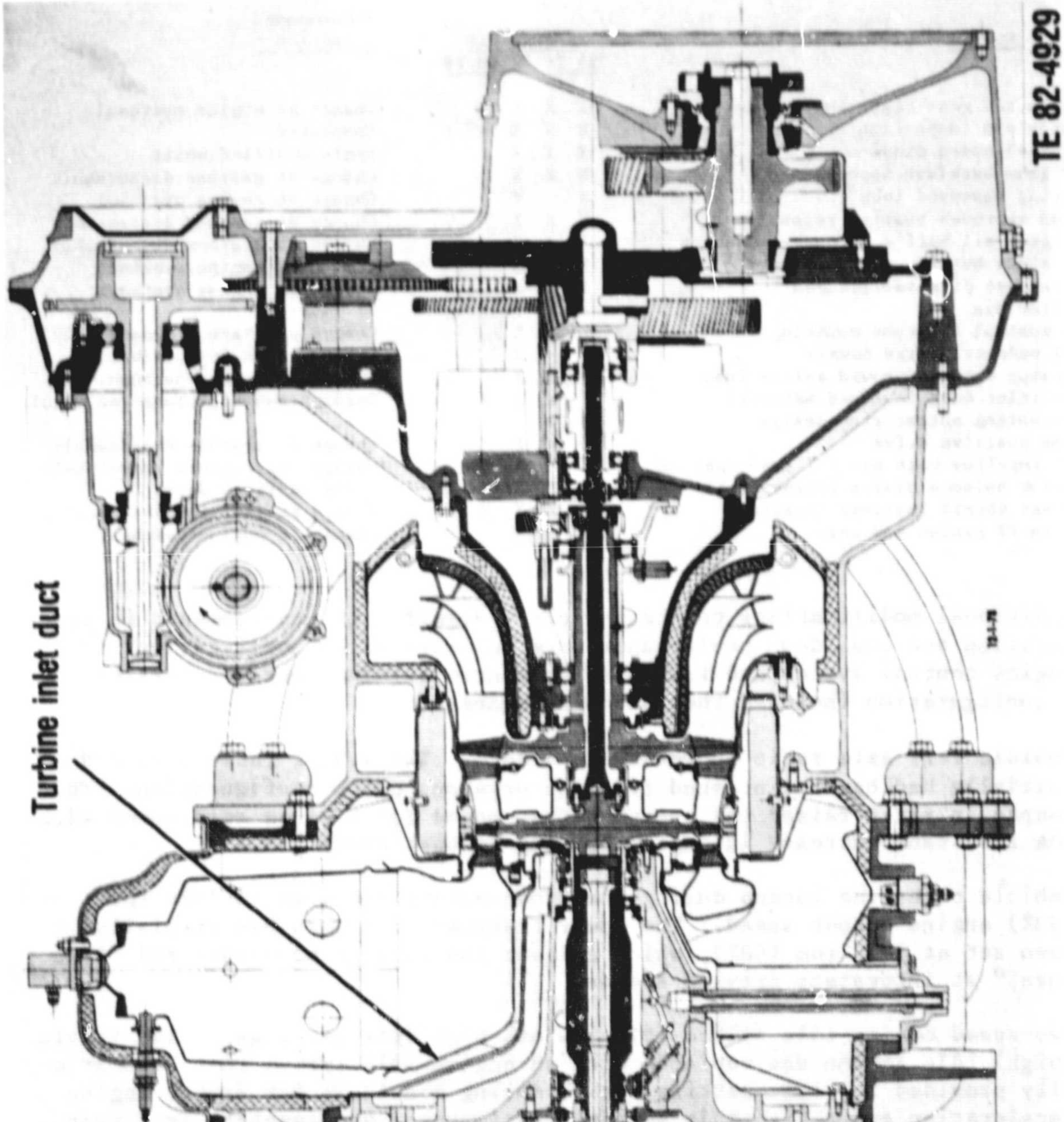

Figure 20. GT404-4 engine general arrangement cross section.

Table IV.
Greyhound engine update status.

Update	Engine S/N T5	T6	T7	T8	T9	DDA recommended action
PT pinion and gear tight shaft fits	X	X	X			Change at engine overhaul
Bump-stop pin inspection	X	X	X	X	X	Completed
Relay panel added diode	X	X	X			Cycle modified units
Output gear backlash increase	X	X	X			Change at gearbox disassembly
PT bearing improved lube	X		X			Change at engine overhaul
Oil pump improved bushing retention	X	X	X			Change at gearbox disassembly
Output gear oil baffle stronger mounting	X	X	X			Change at gearbox disassembly
Output shaft bearing positive lube	X		X			Change at engine overhaul
Inner exhaust diffuser reduced splitter dia	X	X	X			Change at engine overhaul
Clutch control oil tube mounting	X	X	X			Change at gearbox disassembly
Rear PT pedestal large dowels	X		X			Change at engine overhaul
Regenerator drive improved spline lube			X			Change at engine overhaul
Turbine inlet duct improved material and floating outlet ring design		X	X	X		Inspect 500 hr, change as required
Oil pump positive drive			X			Change at gearbox disassembly
Install impeller with new filtered casting		X	X	X		Change all engines immediately
Fuel valve balance piston improvements	X	X	X	X	X	Cycle modified units
Outer heat shield improved locking		X	X	X		Change at gasifier disassembly
Shot peen PT pinion and gear						Change at engine overhaul

for additional modifications to the vehicle. Significant improvements in coach acceleration and coastdown performance were achieved after modifications to the engine control system and transmission controls. The improved turbine coach configuration included the following changes:

- Vehicle rear axle ratio increased to 4.88:1. The 4.33:1 ratio utilized initially had been maintained from the previous coach configuration. The change in ratio raised the engine output speed for a given road speed with the resultant increase in engine braking at that condition.

- Vehicle to engine lockup during coastdown maintained down to 1526 rpm (53%) engine output speed. The power transfer idle dump had initially been set at 1958 rpm (68%), which allowed the vehicle to unlock and "free wheel" at interstate driving speeds.

- Two-speed engine idle system (52% low/64% high idle settings). The single (high) idle scheme was replaced with an engine idle system that automatically provided low idle setting active during coastdown for faster engine deceleration and a high idle setting for improved acceleration from rest. Use of the single (high) idle resulted in slower engine deceleration and caused the driver to ride the vehicle brakes to maintain low speeds during vehicle coastdown.

- Engine minimum fuel setting (deceleration/braking mode) reduced to 11 pph (4.99 kg/h). The minimum fuel flow setting was originally specified at 15 to 18 pph (6.8 to 8.16 kg/h) but this provided a higher temperature level and resultant slower engine deceleration.

- o Faster engagement of the transmission coupling lockup clutch. The time required to engage the lockup clutch fully and achieve direct drive was reduced for faster vehicle acceleration from rest.

- o Transmission automatic downshift speeds increased. Speeds at which automatic downshifts occur were raised above the power transfer idle dump setting to maintain continuous vehicle-to-engine lockup (braking) during coastdown.

- o Smoother transmission downshifts and upshifts. Shift quality was improved for better vehicle control while operating on slippery road surfaces.

Comparative tests were conducted on 5 March 1981 at the GM Proving Grounds in Milford, Michigan, with the improved Greyhound turbine coach and a Greyhound production diesel coach to evaluate the following:

- o acceleration from rest
- o deceleration (coastdown) from 60 mph (96.6 km/h) with automatic and manual downshifting of the transmission
- o coach rollback from rest on a grade
- o vehicle control during normal and panic stops on the skid pad

Greyhound, NASA Lewis, and DDA personnel were in attendance during these evaluation tests.

Acceleration performance (see Figure 21) was obtained for 0 to 60 mph (96.6 km/h) with both the turbine and diesel coaches starting together from rest. The turbine vehicle experienced a 1 sec lag before movement, but thereafter it assumed a faster acceleration rate, which resulted in the turbine and diesel coaches reaching an equivalent speed at 12.5 sec (28 mph [45.1 km/h]) with the turbine coach passing the diesel coach at approximately 42 mph (67.6 km/h).

The coach deceleration tests (see Figure 22) conducted from 60 to 20 mph (96.6 to 32.2 km/h) utilized both automatic and manual downshifting of the transmission and showed that the diesel coach achieved faster comparative coastdowns but that manually downshifting the turbine vehicle provided acceptable performance to accommodate all driving requirements. From 55 to 50 mph (88.5 to 80.5 km/h) with natural deceleration (automatic downshifting) of the vehicles, the turbine coach required 8.5 sec (654 ft [199.3 m]) and the diesel coach 7 sec (539 ft [164.3 m]), a difference of 2.8 bus lengths. This is a significant improvement when compared to the 7.7 bus length difference experienced prior to engine and transmission controls modifications.

One of the most dramatic tests conducted at the proving grounds compared the turbine- and diesel-powered coaches for vehicle control on the skid pad, a large asphalt surface specially prepared so that, when wetted down with water, the surface conditions approximate ice. Each vehicle executed normal and panic stops on this surface from an approach of 30 mph (48.3 km/h). Both coaches demonstrated good directional stability and control on the slippery pavement.

The turbine and diesel coaches were also stopped on a 7.2% grade. Acceleration from rest demonstrated no significant rollback at initiation of start for either coach.

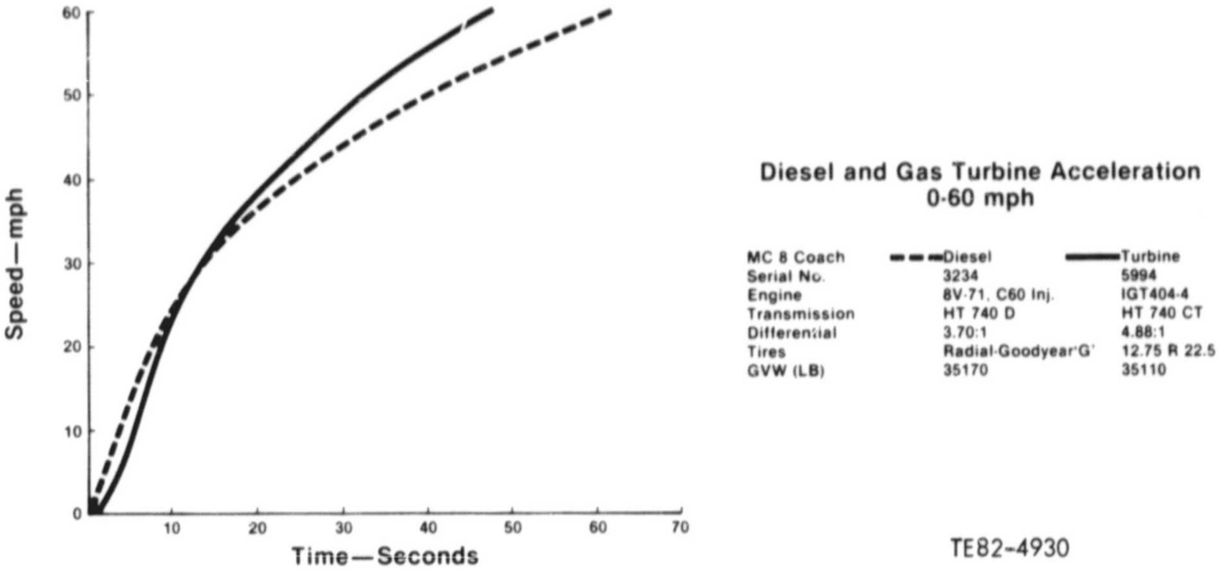

Figure 21. Greyhound MC-8 coach acceleration tests.

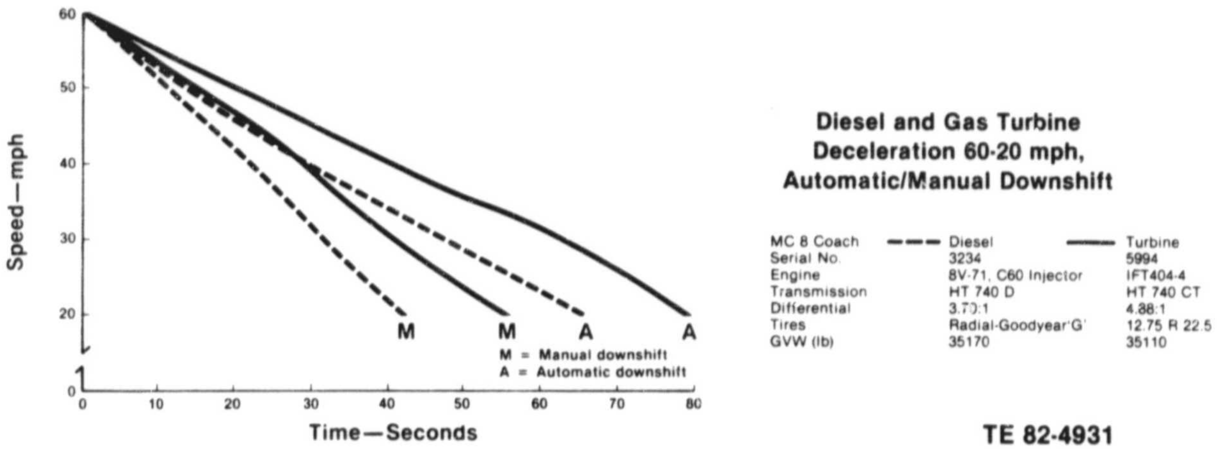

Figure 22. Greyhound MC-8 coach deceleration tests.

The comparative acceleration, braking, and handling tests conducted at the proving grounds with the turbine and diesel vehicles demonstrated that the improved turbine coach performed satisfactorily in those critical operating modes and the coaches were released to service. It was concluded that, in order to maximize engine braking, the Greyhound driver should routinely act in the following way:

- o operate in third range (rather than fourth) whenever practical
- o manually downshift when approaching exit ramps
- o manually downshift when road conditions or traffic patterns indicate the need for more rapid coastdown

Greyhound management considered these recommendations to be within the scope of existing practice used for the diesel production coaches.

Prior to the continuance of Greyhound service, additional test effort with the engine fuel valve was initiated to correct instability of the reduced minimum fuel setting required for improved braking. It was found that the minimum fuel setting, active during the deceleration/braking mode and reduced from 18 pph (8.16 kg/h) to 11 pph (4.99 kg/h) for improved braking (lower temperature level), gradually reduced during engine operation until flameout occurred. This resulted from minimal surface distress on the hard-coated aluminum pin used as the mechanical stop in setting the minimum fuel flow (see Figure 19). Operation with the original minimum flow setting of 15 to 18 pph (6.8 to 8.16 kg/h) had not required the minimum fuel flow setting mechanism in the fuel valve to hold fuel flow within the tolerance later identified as a requirement for improved braking performance.

The material of the stop pin was changed from hard-coated aluminum to case-hardened steel. This eliminated the surface wear effect but introduced thermal differences between the aluminum valve and steel pin which resulted in decreasing minimum fuel flow for increasing valve temperature, 3 to 4 pph (1.4 to 1.8 kg/h) decrease for 50°F (10°C) increase. The fuel valve was calibrated at the expected compartment valve temperature of 125°F (51.7°C) to achieve the desired 11 pph (4.99 kg/h) setting and this configuration was utilized with the engines when the coaches were returned to service operation on 27 April 1981.

A second modification involved use of the aluminum stop pin with carbide inserts at the tips, which eliminated both the wear effect of the original pin and the temperature effect of the steel pin, as verified through bench testing. The program ended before this valve configuration could be evaluated in the Greyhound service environment.

GREYHOUND SERVICE OPERATION--MAJOR TRANSMISSION PROBLEMS

The major problems experienced with the HT740CT transmission during Greyhound operation are these:

- o transmission overheating
- o engine overspeed on inhibit downshift
- o pitot can failure

Transmission Overheating

During Greyhound operation, three incidents of transmission overheating were experienced.

Transmission S/N 30575 was installed in coach 5994 while the vehicle was being driven from Motor Coach Industries to DDA for engineering tests. During a rest stop, the engine remained at idle in order to maintain bus heat with the outside ambient temperature at -35°F (-37°C). Upon returning to the vehicle, the driver observed that the transmission hot oil temperature warning light was indicating. The transmission oil level was checked and found to be acceptable. However, continued investigation revealed oil leaking from the engine gear housing drain hole in the transmission coupling cavity. Transmission teardown inspection revealed that the lockup clutch section of the transmission, shown schematically in Figure 23, had suffered considerable heat damage and the clutch plates showed evidence of clutch slippage (see Figures 24 and 25). This slippage was the source of the overheating, and the resultant high temperature damaged the seals, which caused the oil leakage. No problems were found in the transmission that would account for the failure.

The circumstances suggest that the most likely cause of failure involved transmission operation in the extremely cold ambient temperatures with the oil-to-air transmission oil cooling system employed in the gas turbine installation. Experience in diesel applications that use the oil to air heat exchanger for oil cooling has shown a similar failure mode during operation in cold ambient temperatures. The problem results from the viscosity effect with cold oil, which impedes circulation and drain back to the oil sump, thus providing reduced lubrication and cooling oil flow. Operation under these conditions will result in localized overheating in the clutch, which causes plate damage, slippage, and heat generation. The diesel production Greyhound coach utilizes the conventional oil-to-water cooling system, which, during operation in extremely cold ambient temperatures, actually provides heat to the transmission oil through heat rejection from the engine water.

The program ended before corrective action involving transmission oil heating at cold ambient temperatures could be evaluated.

Two incidents of transmission overheating resulted from quality-related deficiencies. One of these involved overfilling due to an improperly calibrated dipstick. Because of installation differences in the turbine application, a revised transmission oil dipstick was required. However, the revised dipstick provided an operating oil level above the allowable level required to prevent oil churning and the overtemperature condition was experienced. Greyhound instituted design changes to the dipstick which not only corrected the improper readout but improved readability. All of the coaches were updated with new dipsticks. The other incident of transmission overheating resulted from improper connection of the transmission cooling oil circuit to the oil cooler. The transmission oil cooling circuit is shown schematically in Figure 26. The oil routing lines between the oil cooler and the transmission were reversed, which prevented cooling oil flow through the cooler. Proper connection to the cooler corrected the problem. Inspection of the remaining Greyhound coaches revealed no discrepancies.

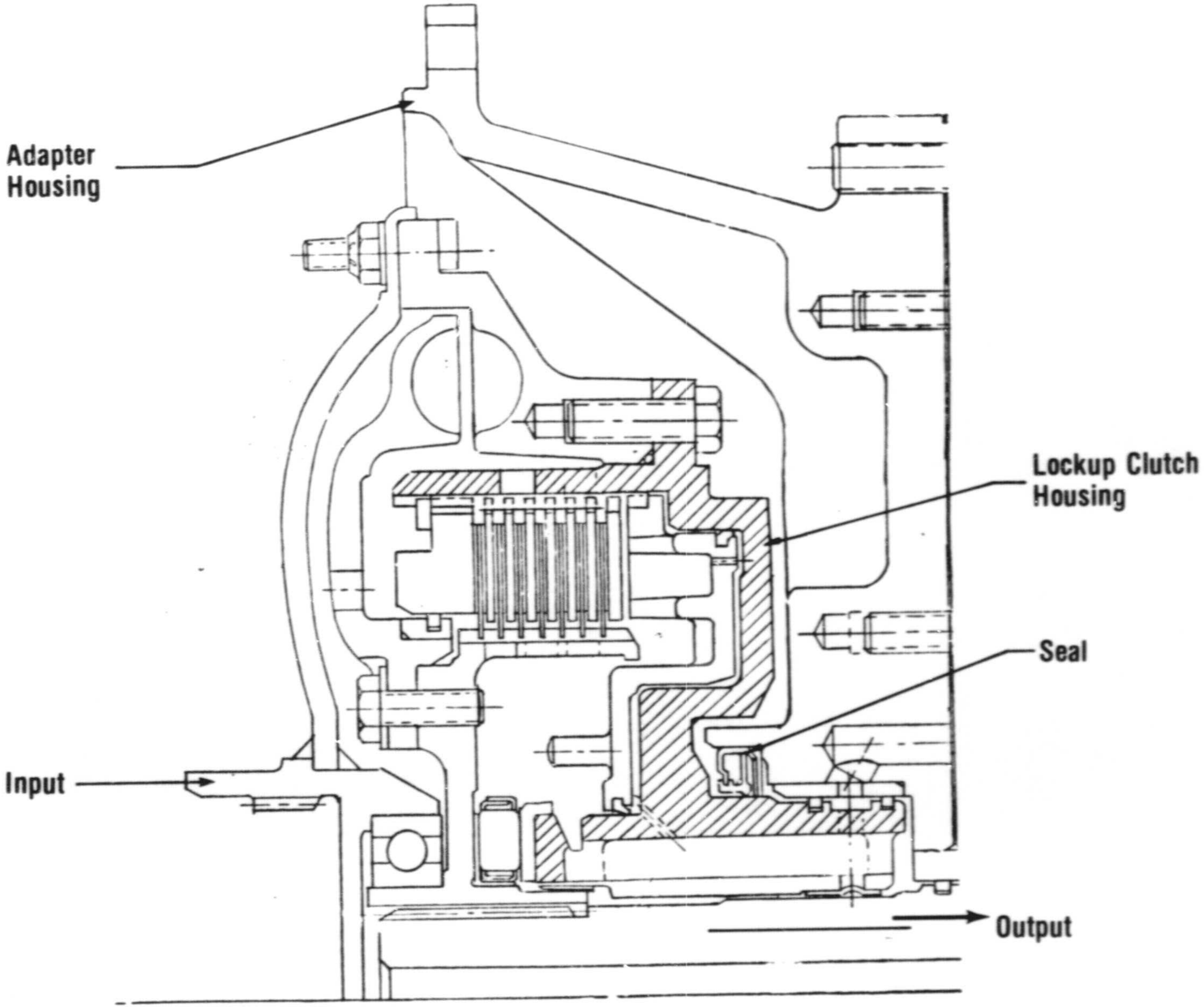

Figure 23. HT740CT transmission lockup clutch schematic.

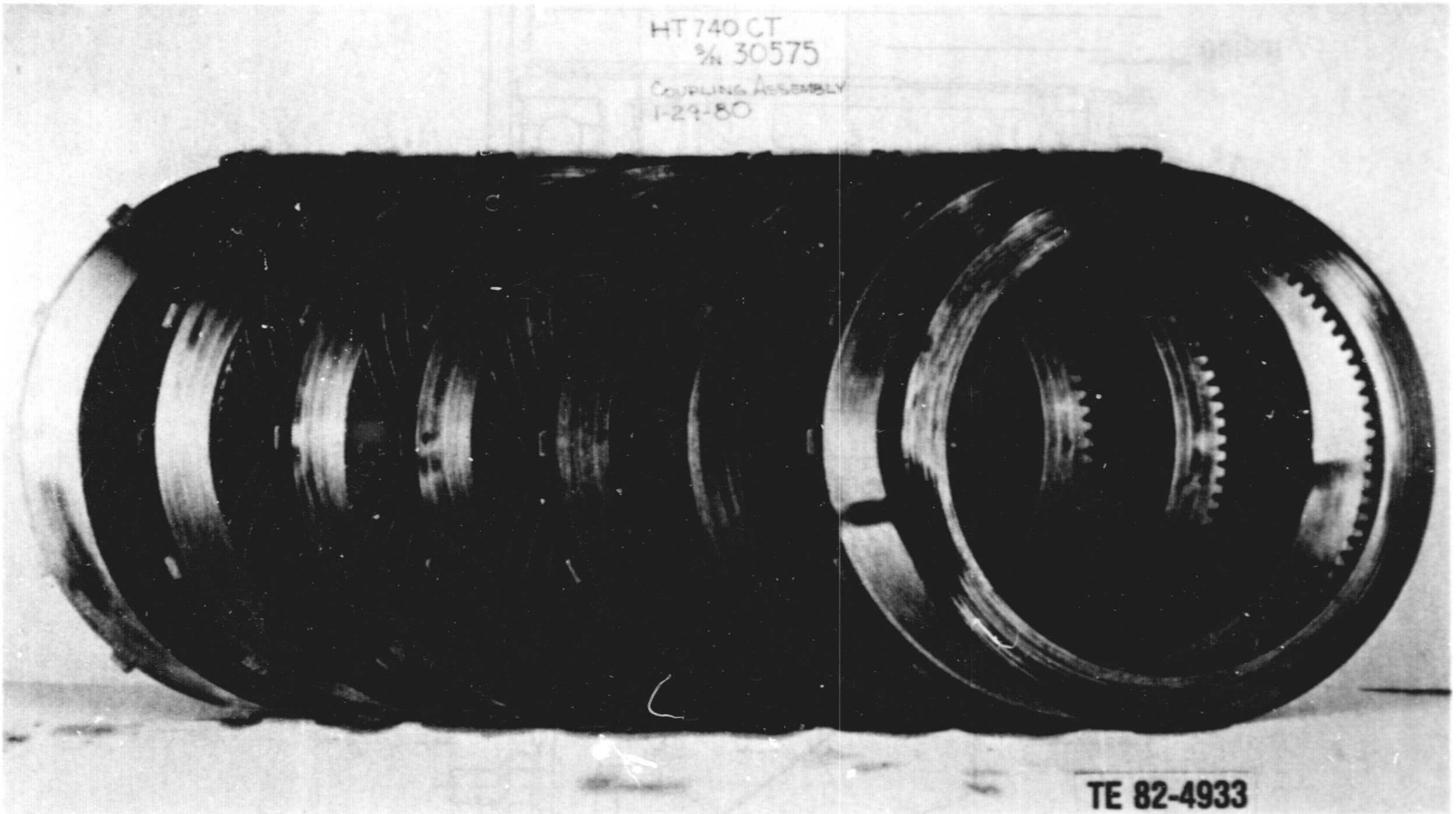

Figure 24. HT740CT transmission S/N 30575 coupling clutch plate failure.

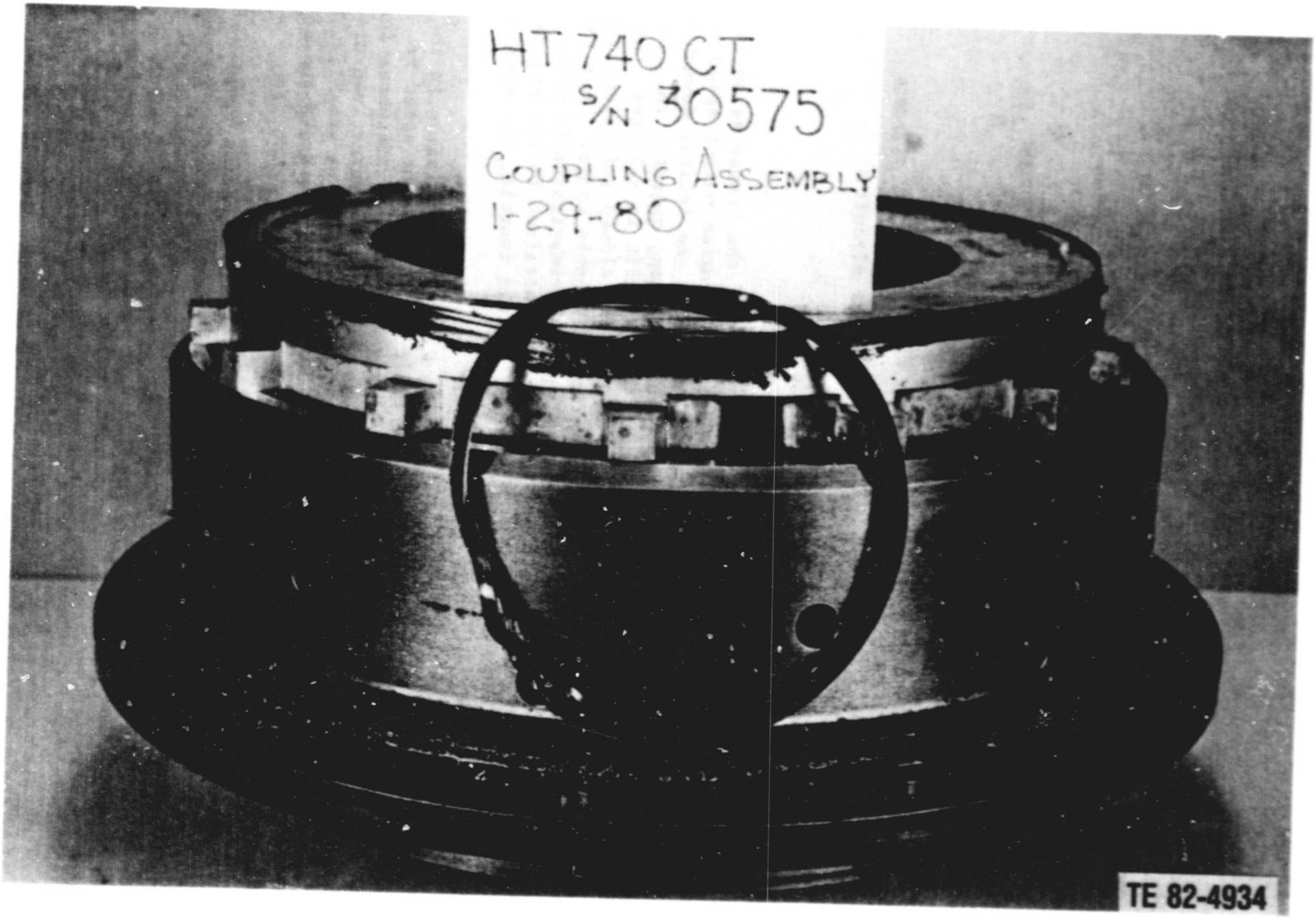

Figure 25. HT740CT transmission S/N 30575 coupling assembly showing seal damage.

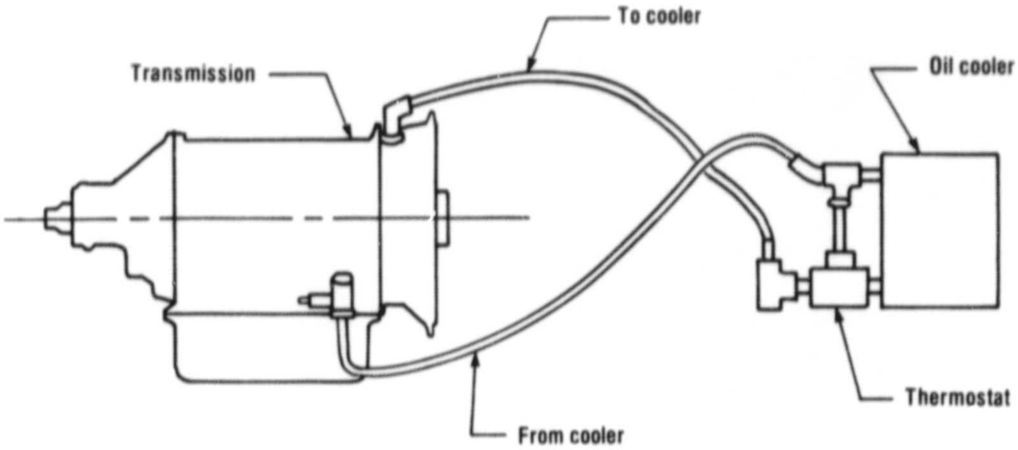

Figure 26. HT740CT transmission oil cooler circuit.

Engine Overspeed on Inhibit Downshift

During early Greyhound operation, manual downshifting of the transmission by the drivers to achieve more engine braking resulted in engine output speed excursions beyond the maximum allowable value of 3100 rpm. An inhibit downshift is made by manually selecting a lower range than that being operated in. The hydraulic shift controls are designed so that, when a shift is selected, the shift is inhibited from occurring until the vehicle has slowed sufficiently to keep the resultant engine speed within the maximum allowable range. When the downshift occurs, the vehicle is decelerating and the transmission is being driven by the vehicle rear wheels. The maximum speed attained by the engine is, therefore, a function of the engine inertia, vehicle inertia, the speed at which the shift occurs, and the ratio selected.

During calibration and acceptance testing of the HT740CT transmission in the build program, the controls were adjusted to limit maximum engine speed to 2900 rpm during inhibit downshift. However, owing to inertia differences for the test engine (previous model GT505-3) and test stand dynamometer, vehicle simulation was not achieved. As a result, the inhibitor settings established during acceptance testing were too high and the vehicle inertia drove the engine speed beyond the maximum allowable value.

Figure 27 shows the inhibit shifts obtained during coach operation based on the inhibitor settings established during acceptance testing. Figure 28 shows the revised inhibit shift ranges after recalibration, which required a new spring in the hold regulator valve. All of the HT740CT and V730CT coach transmissions required adjustment of the hold regulator valve, and no further problems were experienced.

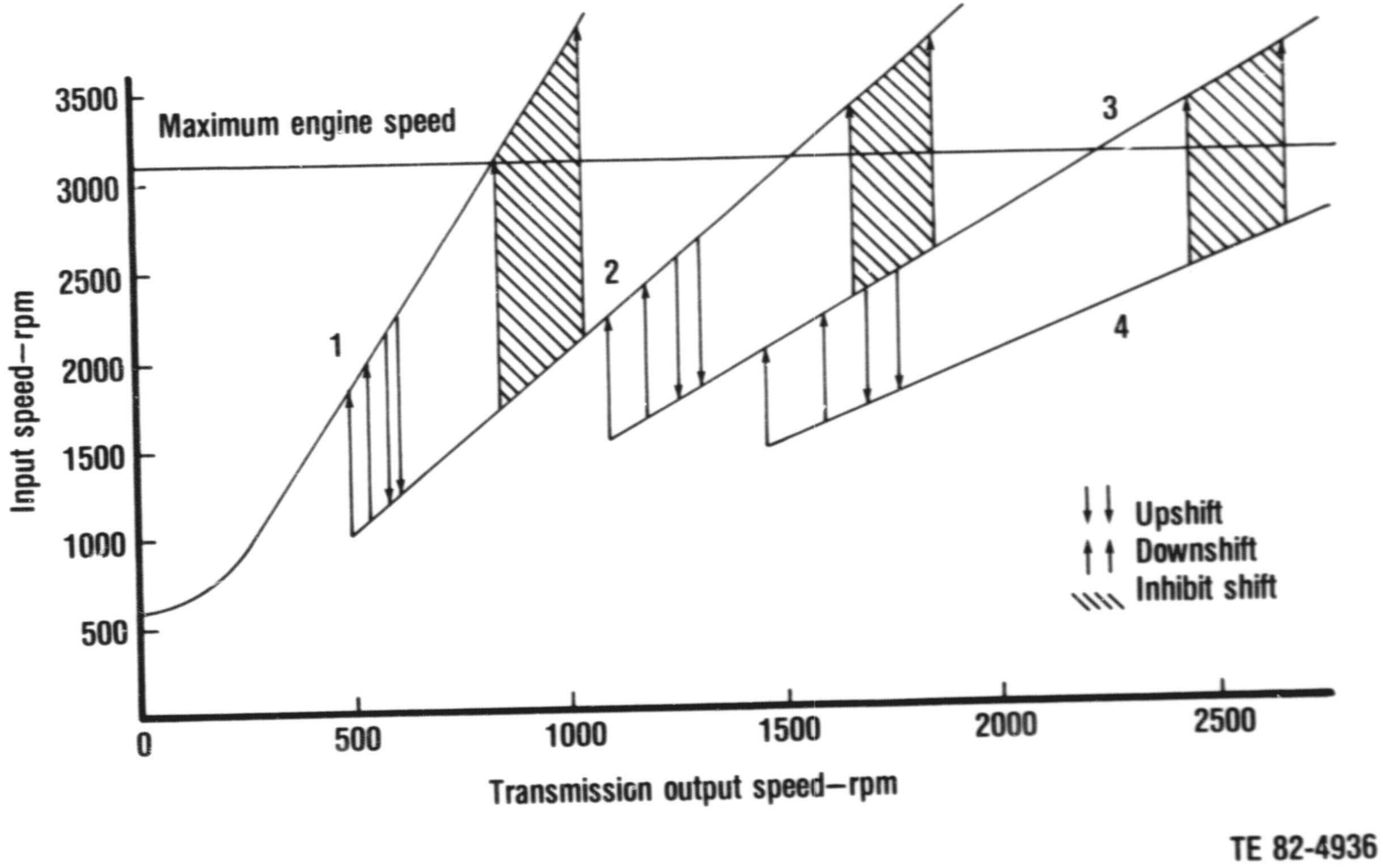

Figure 27. HT740CT transmission shift point schedule--inhibit downshift speed ranges in coach based on acceptance test.

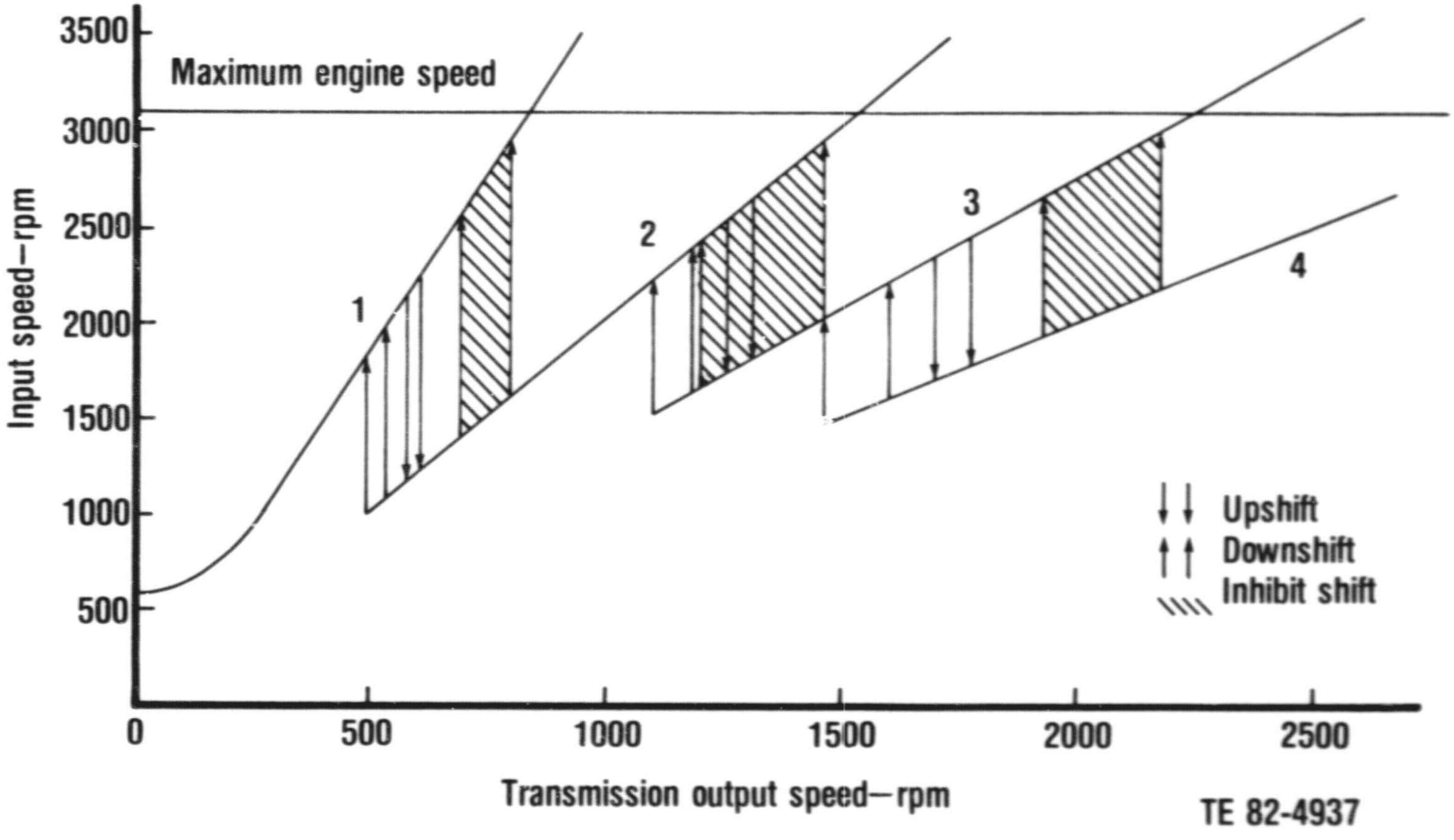

Figure 28. HT740CT transmission shift point schedule--inhibit downshift speed ranges in coach based on decreased hold pressure.

Pitot Can Failure

Failure of the transmission pitot can vanes during Greyhound operation resulted from a design deficiency. The pitot can configuration utilized in the HT740CT transmission is shown in Figure 29. The pitot collector is a stamped steel can that retains oil for the pitot tube. In this design, the pitot tube is stationary and the pitot collector rotates. Oil is supplied to the collector, and stamped steel vanes, spotwelded to the interior of the can, cause the oil to rotate with the can and provide a pitot pressure signal. The pitot pressure signal acts on a regulator valve that supplies pressure to the clutch trimmer valve. The function of the trimmer valve is to regulate the rate at which a clutch is applied and, therefore, provide optimum shift quality and smoothness. The pitot pressure causes the force balance on the trimmer valve to vary with the speed of the engine and is designed and calibrated to give shifts of optimum quality.

Pitot can failure occurred in fatigue due to vane vibration from transmission operation at the higher input speeds provided by the gas turbine engine. The subsequent loss of pitot pressure signal to the transmission controls was evidenced by deterioration of shift quality. However, no damage was incurred by the transmission as a result of the pitot can failure. This same condition was noted in HT740D high-speed diesel applications, which prompted redesign of the pitot collector to incorporate increased can and vane material thickness and hardness.

Since failure of the vanes did not cause a loss of drive or secondary failure or result in severe performance degradation, it was decided not to involve a costly and time-consuming service interruption and retrofit of the HT740CT transmission with the redesigned pitot collector until transmission inspection was required. The redesigned pitot can was installed in two transmissions and operated without incident during the remainder of the program.

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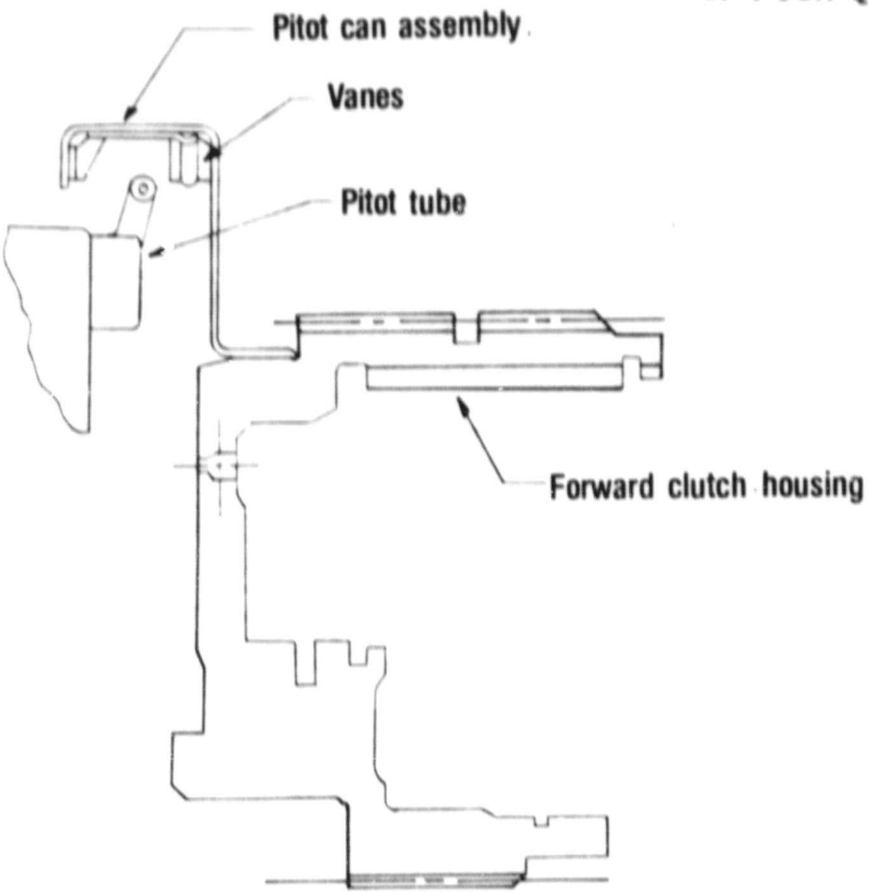

Figure 29. HT740CT transmission pitot configuration.

V. GAS TURBINE INTRACITY BUS DEMONSTRATION PROGRAM

SCHEDULE

Figure 30 shows the Gas Turbine Intracity Bus Demonstration Program schedule. Phase I of the Intracity Bus Demonstration Program involved the operation of four gas turbine powered General Motors Corporation RTS II model coaches supplied by the Mass Transit Administration (MTA) of Baltimore, Maryland. The program plan included the evaluation of one of the turbine-powered coaches at a test track followed by operation of the coaches in revenue service on Baltimore city runs for one year. Due to budget restraints, however, transit coach operation in the program terminated slightly over 3 months after the start of the city service.

DDA procured the hardware and assembled and delivered six GT404-4 gas turbine engines and V730CT automatic transmissions to Modern Engineering Service Company in Michigan, the coach conversion facility, under separate contract to the U.S. Department of Energy (see Appendix A). These power packages were installed in the four coaches (two power packages were retained as spares).

The first transit coach power package was delivered to Modern Engineering nearly 3 months before the first coach, 3319, was originally scheduled for delivery. Several unanticipated setbacks were experienced in completing the installation and achieving satisfactory checkout, and the first coach was 6 months late in commencing test track evaluation. These delays were attributed principally to the following conditions:

- Inadequate oil cooling for both the engine and transmission and insufficient cooling airflow through the engine compartment. These conditions necessitated considerable test verification to identify corrective actions while imposing minimum alteration to vehicle and installation. Timely progress toward resolving these deficiencies through design modifications and component part replacements was hampered by funding limitations at the coach conversion facility.

- Functional problems associated with the modified vehicle heating and air conditioning systems. Efforts to identify and correct problems in these systems were largely unsuccessful up to the time the coach was delivered to the test track and, therefore, testing at the track commenced with these system deficiencies intact.

Test track evaluation commenced in June 1980 and continued until mid-March 1981. Baltimore revenue service started on 25 March 1981 with release of the first coach to the Baltimore to Annapolis run. Transit coach service was suspended on 2 July 1981, providing only limited engine experience in this service environment.

Figure 30 also notes that the number of coaches operating in the demonstration program was reduced from 5 to 4. This decision was made during the Transit Coach Readiness Meeting held on 24 November 1980 in Washington, DC, and attended by representatives from DOE, DOT, NASA Lewis, Booz.Allen and Hamilton, MTA of Baltimore, and DDA.

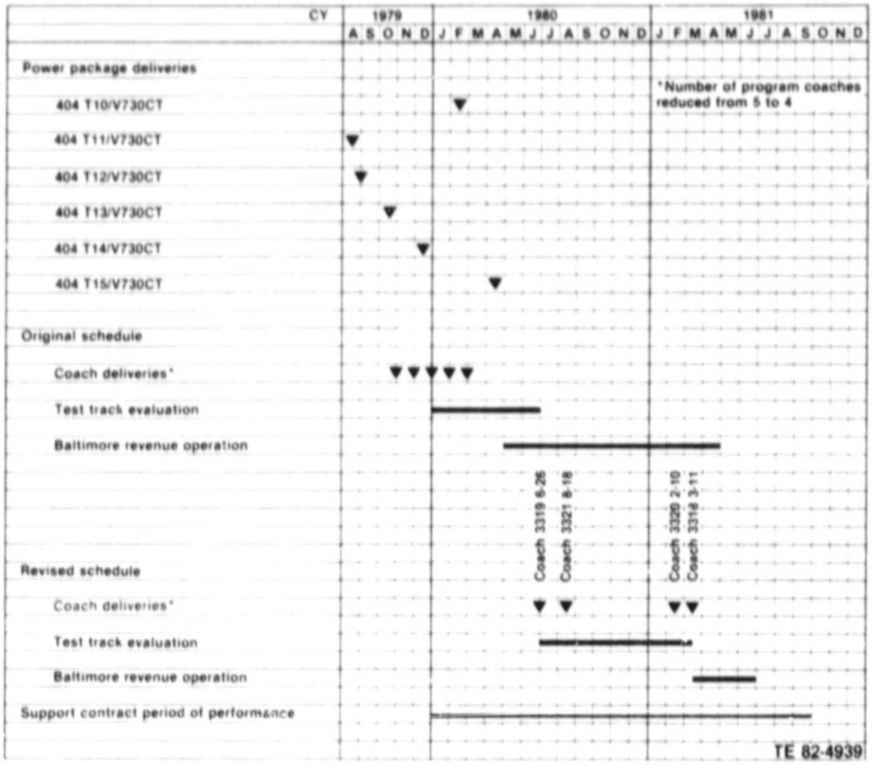

Figure 30. Gas Turbine Intracity Bus Demonstration Program schedule (Phase I).

TRANSIT COACH TEST TRACK OPERATION

Transit coach test track evaluation began in June 1980 and continued until mid-March 1981.

The purpose of the test track evaluation, conducted at the Transportation Research Center Proving Grounds in Ohio, was to subject the first coach to transit cycle durability in a controlled environment in order to identify and correct deficiencies in the engine, transmission, and vehicle systems and to subject subsequent coaches to acceptance testing prior to entering city service.

The transit coach duty cycle used for durability testing conformed to the design operating profile of the Baseline Advanced Design Transit Coach Specifications, Part II: Technical Specifications, Department of Transportation, dated November 1978. The ADB (Advanced Design Bus) cycle, shown in Figures 31 and 32, simulates transit type service and is composed of three phases repeated in sequence: a central business district (CBD) phase of 2 miles with 7 stops per mile and top speed of 20 mph, an arterial route phase of 2 miles with 2 stops per mile and a top speed of 40 mph, and a commuter phase of 4 miles with 1 stop and a maximum speed of 55 mph.

The turbine transit test coach was subjected to the ADB transit coach duty cycle and accumulated 450 cycles (6750 cycle miles [10863 km]) on this schedule. The total test miles accumulated by the turbine coaches operating at the test track was 11,088 mi (17,844 km). Of this total, nearly 9000 mi (14,484 km) was logged on the durability test coach.

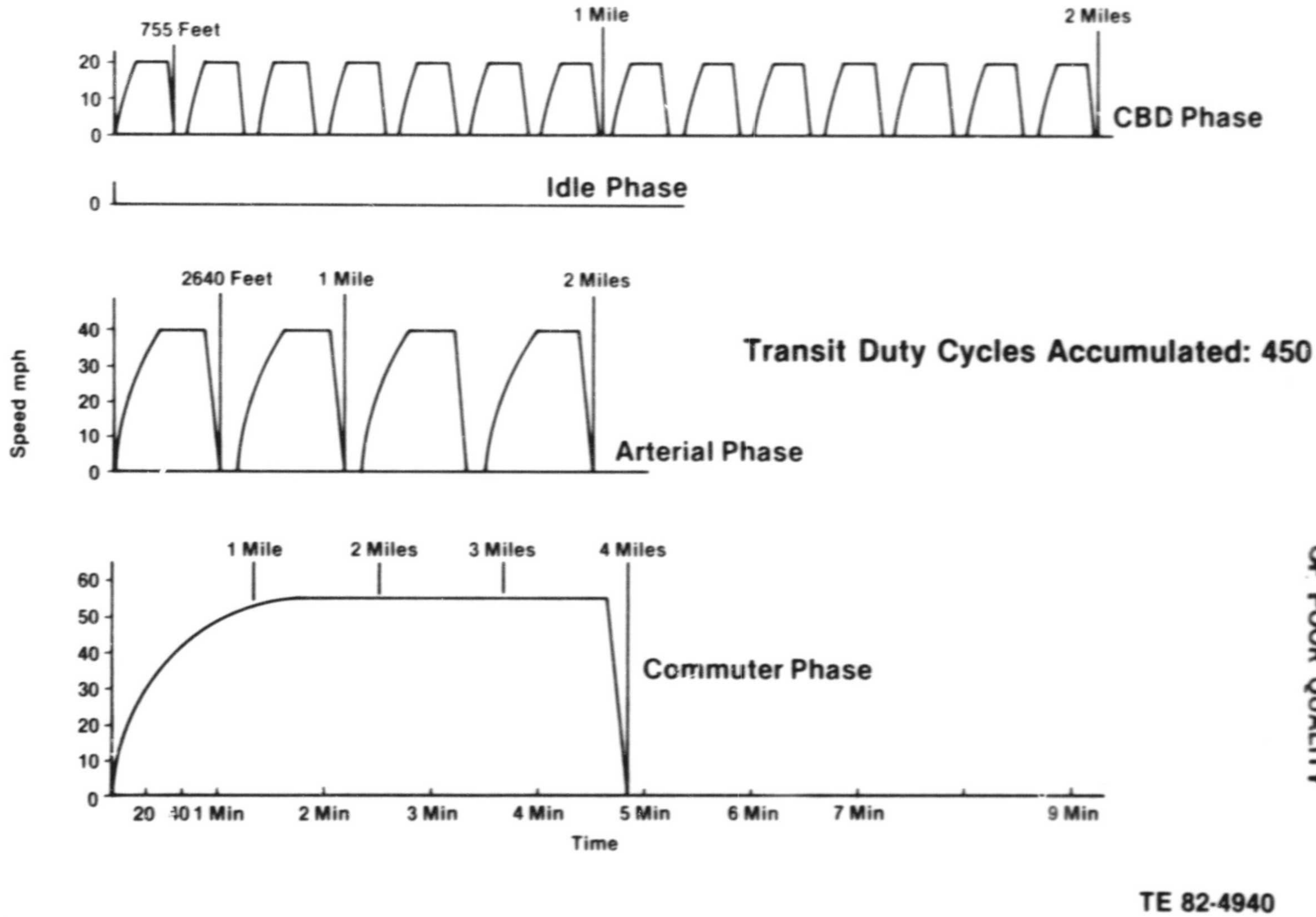

Figure 31. ADB transit coach operating profile duty cycle.

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Phase	Stops/ mile	Top speed (mph)	Miles	Accel. distance (ft)	Accel. time (sec)	Cruise distance (ft)	Cruise Time (sec)	Decel. rate (ft/sec2)	Decel. distance (ft)	Decel. time (sec)	Dwell time (soc)	Cycle time (min-sec)	Total stops
CBD	7	20	2	155	10	540	18.5	6.78	60	4.5	7	9-20	14
Idle	–	–	–	–	–	–	–	–	–	–	–	5-0	–
Arterial	2	40	2	1035	29	1350	22.5	6.78	255	9	7	4-30	4
CBD	7	20	2	155	10	510	18.5	6.78	90	6	7	9-20	14
Arterial	2	40	2	1035	35	1350	22.5	6.78	255	9	7	4-30	4
CBD	7	20	2	155	10	510	18.5	6.78	90	6	7	9-20	14
Commuter	1 stop for phase	Maximum or 55	4	5500	90	2 mile + 4580 ft	188	6.78	480	12	20	5-10	1
Total			14									47-10	51

Average Speed = 17.8 mph

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Figure 32. ADB transit coach operating duty cycle.

Although DDA has sponsored several field evaluation programs during the past decade with previous models of the GT404-4, none of these have involved transit operation. Thus, the GT404-4 engine installation in the RTS II coach was the first opportunity to evaluate the gas turbine powertrain and modified coach systems in the severe transit coach environment. Persistent problems in the modified heating and air conditioning systems and other vehicle testing committed to establishing comparative performance and modifying engine and transmission controls for satisfactory vehicle operation all worked to consume available time. Therefore, sufficient checkout was not achieved prior to the start of revenue service. Many valuable lessons were learned during the test track evaluation, however, which can contribute significantly to the design of future gas turbine transit coaches.

Vehicle Acceleration and Braking

Early shakedown testing with the turbine test coach operating on the ADB transit duty cycle indicated the need to improve coach acceleration and braking performance. Of particular interest was the vehicle deceleration rate and frequency of stops as established by the duty cycle (see Figure 32) with the expectation for improved brake life on the turbine coach because of increased dynamic braking available from the engine. This prompted a comprehensive evaluation conducted by DDA, in cooperation with Booz.Allen and Hamilton, to obtain and analyze vehicle test data and correlate these data with comparative analyses of engine capability and duty cycle requirements.

This resulted in a series of modifications to the engine control system, transmission controls, and vehicle driveline (similarly applied to the Greyhound coach as discussed in Section IV, Greyhound Service Operation--Coach Operational Problems) for improved vehicle acceleration and coastdown performance. The turbine coach achieved faster accelerations (see Figure 33), but slower coastdowns (see Figure 34) than the production diesel-powered RTS II coach. The lack of instantaneous braking is evidenced in the coastdown comparison. The higher engine compressor efficiency (less absorption power) and the higher cycle temperature (more heat stored), while slowing heat dissipation through maintenance of a minimum temperature level in the engine during deceleration and braking, noticeably reduced instantaneous braking with the GT404-4 engine. Comparative analyses indicated that improved instantaneous engine braking could be realized through engine compressor bleed, but this was considered to be a long-term development effort beyond the scope of the current program.

Other Problems

Although testing at the track did not afford sufficient experience to reveal most of the startup problems, some deficiencies were identified. The engine deficiencies were single incidents involving poor quality of the regenerator inboard seal and the power turbine shaft. In addition to coach problems in the modified heating and air conditioning systems, the engine air inlet filtration system was found to be inadequate under conditions of heavy road salt and gravel.

A single instance of local separation of the seal leaf retainer from the seal platform on the inboard seal crossarm (see Figure 35) resulted from inadequate welds in the area. This allowed high-pressure air to leak through the gap

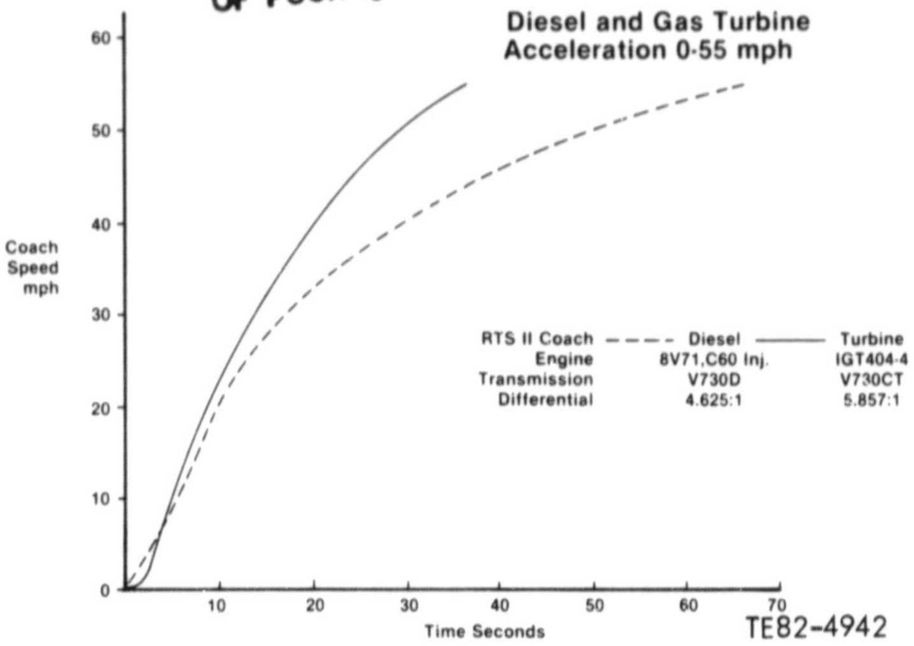

Figure 33. RTS II transit coach acceleration tests.

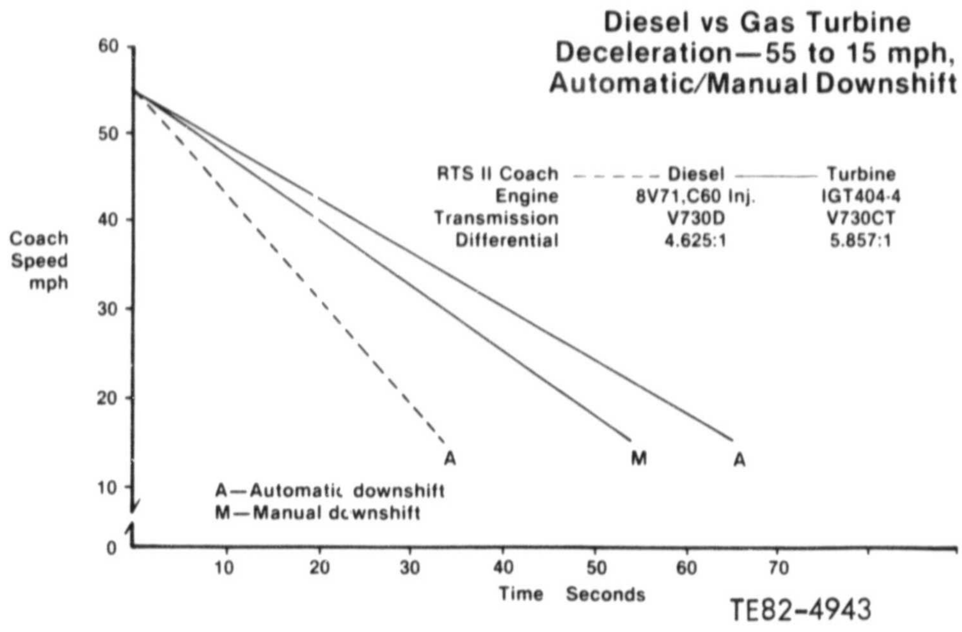

Figure 34. RTS II transit coach deceleration tests.

created by the separation and the resultant high-velocity impingement directed against the edge of the sheet metal insulation retainer in the power turbine exhaust cavity caused distortion of the retainer (see Figure 36). Subsequent retainer contact with the disk caused surface damage. Improved control of weld quality corrected the problem.

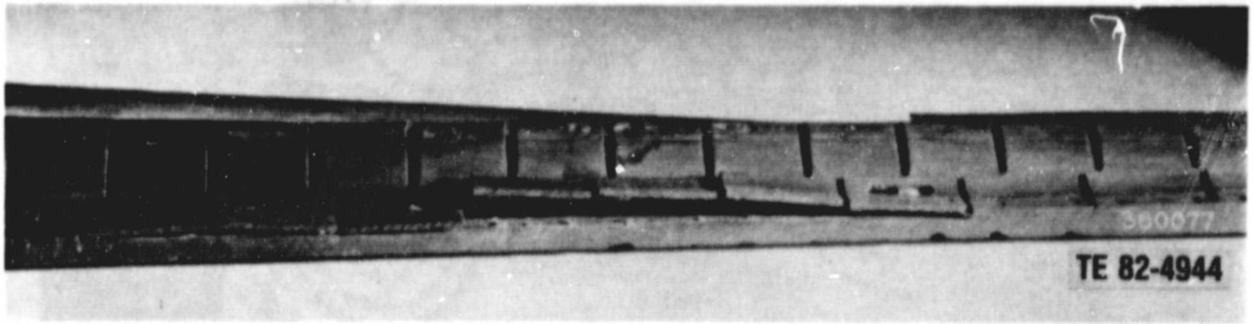

Figure 35. Regenerator inboard seal showing seal leaf retainer separation from platform.

The power turbine rotor and shaft assembly, shown in Figure 37, experienced loss of the labyrinth seal ring during transit coach operation at the test track. This type of failure had not been experienced during extensive engine development testing and it was not repeated in the Bus Demonstration Programs. The failure was attributed to cracks induced during machining of the labyrinth seal and not detected in the subsequent inspection. A reinspection was implemented for all stock of this part and for coach engine parts when they became available but no discrepancies were found. Instructions were issued for increased attention to this area during power turbine shaft inspection.

The engine air inlet filtration system on the Transit Coach installation was found to be inadequate during winter operation at the test track. Figure 38 shows the left (street) side of the turbine coach and the location of the engine air inlet. The close proximity of the inlet to the road surface provided for entry of particles used in a salt/gravel mixture which was applied to the driving lanes to permit continued operation during adverse weather conditions. The heavy concentration of particles entering the air inlet system in the splash generated from the coach rear wheels and from passing vehicles exceeded the capability of the filtration system. This permitted many of the particles to enter the engine and cause local distress. Although the test track experience was considered to be more severe than would be experienced during winter operation on the Baltimore city runs, it was recommended that design changes be incorporated to replace the single-stage inertial air cleaner with a two-stage series air cleaner for improved filtration. This would provide an inertial panel ahead of a barrier-type filter. However, the program ended before the required design changes could be evaluated.

Driving Cycle Braking Requirements

The significance of the coastdown performance for the turbine and diesel coaches is better understood through analysis of the driving cycle braking requirements.

The ADB transit coach operating duty cycle incorporates 51 stops in the cycle time of 47 min 10 sec. The stops on this cycle require a vehicle deceleration rate of 6.78 ft/sec ^{2} (2.07 m/s ^{2}). The corresponding stopping times of 12 sec from 55 mph (88.5 km/h), 9 sec from 40 mph (64.4 km/h), and 6 sec from 20 mph (32.2 km/h) with the turbine coach cause the output shaft to slow more

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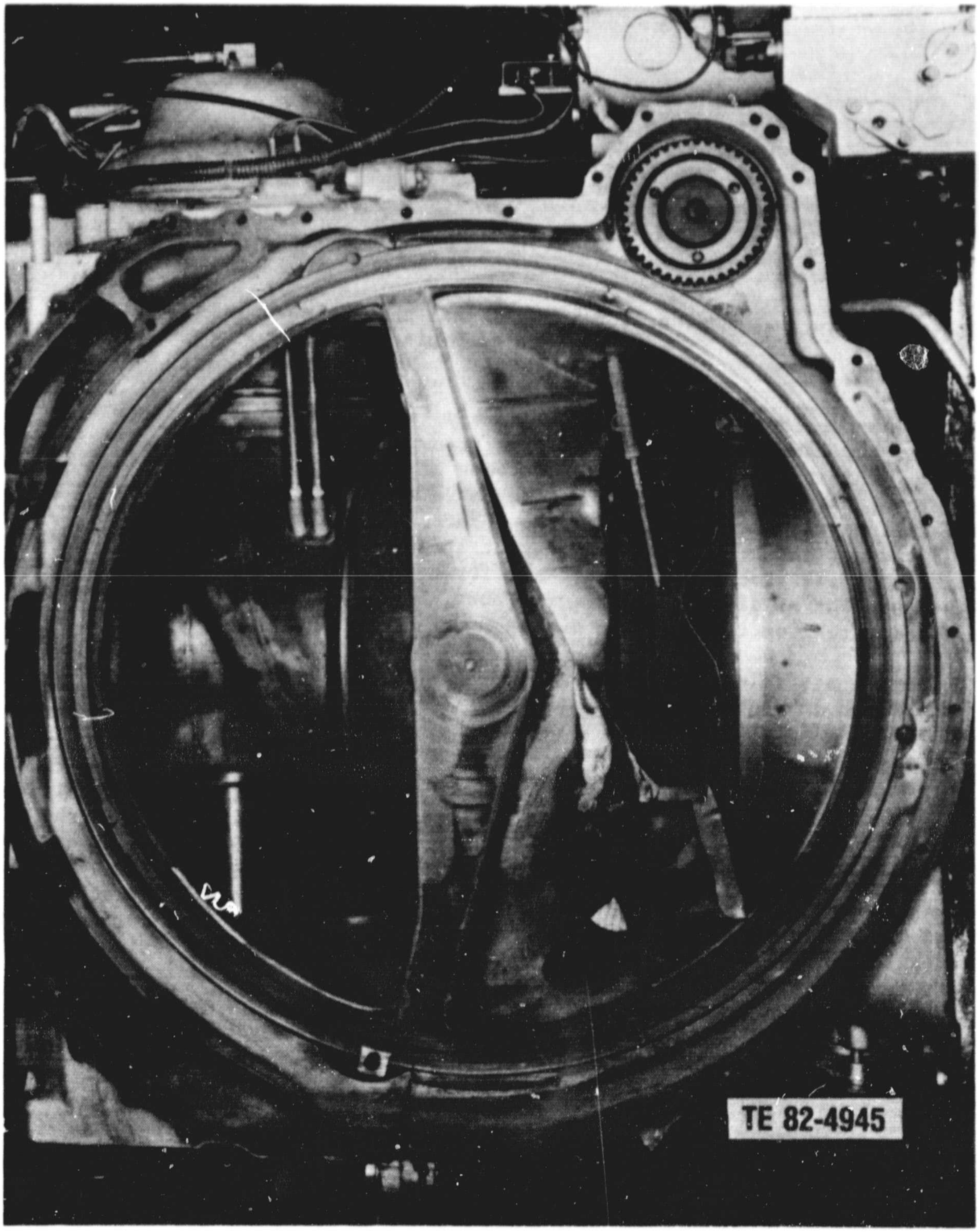

Figure 36. Left side of engine showing sheet metal insulation retainer distortion.

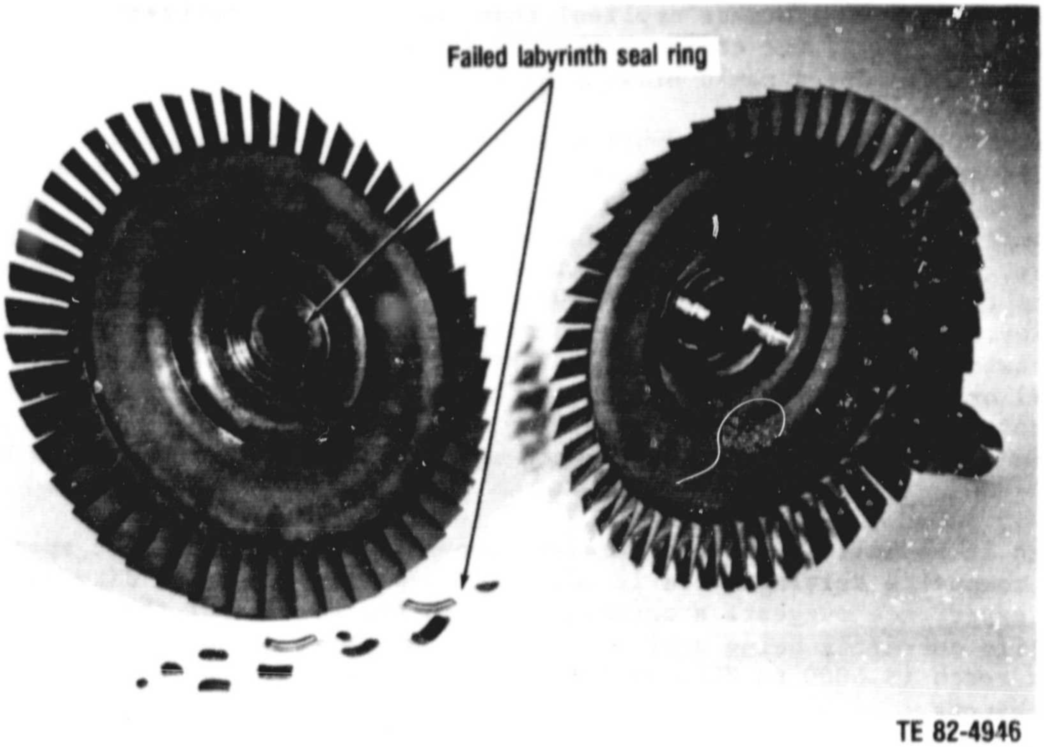

Figure 37. Power turbine rotor and shaft assembly showing failed labyrinth seal ring in comparison with new like part.

Figure 38. GT404-4 powered RTS II transit coach.

rapidly (with service brakes applied) than the natural deceleration rate of the gasifier. Thus, the engine lacks the instantaneous braking required to provide satisfactory dynamic braking on these stops.

The analysis of the power absorption required by the vehicle brakes to achieve the cycle deceleration rate with the turbine and diesel engines is shown in Figure 39. The total deceleration horsepower required for the coach at 55 mph (88.5 km/h) is 1040 hp (776 kW). The power absorbed by wind and rolling resistance, vehicle accessories, driveline, transmission, and engine resistance with the turbine-powered coach is 160 hp (119 kW) or 16% of the total. The remainder, 880 hp (657 kW) or 84%, is absorbed by the vehicle brakes. With the diesel-powered coach, the vehicle brakes are required to absorb 770 hp (574 kW) or 74% of the total during a stop from 55 mph (88.5 km/h), a 10% improvement when compared with the turbine vehicle. Still, the analysis shows that the vehicle brakes on either coach must absorb considerable power during a stop.

Although it is unlikely that a deceleration rate as severe as that specified in the composite driving cycle is routinely experienced during city operation, actual experience suggests a correlation with the results of the analysis. Brake life currently being achieved with the original equipment on the diesel-powered coach is 6000 to 8000 mi (9656 to 12,875 km), which is unacceptable to the operators.

Considerable effort is being applied in the bus industry to incorporate either a transmission or a driveline retarder to improve vehicle dynamic braking and brake life. It is estimated that on the transit coach with a transmission retarder and braking from 55 mph (88.5 km/h), the power absorbed by the brakes is reduced to 200 hp (149 kW), or 20% of the total. Experience in the transit program has shown that the most likely solution for extending brake life is the vehicle retarder.

BALTIMORE TRANSIT SERVICE OPERATION

The total service miles accumulated by the four GT404-4 powered transit coaches is shown in Figure 40 for each of the service months in Baltimore. The Baltimore service period for each of the coaches is also indicated. The first coach was released to the Baltimore to Annapolis run on 25 March 1981. City service on this run was suspended on 2 July 1981 due to budgetary restraints that caused the termination of the Intracity Bus Demonstration Program.

The coaches were operated from the Bush Street Division on a five-day service schedule. The Baltimore to Annapolis run offered capacity loads and numerous stops depending on the time of day, and the coaches ran on the four rush hour round trip schedule per day.

Total service operation accumulated by the transit coaches was 19,660 mi (31,639 km) and 1096 hr. Of the total service hours accumulated by the coaches, 958 hr were logged in revenue operation and 138 hr in driver training. It had been anticipated that the Baltimore city operation would continue for one year and accumulate 6000 hr. However, the program was terminated slightly over 3 months after the start. Although the 1096 coach hours logged during the service period was a lower figure than the anticipated accumulation of 1500 hr for the period, the performance achieved was within expectations for the start-up of new equipment.

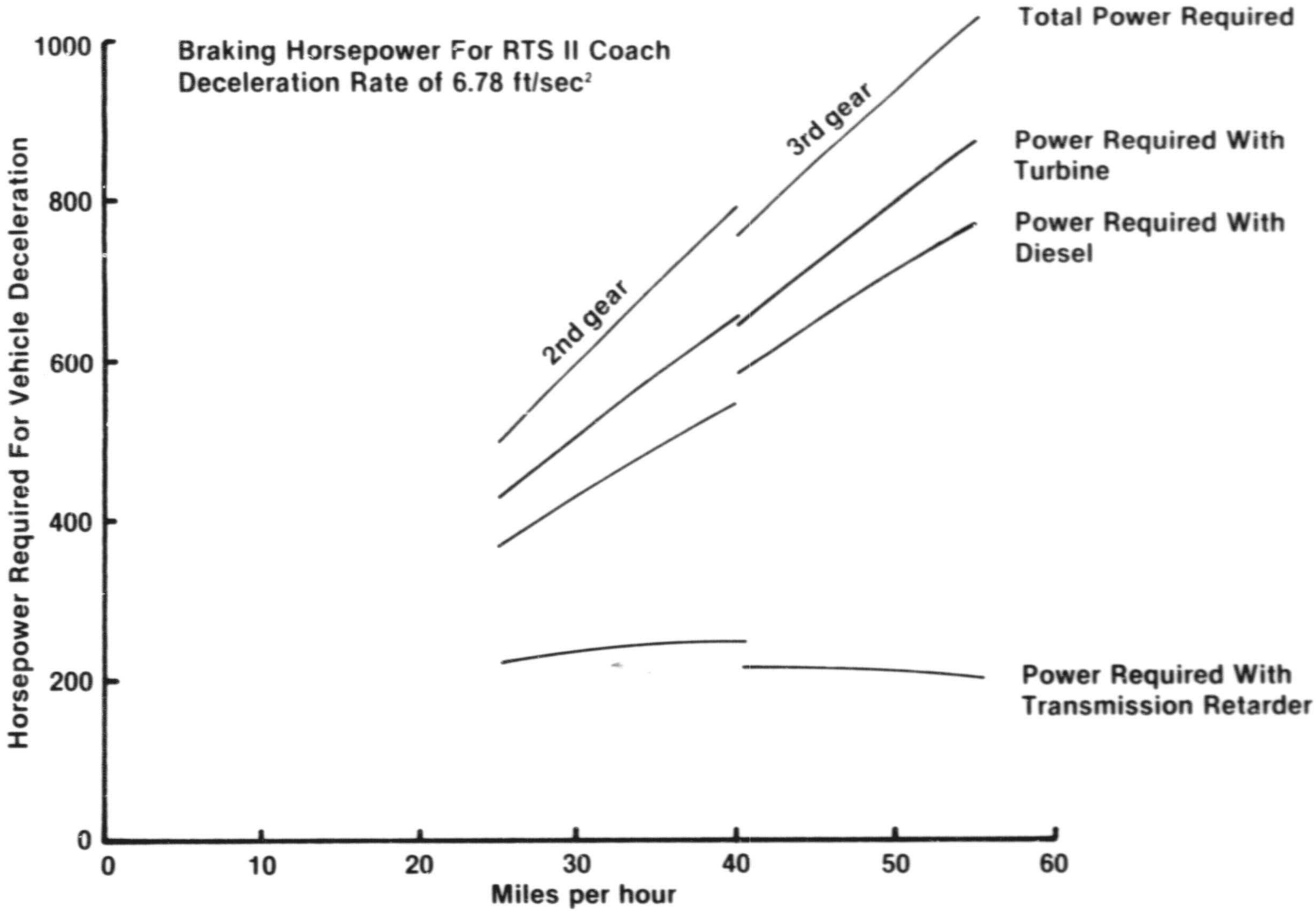

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Figure 39. ADB transit coach driving cycle braking analysis.

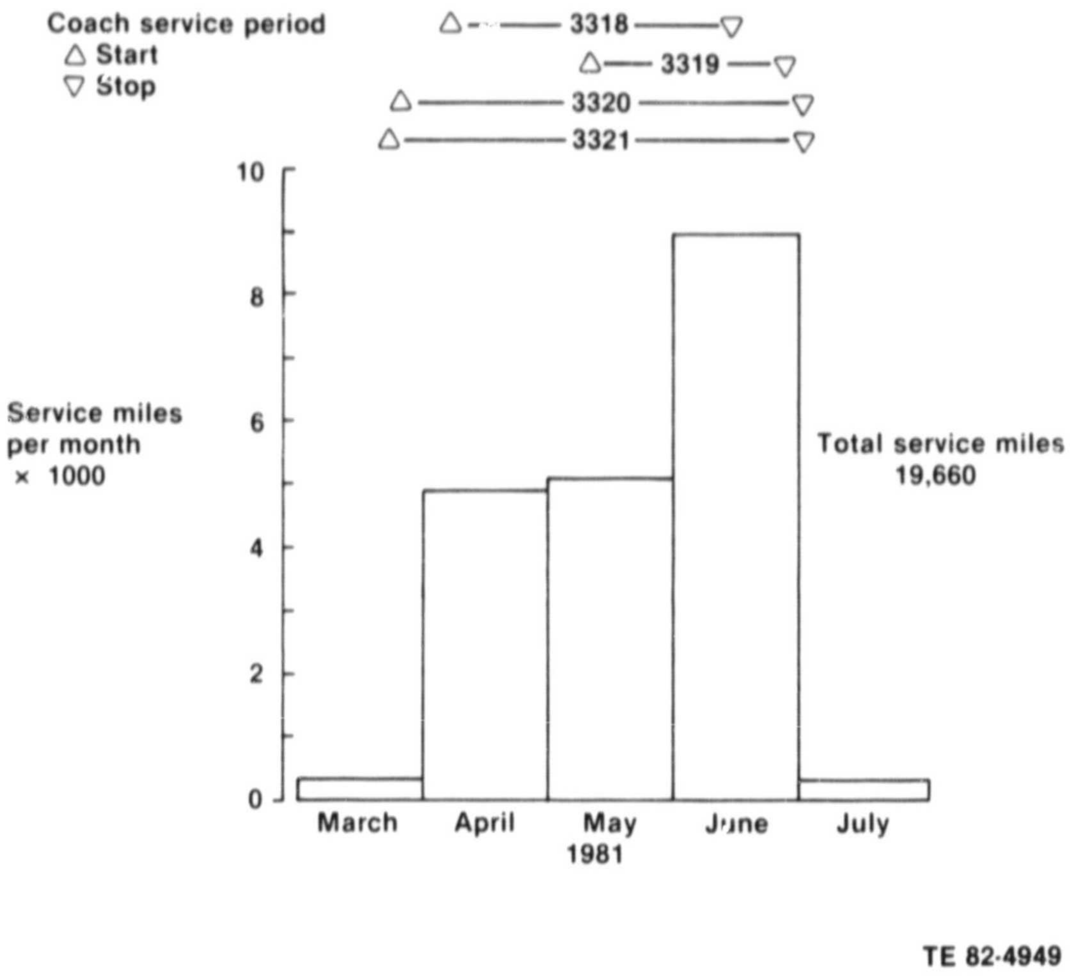


Figure 40. Baltimore transit service operation.

Driver training was periodically conducted with the coaches during the service period, which provided turbine bus familiarization to a large number of MTA drivers. This was not only necessary to ensure the availability of trained drivers to meet schedule requirements but was also useful in obtaining a larger sample of drivers' comments for evaluation of the gas turbine bus.

BALTIMORE TRANSIT SERVICE EXPERIENCE

Service experience with the four GT404-4 powered transit coaches operating on the Baltimore to Annapolis run is summarized in Figure 41. Coach operation in March and July was minimal and has not been included in this summary. The service experience is segmented into the three main operating months to profile, as a percentage of available service days, the coach operating days and the service days lost due to incidents that prevented the coach from starting a scheduled revenue run or completing a run in progress. The coaches were operational an average 54.8% of the available service days while lost service time due to engine problems was an average 20.1%. Service time lost due to coach problems, at an average 19.1%, nearly equaled the operating days lost due to engine incidents.

The number of incidents attributable to the engine, transmission, and coach and the mean miles between incidents for the service period are also shown in Figure 41.

The data obtained during this limited city demonstration show that coach-related incidents significant enough to cause the coach not to operate in revenue service were nearly 2.5 times more prevalent than engine incidents. However, many of the coach problems experienced during service operation involved components and systems modifications required for installation of the GT404-4 engine. The turbine-unique features of the installation lacked sufficient operating experience prior to the start of service in Baltimore to preclude the startup problems actually encountered.

Failures in the regenerator system were the major contributor to lost operating days due to the engine. The other engine problems involved adjustments in the control and lubrication systems.

The engine and transmission problems experienced during Baltimore Transit service operation are discussed later in this section. The chronological histories of the GT404-4 engines and V730CT transmissions involved in the Baltimore Transit program are presented in Appendix D.

The fuel mileage achieved with the GT404-4 engine in Baltimore city service was approximately 2.7 mpg. Baltimore diesel coach fleet average in a similar service environment is 4.5 mpg.

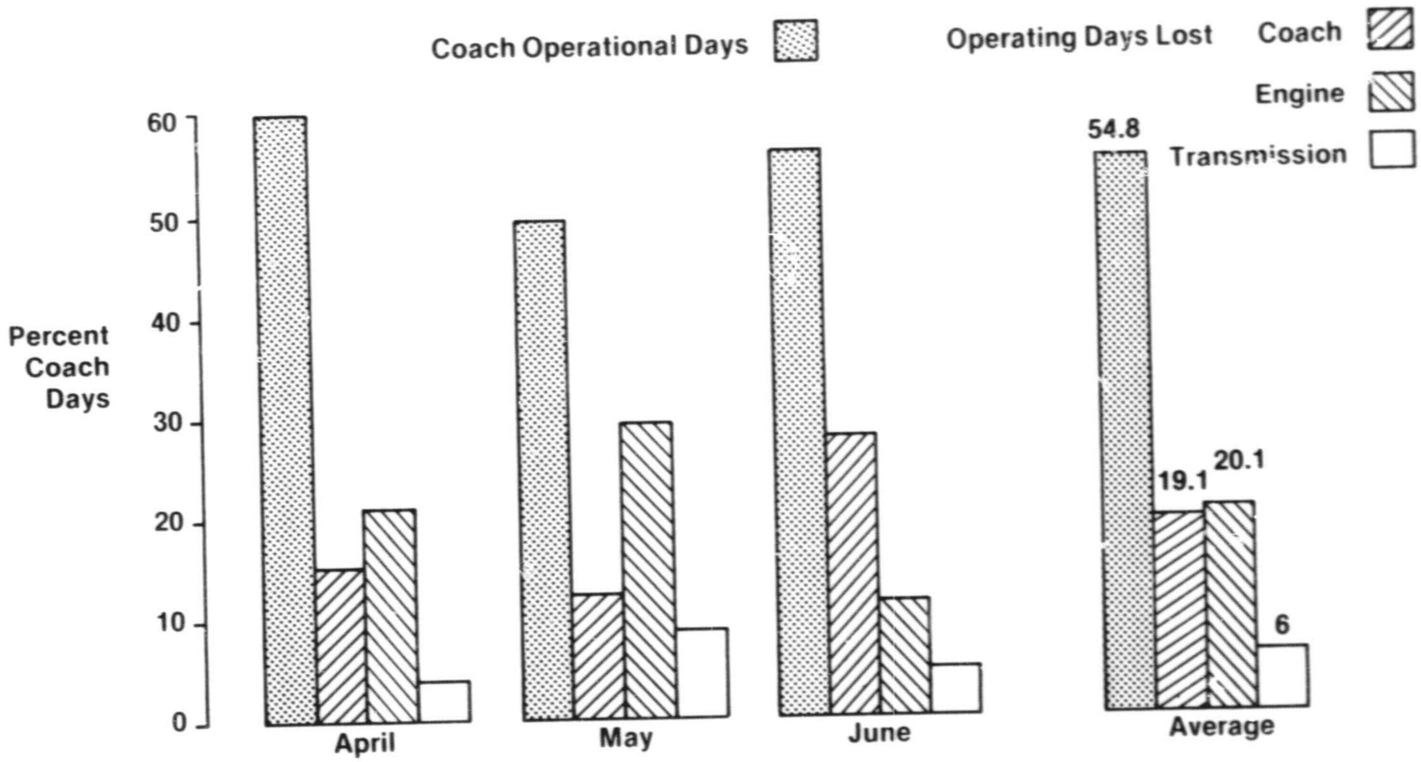
BALTIMORE TRANSIT SERVICE OPERATION--ENGINE PROBLEM

Ceramic Regenerator Disk Surface--Quality Deficiency

Ceramic regenerators were configured in the transit coach engines because of concern for metal regenerator oxidation on the more severe transit duty cycle with the associated higher number of engine accelerations. Ceramic regenerators, in comparison, have demonstrated good oxidation resistance on the transit duty cycle.

Testing has shown that poor surface finish on the disk in the rim seal area can result in premature wear-out of the regenerator seal graphite and in subsequent disk damage. Two incidents of seal wear all the way down to the metal platform occurred in transit service after 105 and 267 hr of operation (see Figure 42). This experience has indicated the need for improved surface finish on the disk, and surface grinding improvements are being implemented.

The transit duty cycle may account for part of the faster seal wear. Engine test operation on a simulated transit duty cycle resulted in a projected seal life of 1850 hr whereas truck cycle testing projected 4000 hr seal life. Figure 43 shows seal graphite wear data obtained with ceramic disks. The two regenerator failures in transit service involved seal wear all the way down to the metal platform. The transit bus seal life is based on wear measurements obtained during operation on the simulated ADB duty cycle and projected to the recommended graphite wear limit. The projected seal life in transit bus service is contrasted with data obtained during simulated testing on the less severe truck duty cycle.



Number of Incidents	April	May	June	Total	Mean Miles/Incident
Coach	3	6	13	22	862
Engine	3	2	4	9	2107
Transmission	2	1	0	3	6322
Powerplant (Engine + Transmission)				12	1580

18966 Total Service Miles: April 1 — June 30, 1981

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Figure 41. Baltimore transit service experience.

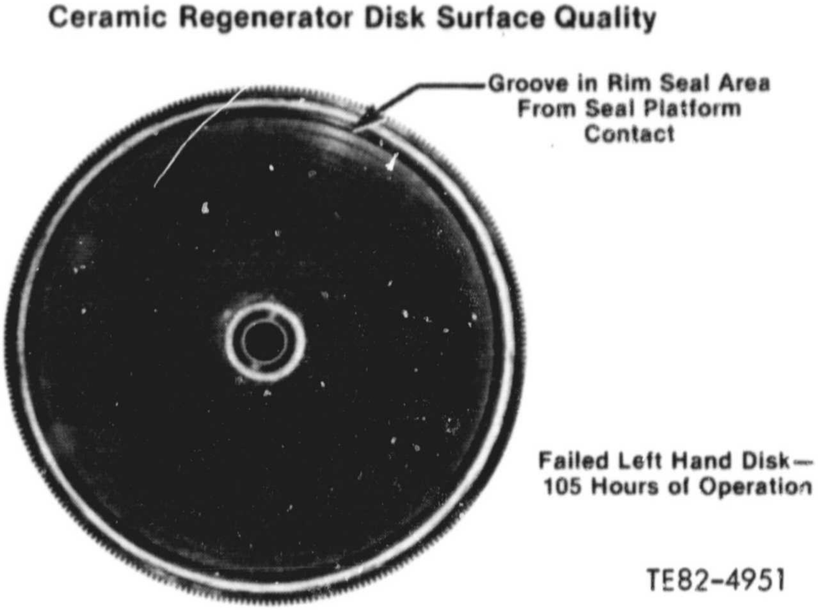

Figure 42. Ceramic regenerator disk showing surface damage.

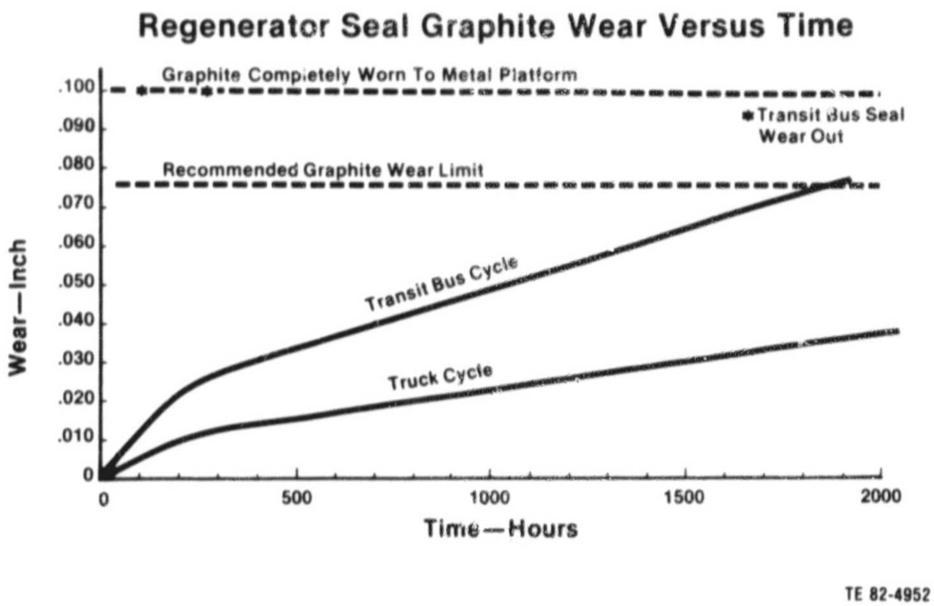

Figure 43. Ceramic regenerator seal graphite wear data.

The program ended before the effects of disk surface finish and transit bus duty cycle on seal graphite life could be fully evaluated.

TRANSIT ENGINE UPDATE CONFIGURATION

Table V shows the transit coach engine update status at the completion of the Intracity Bus Demonstration Program. The updates listed were those which had

Table V.
Transit engine update status.

Update	Engine S/N						DDA recommended action
	T10	T11	T12	T13	T14	T15	
PT pinion and gear tight shaft fits							Change at engine overhaul
Bump-stop pin inspection	X	X	X	X	X	X	Completed
Relay panel added diode		X	X	X	X		Cycle modified units
Output gear backlash increase							Change at gearbox disassembly
PT bearing improved lube							Change at engine overhaul
Oil pump improved bushing retention			X				Change at gearbox disassembly
Output gear oil baffle stronger mounting						X	Change at gearbox disassembly
Output shaft bearing positive lube							Change at engine overhaul
Inner exhaust diffuser reduced splitter dia							Change at engine overhaul
Clutch control oil tube mounting							Change at gearbox disassembly
Rear PT pedestal large dowels							Change at engine overhaul
Regenerator drive improved spline lube							Change at engine overhaul
Turbine inlet duct improved material and floating outlet ring design	X	X	X	X	X		Inspect [illegible]00 hr, change as required
Oil pump positive drive		X	X				Change at gearbox disassembly
Install impeller with new filtered casting	X	X	X	X	X		Change all engines immediately
Fuel valve balance piston improvements	X	X	X	X	X		Cycle modified units
Outer heat shield improved locking	X	X	X	X	X		Change at gasifier disassembly
Shot peen PT pinion and gear							Change at engine overhaul

been identified and recommended for coach engine modifications during the period of performance of the support contract. These modifications corrected deficiencies identified through field operation and development testing of the engine. Because of funding limitations, many of the coach engines could not be upgraded or maintained to the desired configuration.

BALTIMORE TRANSIT SERVICE OPERATION--TRANSMISSION PROBLEM

The principal problem experienced with the V730CT transmission involved the calibration and control of the clutch coupling lockup shift. During test track evaluation of the transit coach, a series of modifications to the engine control system, transmission controls, and vehicle driveline were implemented for improved vehicle acceleration and coastdown performance. The adjustments required in the coupling/clutch control to reduce the time required to fully engage the lockup clutch and achieve direct drive for faster vehicle acceleration from rest were identified but a problem was experienced in achieving repeatable control and satisfactory quality of the lockup shift.

In the gas turbine model of the transmission, the torque converter of the V730D diesel production unit has been replaced by a fluid coupling with an integral lockup clutch. The clutch/coupling functions to do the following:

- o maintain a minimum engine idle speed during normal vehicle stops to ensure continuous operation of the power turbine driven accessories
- o retain ability to utilize gas turbine engine stall torque characteristics when steep grade conditions warrant

- provide means for getting the engine and transmission coupled into direct drive as quickly as possible during acceleration

- provide means for keeping the engine and transmission coupled in direct drive as long as possible during deceleration in order to utilize engine braking to the lowest possible speeds

Based on satisfactory operation of the coupling/clutch control system on the HT740CT transmission, the coupling/clutch control circuit and calibration were utilized without modification in the V730CT configuration. This was considered to be acceptable based on the similarity of the transmissions and their respective applications. At the start of the Intracity Bus Demonstration Program, no previous V730CT experience existed in transit bus operation. In addition, sufficient experience was not achieved with the transit coach at the test track prior to the start of service to provide proper evaluation of the transmission and identify controls calibration requirements.

The control for the clutch/coupling is provided by a complex system of hydraulic circuitry, valves, springs, and pressures. A schematic of the control valve is shown in Figure 44. The lockup control circuit uses coupling charging pressure as a regulation reference base. Coupling charging pressure, the oil pressure generated within the fluid coupling element during operation, acts with the bias valve spring to produce a force on the bias valve. This force is resisted by the force produced from modulator pressure acting on the valve. As shown in Figure 45, modulator pressure is scheduled as a function of the engine compressor discharge pressure. Modulator pressure decreases as the compressor discharge pressure increases (increasing throttle). During vehicle acceleration from rest, increasing throttle (engine power) results in increasing coupling charging pressure and reducing modulator pressure, thereby increasing lockup pressure until full-clutch lockup is achieved. The lockup clutch control incorporates an override valve, which forces a lockup engagement, regardless of the engine power level, at a predetermined transmission output speed. The override control also maintains clutch lockup to 6 mph (9.7 km/h) or lower during vehicle deceleration in order to utilize engine braking down to a low vehicle speed.

Since the coupling/clutch control circuit (and calibration) used in the V730CT transmission was maintained from the HT740CT transmission experience, the effect of major differences between the two transmission configurations on the lockup shift problem should be reviewed.

The lower first gear ratio (2.10:1 versus 3.69:1 for the HT740CT) results in reduced vehicle startability from rest. In order to achieve comparable vehicle acceleration from rest, a higher input power level is required. When the lockup clutch is engaged, more power will be absorbed by the clutch and there will be a different differential speed between the clutch members during engagement. Experience with other transmissions indicates that these variables can have a significant effect on shift performance and quality. The different gear ratios also affect the timing of the lockup override shift. Figure 46 shows the lockup and lockup override shift ranges for the V730CT and HT740CT transmissions. The override shift is signaled from the transmission output governor, which senses output shaft speed. Because of the difference in gear ratios, the lockup override shift for the HT740CT transmission occurs at a higher engine output speed than with the V730CT transmission. With the same calibration utilized

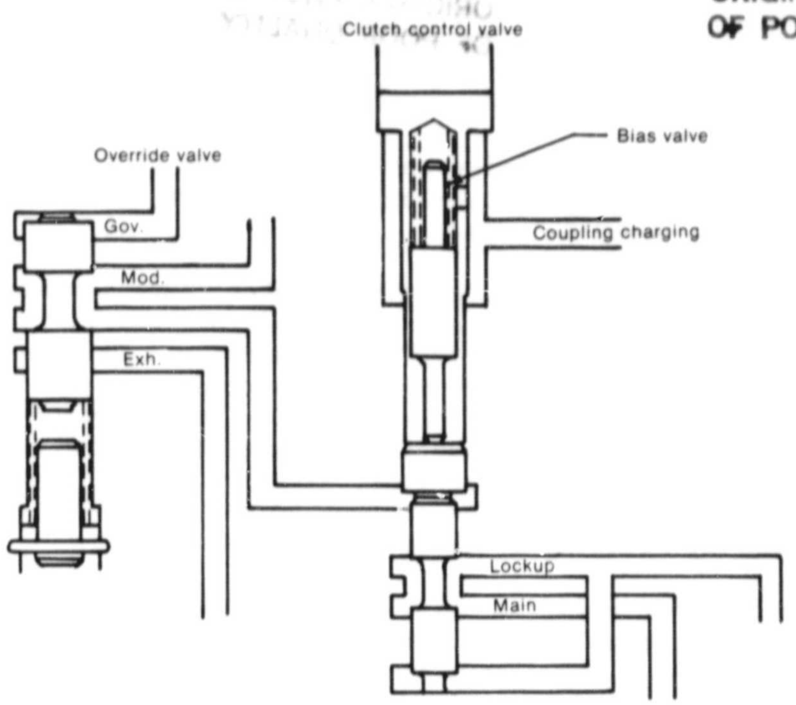

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Figure 44. Transmission coupling/clutch control valve schematic.

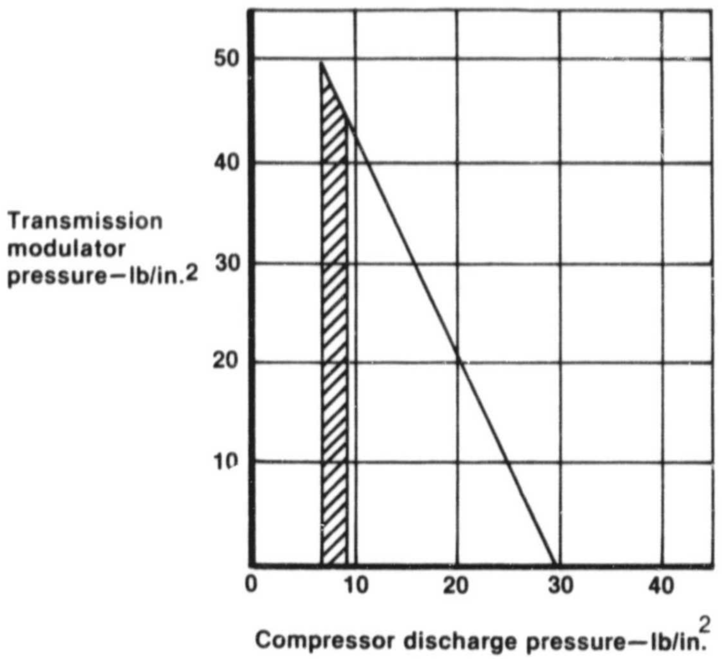

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Figure 45. Transmission modulator pressure schedule.

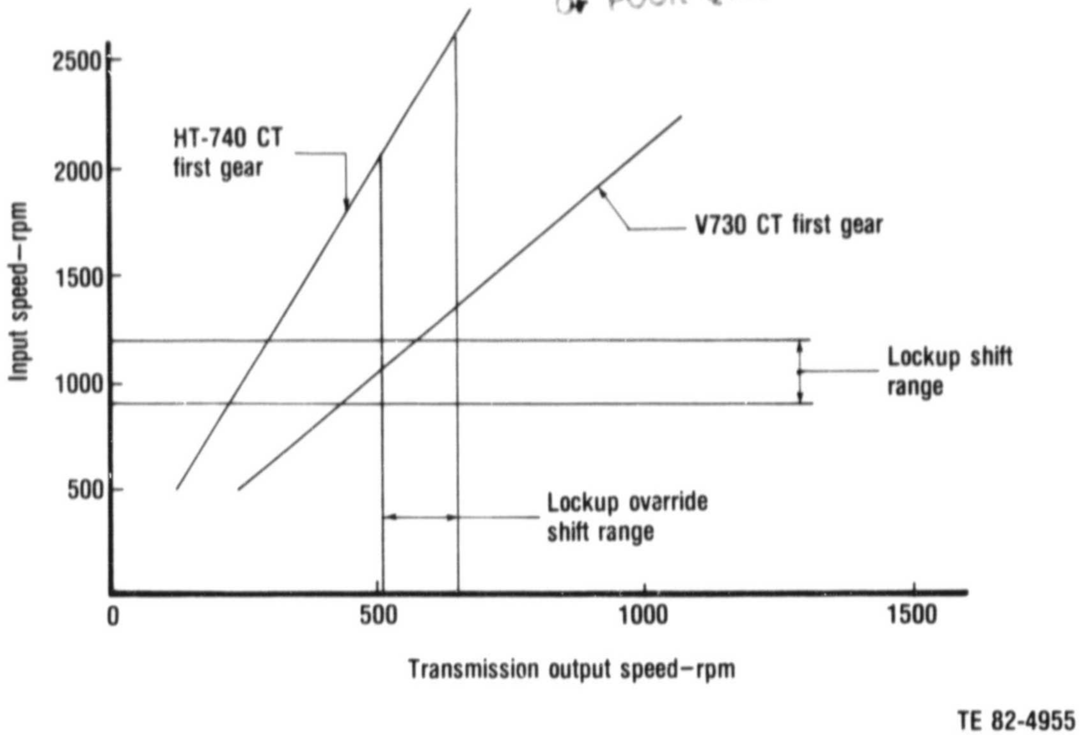

Figure 46. Transmission coupling/clutch lockup shift ranges.

for the coupling/clutch control in the V730CT transmission, it is possible for the lockup and override shifts to occur simultaneously or within close proximity. This condition could be responsible for variations in shift timing and quality.

Another difference between the two transmissions that can affect the timing and quality of the lockup shift involves the hydraulic circuits in the control system. Significant variations in routing of the control pressures introduce pressure differentials that affect valve and clutch responses. Because of the configuration of the V730CT transmission lockup pressure circuit, clutch fill and exhaust would be expected to be slower, causing variations in clutch response characteristics.

The program ended before calibration requirements for the V730CT transmission operating in the transit coach environment could be established and necessary changes implemented.

VI. INTERCITY/INTRACITY BUS SERVICE

ENGINE DUTY CYCLE ON SERVICE ROUTES

Transient recordings of selected GT404-4 engine parameters were obtained on revenue runs in Greyhound and Baltimore service. The purpose of this data acquisition was to profile the engine in these duty cycles in order to aid in analyzing the effects of the more severe intracity bus duty cycle on engine durability.

Data were obtained during Greyhound service operation on the Chicago to Louisville express run, during the Louisville to Indianapolis segment of the local return run, and during Baltimore city service operation on the Baltimore to Annapolis rush hour run and a typical downtown run.

Table VI shows the number of engine gasifier accelerations at 20% or greater speed change per hour of service cycle operation for the Greyhound intercity and Baltimore transit runs. The ADB transit duty cycle used for durability testing the turbine coach at the test track is included for comparison. The Greyhound express run from Chicago to Louisville subjected the engine, as expected, to the fewest number of accelerations at 24/hr of service operation. The GT404-4 vehicular engine design has been established through engine experience in this type of service duty environment. Intracity operation imposed the highest number of accelerations on the engine with the Baltimore to Annapolis rush hour commuter run at 90 accelerations per hour being slightly greater than the downtown run. The Baltimore transit operation subjected the engine to nearly 4 times the number of accelerations imposed by the Greyhound express run.

Table VI.
Intercity/Intracity bus service: coach engine acceleration per hour (20% or greater speed change).

Coach	Type of run	Accelerations/hr
RTS II (MTA)	Test track (ADB cycle)	65
RTS II (MTA)	Baltimore--downtown	86
RTS II (MTA)	Baltimore--commuter (Baltimore-Annapolis rush hour run)	90
MC-8 (Greyhound)	Local (Louisville-Indianapolis)	32
MC-8 (Greyhound)	Express (Chicago-Louisville)	24

Analysis of the ADB transit duty cycle, on which the turbine coach was durability tested, showed that this composite schedule offered 65 accelerations per hour or nearly 28% fewer than the Baltimore commuter run profiled. A modification of the ADB transit duty cycle to reflect the greater number of accelerations is recommended for future development.

Damage relationships were established for the engine gas path rotating components based on the mechanical effects associated with a 5% or greater speed change. These severity factors are shown in Table VII for the bus duty cycles

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Table VII.
Duty cycle severity comparison.

Type of run	Severity factor* (5% or greater speed change) Compressor rotor	Gasifier rotor	Power turbine rotor
Baltimore Transit--downtown	3.96	7.10	3.01
Baltimore Transit--commuter	3.42	4.95	3.80
Greyhound--local	2.43	2.50	2.26
Greyhound--express	1.0	1.0	1.0

*Data normalized for reference to Greyhound express run.

profiled during service operation. The duty cycle data were normalized to provide a basis of comparison with the Greyhound express run, which is the type of service experience used to establish the GT404-4 vehicular engine design. Engine operation on the Baltimore Transit downtown run was nearly 4 times more severe to the compressor impeller, over 7 times more severe to the gasifier rotor, and 3 times more severe to the power turbine rotor than operation on the Greyhound express run. The highest severity factor for the power turbine rotor occurred during the Baltimore commuter run at 3.8 times that for the Greyhound express run. Thus, transit operation is shown to be a significantly more severe service environment, which exceeds some of the original design criteria for the engine.

VII. DISCUSSION OF RESULTS

- The Greyhound coaches operating in the Intercity Bus Demonstration Program accumulated 183,054 mi (294,595 km) and 5154 hr of total operation. Of the total, 170,610 mi (274,568 km) and 4692 hr were logged in service. The service miles achieved was considerably lower than the 450,000 mi (724,205 km) service mileage anticipated for accumulation during the period and is due to the startup problems experienced.

- The Baltimore Transit coaches operating in the Intracity Bus Demonstration Program accumulated 40,567 mi (65,285 km) and 1840 hr of total operation. Of the total, 19,660 mi (31,639 km) and 1096 hr were logged in service during the 3-month service period. The service hours achieved was a lower figure than the anticipated accumulation of 1500 hr for the period. That is due to the startup problems experienced. Baltimore city operation had been planned for one year of service with 6000 hr accumulated during the period, but lack of funding ended the program prematurely.

- Driver and passenger reactions to the gas turbine coach were generally favorable when the vehicle operated without incident (after acceleration and braking improvements were made). However, both drivers and passengers were annoyed when delayed by any failure and the gas turbine system was usually blamed. The lack of engine noise and vibration, which resulted in a quiet and less fatiguing ride, and the lack of exhaust smoke and odor were features often referred to by the drivers and passengers. The drivers also liked the road performance of the turbine, often noting the superior hill climbing ability with the engine.

- The fuel average achieved with the Greyhound turbine-powered coach in intercity service was 4.26 mpg. Diesel coach fleet average in similar service is 5.66 mpg.

- The fuel average achieved with the Baltimore turbine-powered transit coach in city service was 2.7 mpg. Diesel coach fleet average in similar service is 4.5 mpg.

- The mean miles between incident experienced in Greyhound intercity service were 4265 mi for the engine, 21,326 mi for the transmission, and 5170 mi for the coach. The mean miles between incident in Baltimore transit service were 2107 mi for the engine, 6322 mi for the transmission, and 862 mi for the coach. Although anticipated performance was not established at the start of the demonstration programs, these results are considered to be unacceptably low. That is due to the large number of startup problems experienced.

- Analysis of the braking requirements in the transit driving cycle indicates that the necessary vehicle stopping times require significant assistance from the engine, turbine or diesel, but that most of the power required to stop must be absorbed by the brakes. Transit experience has shown that a vehicle retarder is required to extend brake life.

- The bus duty cycle profiles obtained during revenue service revealed that the Baltimore transit operation was 3 to 7 times more severe to the GT404-4 engine gas path rotating components than was operation on the Greyhound intercity express run.

VIII. CONCLUSIONS

- Sufficient experience was not achieved with the coaches prior to the start of service to identify and eliminate many of the problems associated with the startup of new equipment. Vehicle mileage accumulated with the previous model GT404-3 engine prior to the start of DDA sponsored field evaluation was nearly 5 times greater than comparable experience available to the GT404-4 engine at the start of service in the bus programs. Because of startup problems, only about 40% of the anticipated mileage in Greyhound service and 70% of the anticipated hours in Baltimore city service were accomplished. Although the program did not accomplish the operational miles and hours anticipated and was ended prematurely for lack of funding, a great deal of valuable experience was obtained. Critical knowledge gained in such areas as duty cycles, vehicle acceleration and braking, inlet filtration during winter driving, and coach systems interface will be useful in the design and development of future gas turbine systems.

- In-service fuel mileage achieved with the turbine-powered Greyhound and Transit coaches were approximately 25% and 40% lower, respectively, than the production diesel-powered coaches. These comparisons are within 3% of computer predictions using the simulated operating profiles. The bus programs had been planned to occur in three phases, with ceramic technology from the DOE/NASA CATE program introduced in the latter phases to demonstrate improved performance. Due to funding cutbacks, Phases II and III did not occur. In view of the growing importance of fuel consumption, the gas turbine will be required to demonstrate fuel economy equivalent not only to that of today's diesel engines but also to the projected fuel economy of the advanced diesel engines of the 1990s. It is anticipated that the necessary improvements in fuel consumption can be obtained through the use of advanced ceramic development currently being sponsored by the DOE and NASA.

- The bus duty cycle profiles obtained for the Greyhound intercity and Baltimore city runs revealed that transit operation represents a significantly more severe service environment for the GT404-4 engine. Since the GT404-4 vehicular engine design has been established through engine experience on the intercity express type duty cycle, transit operation exceeds some of the original design criteria for the engine.

- Because of the problems associated with the introduction of new systems, the mean miles between incident were an unacceptably low figure. This made it difficult and costly to properly evaluate the suitability of the gas turbine for coach operation. In the future, it is recommended that the gas turbine system be subjected to sufficient development in each specific application to establish satisfactory durability prior to evaluation in the revenue service environments. The bus programs have established the basis for formulating future demonstration programs with the gas turbine engine, and commercialization of the gas turbine bus engine remains a viable goal for the future.

APPENDIX A. ENGINE/TRANSMISSION BUILD PROGRAM

INTRODUCTION

Detroit Diesel Allison (DDA), Division of General Motors, submitted a proposal to the Department of Energy (DOE) in January 1978 to manufacture and deliver 11 gas turbine engines and automatic transmissions for use in the Intercity and Intracity Bus Demonstration Programs. Contract negotiations were conducted with the DOE Chicago contracting office during the months of July and August 1978. Final agreement was reached and the contract signed 28 August 1978. The contract, DE-AC02-78CS54867, required the delivery of 11 Allison GT404-4 industrial gas turbine engines and five HT740CT and six V730CT Allison automatic transmissions for the intercity (Greyhound) and intracity (Transit) coach programs, respectively. In addition, software items such as cost reports, technical reports, installation drawings, acceptance test data, parts lists, and a typical coach engine performance map were required. Engine/transmission power package deliveries were scheduled to start at the end of April 1979 and be completed by October 1979, with the five GT404-4 engine/HT740CT transmission packages for Greyhound delivered first.

The engine configurations for this build program were originally intended to include all-metal components. Future progress in the coach programs included the timely introduction of proven engine ceramic components for demonstration of the continuing improvements in fuel efficiency achievable with these engine configurations. Concern for the detrimental effect of the transit coach duty cycle on the life of the engine regenerator disks (oxidation due to the higher number of engine accelerations) caused the DOE to modify the build configuration for the last four transit coach engines. It was decided by the DOE at a meeting in Washington, DC, on 28 March 1979 with representatives from DDA, NASA/LeRC, JPL, and Booz.Allen and Hamilton that these engines would be built with ceramic regenerators.

POWER PACKAGE CONFIGURATION

The GT404-4 engine is a highly regenerative two-shaft low pressure ratio industrial gas turbine engine designed for heavy-duty commercial and military applications.

The engine is rated at 300 hp SAE conditions (85°F and 500 ft) in the all-metal configuration with nominal inlet and exhaust losses and operates at 1875°F turbine inlet temperature.

The general mechanical arrangement of the GT404-4 industrial gas turbine engine is shown in isometric cutaway in Figure 47.

The main structure of the engine is a two-piece nodular cast iron block. The interior of the block is suitably insulated from the heat, using insulation blankets covered with the sheet metal liners. Major flow-path components in the all-metal configuration include a single-stage precision cast aluminum alloy centrifugal compressor, single-stage axial gasifier, and power turbine rotors cast with integral blades and disks, cast gasifier and power turbine nozzles, and stainless steel regenerator disks. The fixed geometry nozzle rings are one-piece castings; the gasifier nozzle vanes are cooled with compressor discharge air while the power turbine nozzle vanes are uncooled.

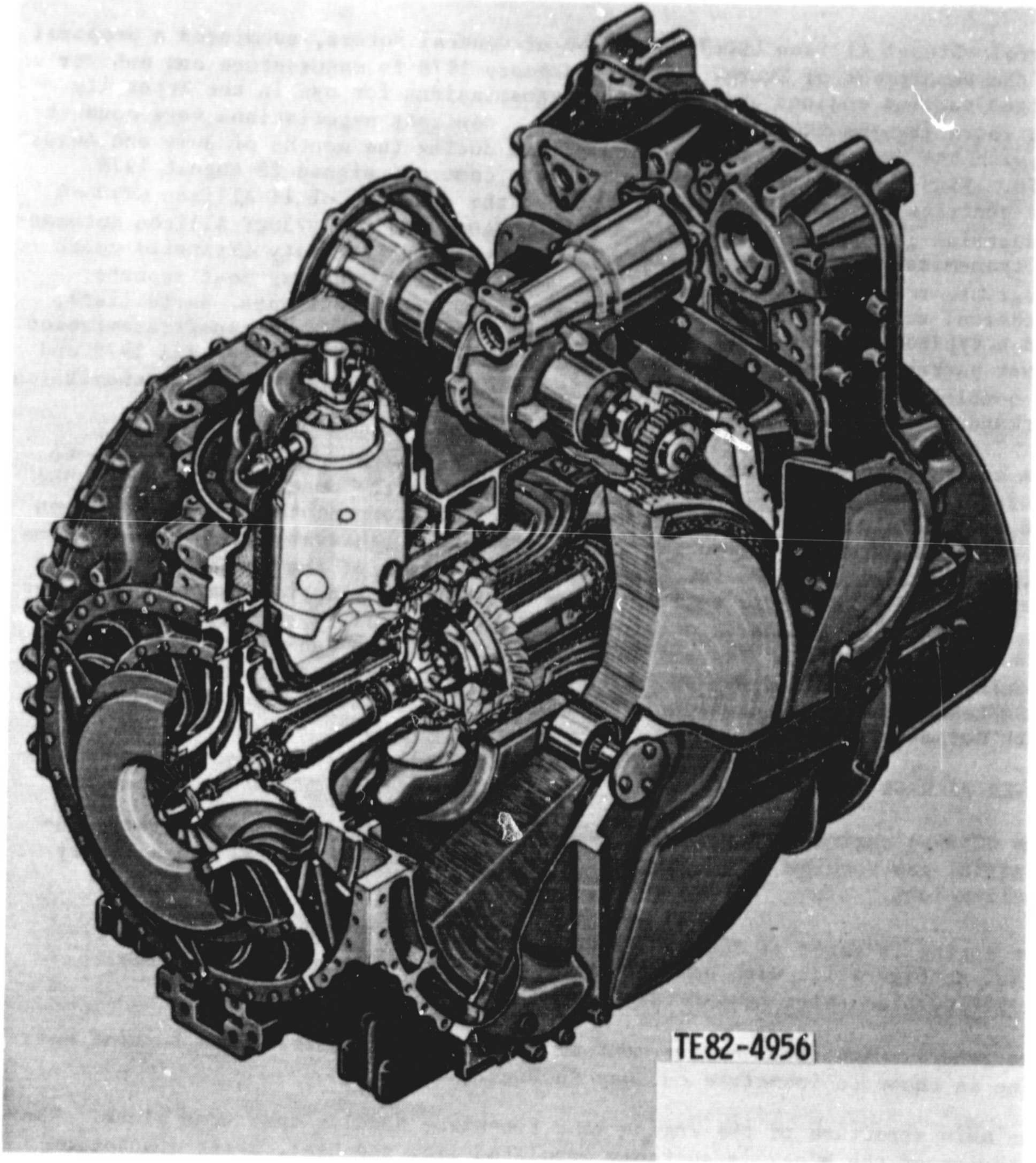

Figure 47. 404-4 IGT engine configuration.

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The five Greyhound coach engines and the first two transit coach engines were built with all-metal components while ceramic regenerators were configured in the builds for the remaining four transit coach engines.

The ceramic regenerator disks used in the transit coach engines are aluminum silicate with thin wall triangular matrix. The typical regenerator system shown in Figure 48 is composed of the ceramic regenerator with an elastomer mounted ring gear for rim drive, the hot (inboard) regenerator seal, and the cold (outboard) regenerator seal. Both the hot and cold seals are metal structures faced on one side with applied wearface materials and with leaf springs on the opposite side. The wearface on the cold seal, as well as the periphery of the hot seal, is a graphite material. The wearface on the cross-arm portion of the hot seal is plasma sprayed 85% NiO/15% CaF_2 over the metal substrate.

The GT404-4 engine uses an electronic control system for fuel management and control of the power transfer system. Power transfer is a GM patented device for improving part load fuel economy and additionally provides for a variety of operating modes, including single-shaft or two-shaft operation, engine braking, and power turbine overspeed protection.

The combustion system incorporates a prechamber burner and air blast fuel nozzle.

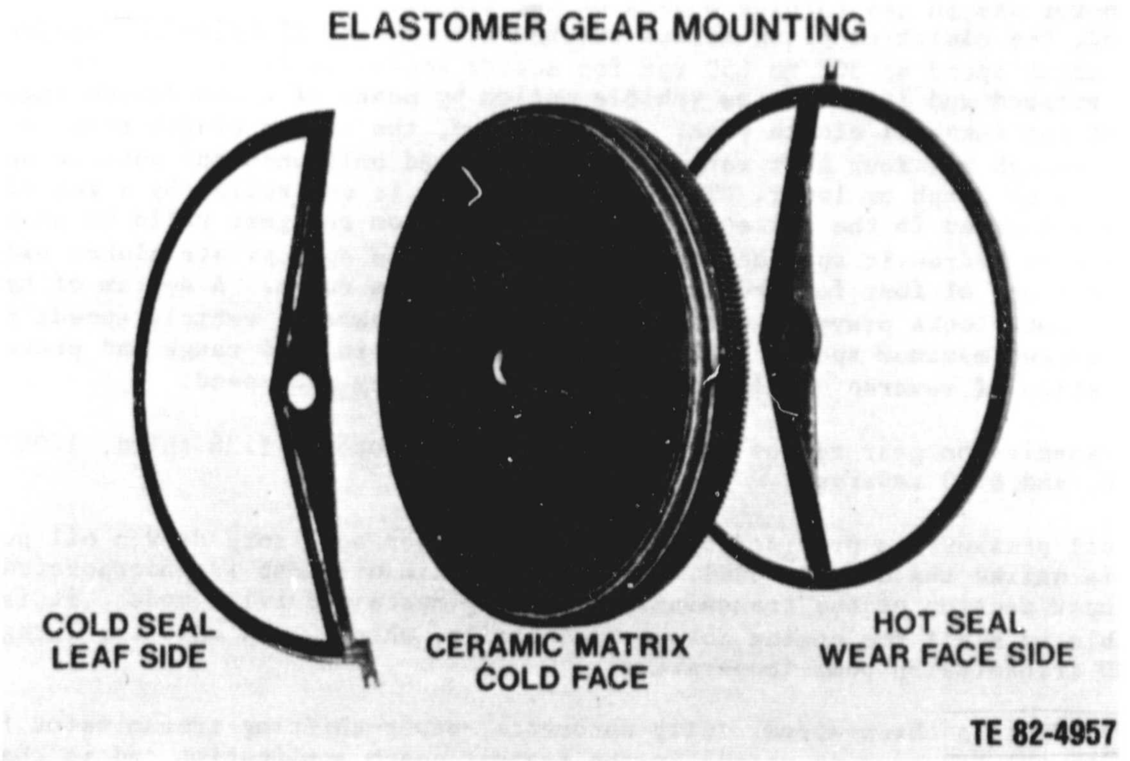

Figure 48. Rim drive ceramic regenerator and seals.

The Greyhound coach engine configuration incorporates an SAE No. 2 gear housing with right-hand output shaft rotation. The transit coach engine utilizes a designated SAE No. 1 1/2 gear housing with left-hand output shaft rotation to match input requirements for the V730CT automatic transmission. An abundant number of accessory drives are provided at the rear of the engine (two drives gasifier driven and four or three drives power turbine driven depending on coach configuration) to accommodate coach accessory requirements. The rear gear housing is cast aluminum for reduced engine weight.

Maximum output shaft speed for the coach engines is 2880 rpm.

The HT740CT is a four-speed, fully automatic, power-shifting transmission for use with the gas turbine engine in the Greyhound coach application and is shown in cross-sectional view in Figure 49. This design traces its origin to the heavy-duty HT740D diesel truck transmission first offered in production quantities in 1971.

The transmission is built up of four groups: the input section containing a clutch/coupling, the planetary gearing and range clutch section, an output group, and a hydraulic controls group located in the oil sump. The planetary gearing and output groups are common to the diesel model transmission, as are a majority of the control section parts. Only the clutch/coupling of the input section has no counterpart in a conventional HT740D. The torque converter of the HT740D has been replaced by a fluid coupling with an integral lockup clutch for use in gas turbine models of the transmission. During vehicle operation, the clutch/coupling serves two functions: it maintains the engine idle output speed at 500 to 650 rpm for active accessory drive when the vehicle is stopped and it initiates vehicle motion by means of a controlled engagement of the integral clutch pack. Once engaged, the lockup clutch remains applied through all four gear ranges and is released only when the vehicle speed decreases to 6 mph or lower. The clutch/coupling is controlled by a set of controls located in the oil sump. Range shifts from one gear ratio to another are made by hydraulic application and release of the appropriate clutch packs to select one of four forward ratios and one reverse ratio. A system of hydraulic interlocks prevents downshifting to lower gears at vehicle speeds that would exceed maximum speed capability of the engine in that range and prevents application of reverse until the vehicle is at a very low speed.

The transmission gear ratios are 3.69 first, 2.02 second, 1.38 third, 1.00 fourth, and 6.03 reverse.

Main oil pressure is provided by an engine gasifier accessory driven oil pump. This is unlike the diesel model, in which the main oil pump is incorporated in the input section of the transmission. During certain driving modes, it is possible to stall the engine output momentarily, which would make the integral HT740D transmission pump inoperative.

The V730CT is a three-speed, fully automatic, power-shifting transmission for use with the gas turbine engine in the transit coach application and is shown in cross-sectional view in Figure 50. This design is based on the V730D diesel coach model V-drive configuration, which started production in 1975.

The V730CT is comprised of six major groups: the input bevel gear set, the clutch/coupling group, the planetary gearing and clutch section, an output as-

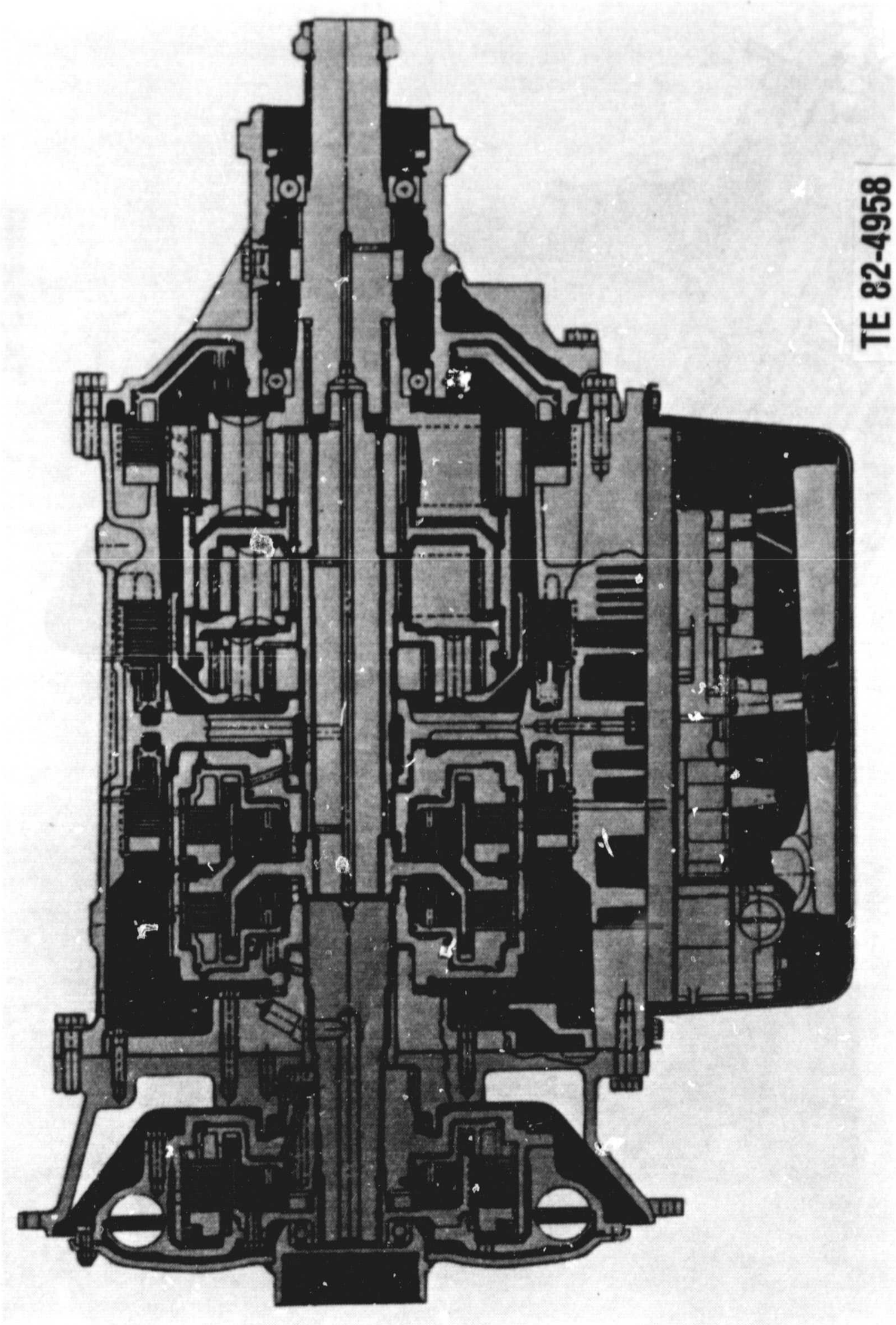

Figure 49. HT740CT transmission cross section.

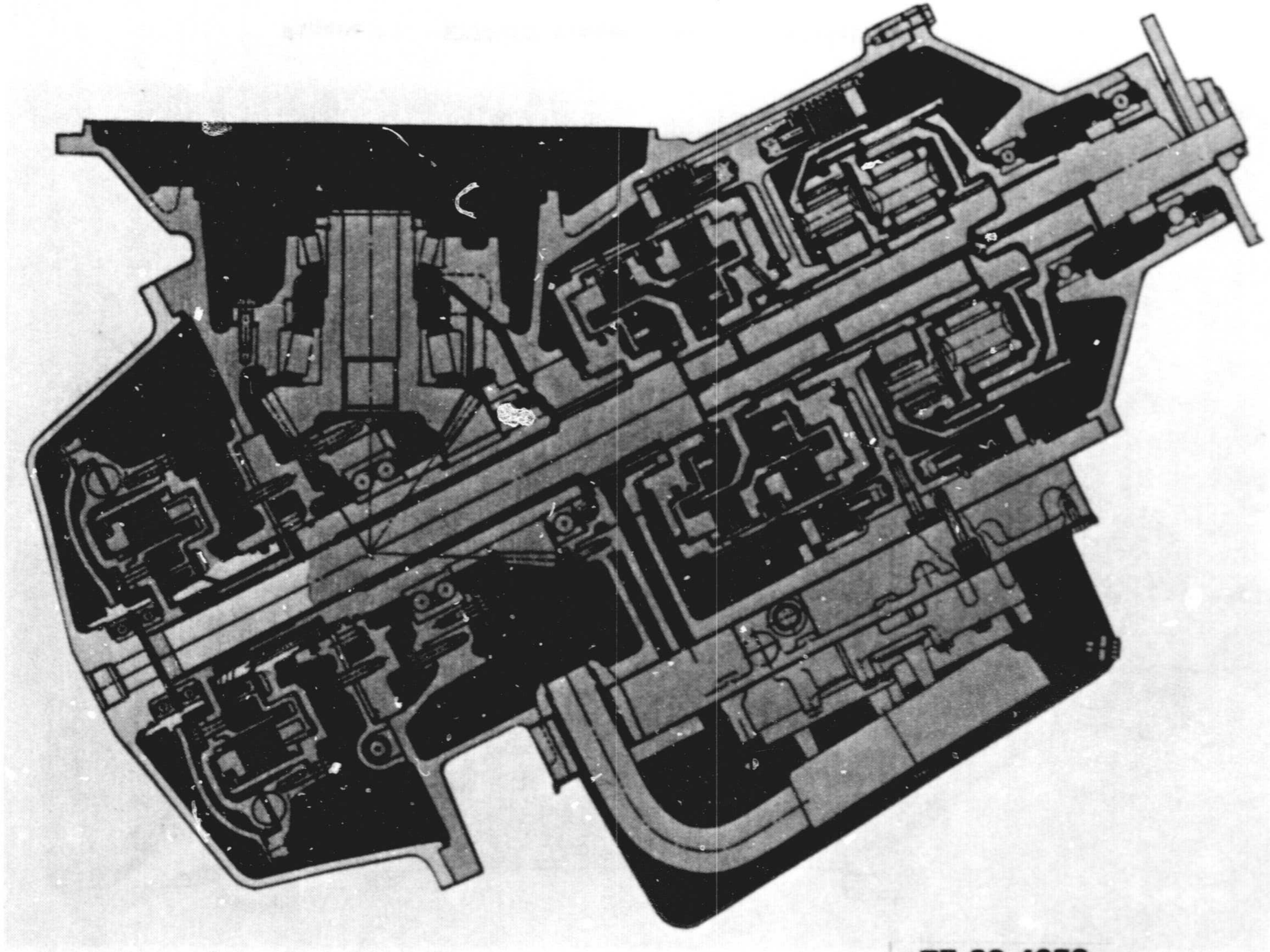

Figure 50. V730CT transmission cross section.

sembly, the hydraulic control system in the oil sump, and the power takeoff group. The input bevel gear set reduces the input speed slightly to the downstream transmission elements and turns the power flow through 117 deg (the powertrain in a transit coach is mounted entirely behind and parallel to the rear drive axle). The cluch/coupling serves to maintain the engine idle output speed at 500 to 650 rpm for active accessory drive when the vehicle is stopped and initiates vehicle motion by means of a controlled engagement of the integral clutch pack. Once the vehicle is in motion, the lockup clutch remains engaged until the vehicle speed decreases to 6 mph or less when the vehicle is coming to a stop. The control system that regulates the clutch/coupling is located in the transmission oil sump. The planetary gearing and clutches accomplish selection of three forward and one reverse ratio in response to the hydraulic logic control system located in the oil sump. The planetary gear sets and clutches, as well as a majority of the hydraulic control system parts, are common to the V730D. A system of hydraulic interlocks prevents downshifting to lower gears at vehicle speeds that would be above the engine's speed capability in that range and prevents application of reverse until the vehicle is at a very low speed. The transmission output group combines the planetary gearing action and applies it to the vehicle driveline by means of the transmission output shaft and flange. The output group also houses and drives a hydraulic governor that provides a speed sensing signal to the main control group. The power takeoff group provides a 30 hp live-shaft drive capability at the side of the transmission available for powering vehicle ancillary equipment such as the coach air conditioning compressor.

The overall transmission gear ratios are 2.10 first, 1.44 second, 1.04 third, and 1.74 reverse.

Main oil pressure is provided by an engine gasifier accessory driven oil pump.

The GT404-4 engine/HT740CT transmission power package for the Greyhound coach application is shown in Figure 51. This is typical of the five power packs that were delivered to Greyhound Lines, Inc., for coach integration and operation in the DOE funded Intercity Bus Demonstration Program.

The GT404-4 engine/V730CT transmission power package for the transit coach application is shown in Figure 52. This is typical of the six power packs that were delivered to Modern Engineering Service Company, Detroit, Michigan, for integration into the coaches provided by the Mass Transit Administration of Baltimore, Maryland, in the DOE/DOT funded Intracity Bus Demonstration Program.

DISCUSSION

DDA management recognized that early procurement action on the engine hardware was crucial to DOE meeting the coach demonstration schedule because of the long-lead nature of many of the engine parts. Therefore, DDA advance released 8 of the 11 GT404-4 engines 5 months before the engine and transmission hardware contract was signed. The remaining 3 engines and the 11 automatic transmissions were released for procurement upon receipt of the contract.

Figures 53 and 54 show the master schedules for this program. The schedules show actual delivery dates for the engine/transmission power packages. These dates reflect delays from those dates initially established for the program. The adjustments were due primarily to two factors.

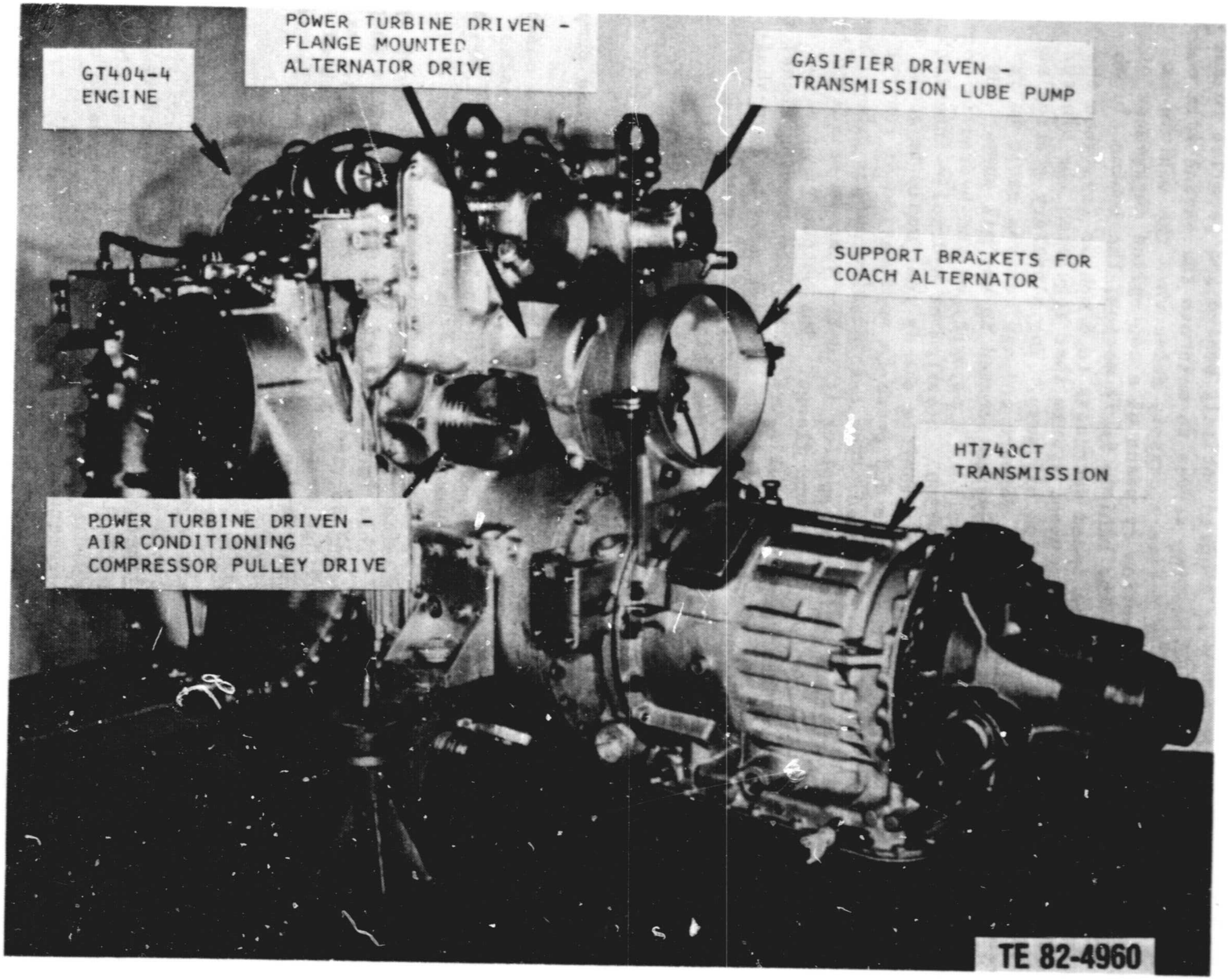

Figure 51. Greyhound coach power package.

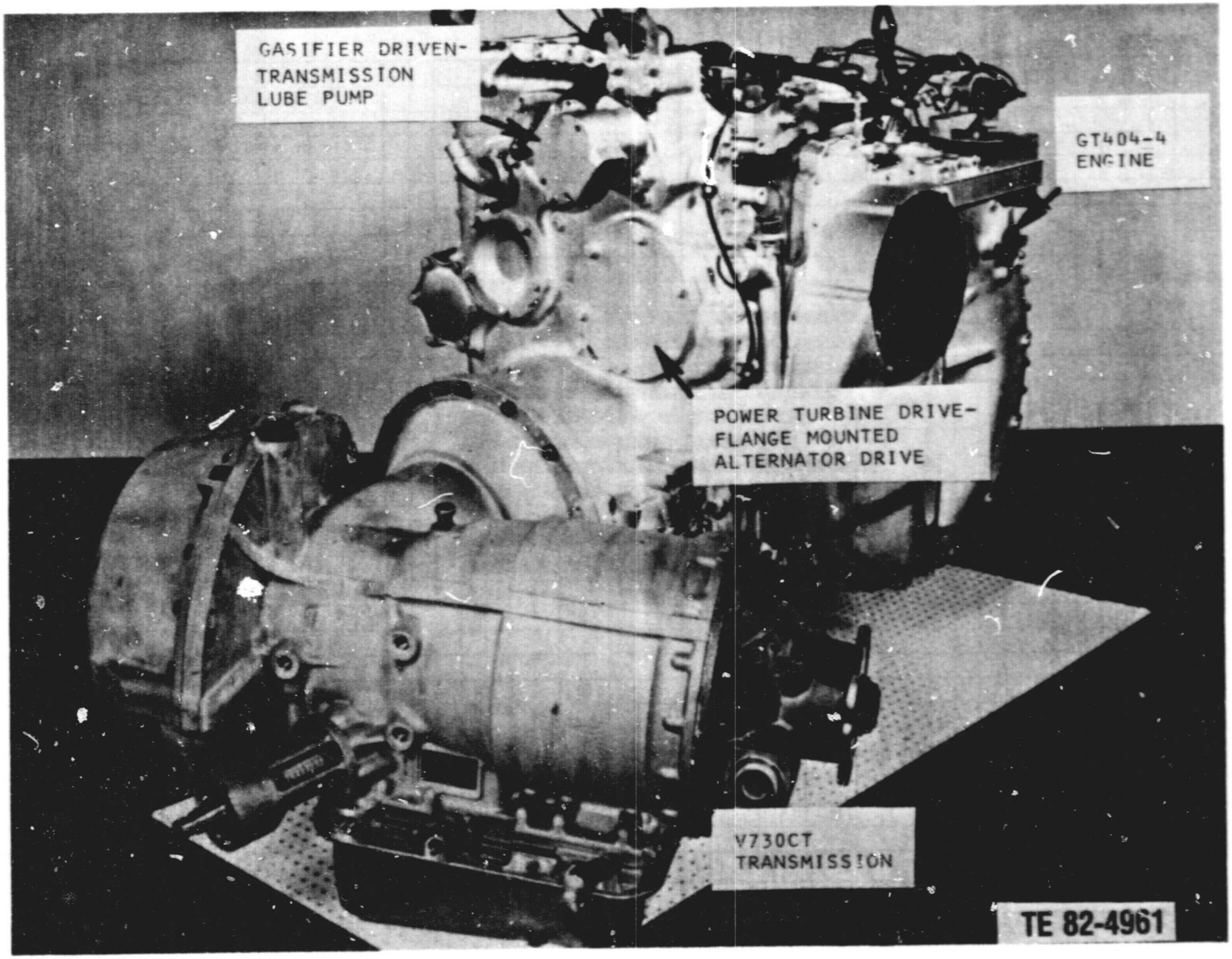

Figure 52. Transit coach power package.

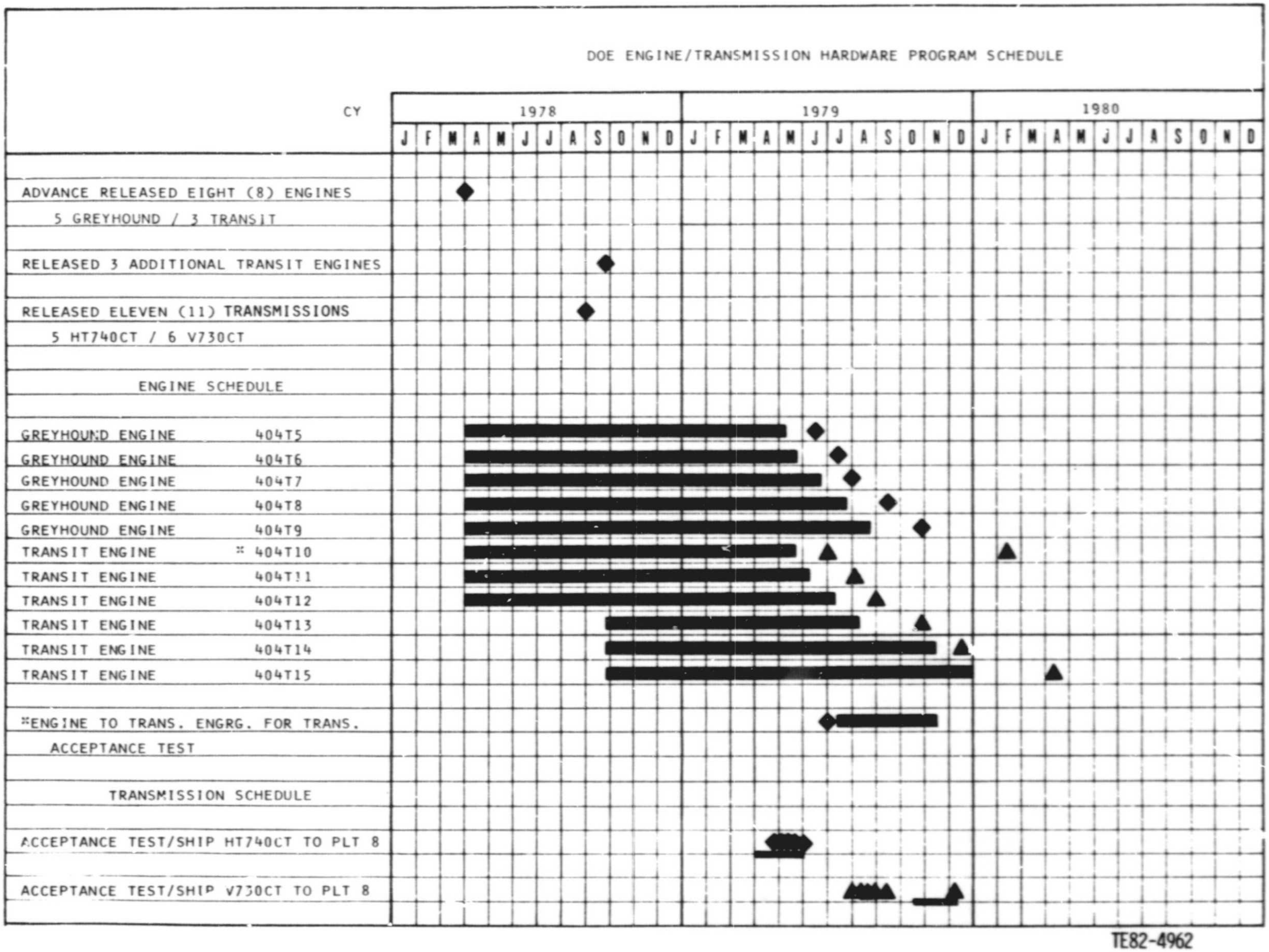

Figure 53. DOE engine/transmission hardware program schedule.

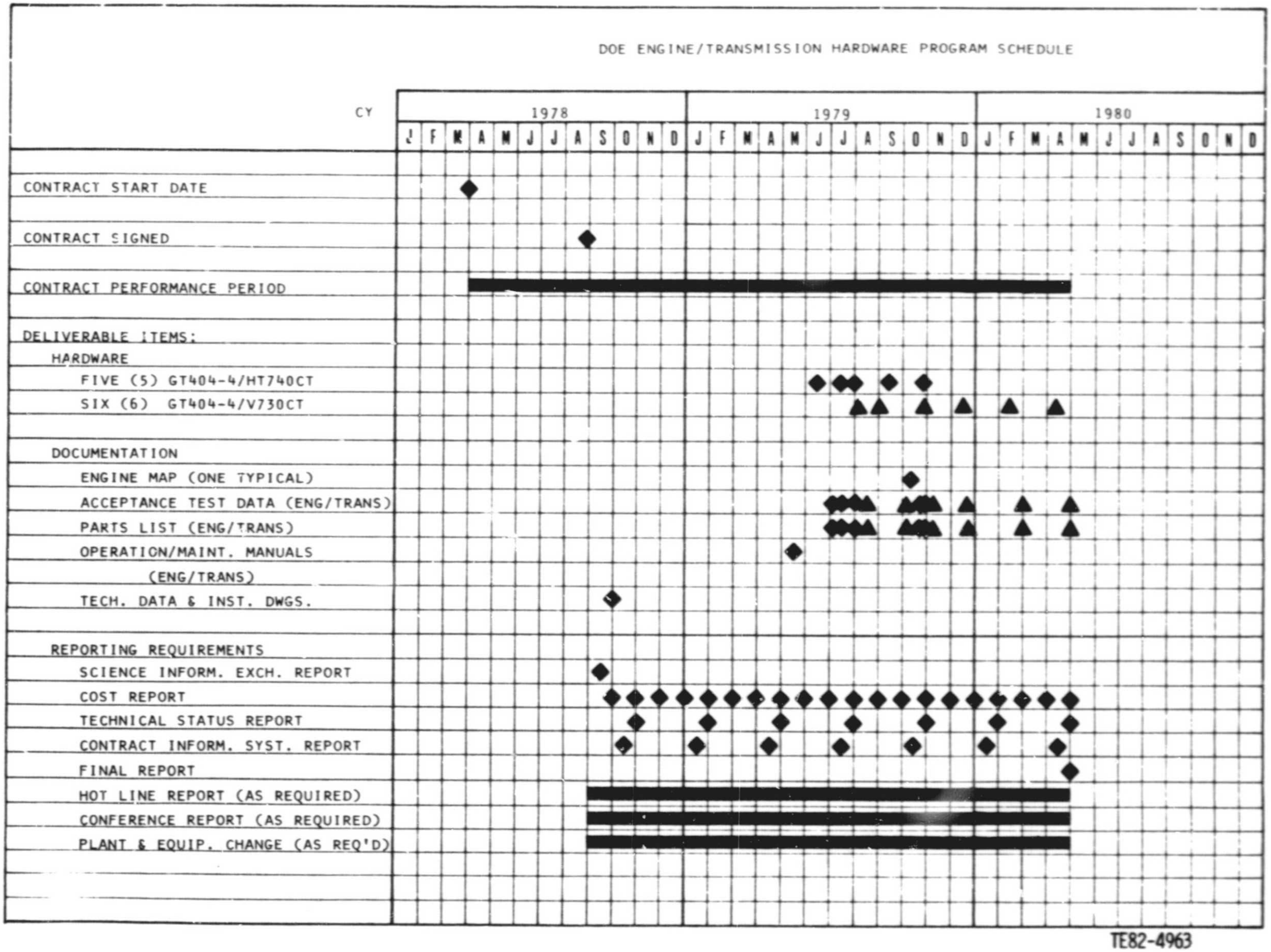

Figure 54. DOE engine/transmission hardware program schedule.

1. Significant parts procurement problems experienced early in the program caused build delays. Since a high percentage of the engine and transmission parts are procured from outside sources, the problems stemmed from late deliveries and poor quality. For material procured for the engine and transmission from outside sources, heavy reliance is placed on vendor provision of good quality parts. Inspection techniques were improved and vendor contacts were increased in order to monitor quality and effect the timely delivery of purchased parts. These actions significantly improved the assembly and test activities for the later builds and allowed the program to progress satisfactorily through the build sequence.

2. The DOE revised the build sequence and delivery schedule to better match coach availabilities in both programs. This resulted in alternating build sequence between Greyhound and transit coach engines rather than completing the Greyhound build first.

Initial planning of program requirements identified the need for the early (ahead of schedule) build and test of the first transit coach engine (S/N T10) for use in acceptance testing the V730CT transmissions. Upon completion of this task, the engine was refurbished prior to delivery.

The five Greyhound coach engines and the first two transit coach engines were built with all-metal components while ceramic regenerators were configured in the builds for the remaining four transit coach engines. The all-metal transit coach engines were used for verification of the coach installation design, systems performance, and overall vehicle operation. The metal regenerator hardware in these engines was replaced with ceramic hardware before the coaches began revenue service operation. Introduction of ceramic regenerator hardware was possible during the build program because of the significant progress being made through the DOE/NASA CATE program in developing ceramic components for use in highway vehicle gas turbine engines. Considerable test experience had been accumulated on the ceramic regenerator system. The ceramic regenerators were subjected to severe shock loadings from rough road truck operation and the rigorous thermal shock environment of the transit coach operating cycle on the test stand. The disks had emerged from this testing in completely serviceable condition. It was planned that other proven ceramic components would be introduced into the coach engines later for demonstration of the continuing improvements in fuel efficiency achievable with these engine configurations.

Even though procurement problems caused delays in the HT740CT and V730CT transmission builds, the delivery schedule was not affected negatively by these delays. The build and test activities for the five HT740CT transmissions started 17 April 1979 and were completed on 29 May 1979. Assembly and acceptance testing for the six V730CT transmissions followed with completion of the final unit on 8 December 1979. The HT740CT transmissions were configured with second gear start in drive range instead of first gear start as employed previously. This change was considered to be a product improvement (eliminate harsh 2-1 downshift for improved passenger comfort) and was consistent with the selective introduction and evaluation of the modified diesel version transmissions in the Greyhound fleet. However, during road evaluation of the first Greyhound coach power package (T5/30576) in Coach 5992, it became evident that vehicle acceleration was unacceptable due to the combined effect of second gear start and the inherent acceleration lag of the engine. Satisfactory vehicle acceleration was restored through transmission modification for first gear start in drive range and elevated engine gasifier speed in gear.

The engine and transmission deliveries are summarized below.

Greyhound coach engine/transmission	Date shipped
Engine S/N T5/HT740CT S/N 30576	6/19/79
Engine S/N T6/HT740CT S/N 29804	7/12/79
Engine S/N T7/HT740CT S/N 30579	8/3/79
Engine S/N T8	9/19/79
Engine S/N T9	10/25/79
/HT740CT S/N 30575	9/10/79*
/HT740CT S/N 30578	9/10/79*

*Shipped in advance of mating engines since needed by Greyhound to replace units requiring first gear start modification.

Transit coach engine/transmission	Date shipped
Engine S/N T11/V730CT S/N 11121	8/7/79
Engine S/N T12/V730CT S/N 11561	8/31/79
Engine S/N T13/V730CT S/N 11489	10/23/79
Engine S/N T14/V730CT S/N 11564	12/14/79
Engine S/N T10/V730CT S/N 11122	2/13/80
Engine S/N T15/V730CT S/N 11488	4/11/80

The test procedure used in acceptance testing the 11 GT404-4 coach engines is shown in Table VIII. This procedure identifies the operational characteristics of the engine for satisfactory performance and establishes the minimum delivery horsepower at rated temperature and fuel flow. The minimum horsepower rating for the GT404-4 engine with metal regenerators is 285 hp. The minimum horsepower rating for the engine with ceramic regenerators is set at 280 hp because of the inherent 5 hp loss due to the additional pressure loss associated with the ceramic cores. All of the engines delivered in this program have exceeded these minimum power levels. These data are summarized in Table IX.

Table VIII.
DOE coach engine acceptance test procedure.

I. Operating Limits

1. N_G--36,936 rpm $\quad$ N_{PT}--33,863 rpm
   N_o--2880 rpm

2. Engine oil main pressure at 200°F ± 25°F
   Idle--20 psig min
   Max throttle--40 psig min

3. Vibration:
   Front 0.3 in./sec
   Rear 0.3 in./sec

4. Max transient N_G--38,000 rpm
   Max transient N_o--3,000 rpm

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Table VIII. (cont)

5. T_4 (BOT)--1920°F max steady state
   T_6--steady state rated max avg (2), 1425 ± 10°F
   T_6--steady state rated max individual, 1500°F

II. Test cell operation:
1. Fluids:
   a. Fuel: Diesel No. 2
   b. Oil: Dexron II
2. Standard test cell air cleaner in use
3. Electrical connections in accordance with 23000968 diagram

III. Data to be Recorded
1. N_G--speed
2. N_o--speed
3. T_4--temperature (BOT)
4. T_1--temperature
5. T_2--temperature
6. P_1--pressure
7. P_2--pressure
8. W_a--airflow
9. W_f--fuel flow
10. Dynamometer torque
11. Engine oil pressure
12. Engine oil temperature
13. Clutch pressure
14. Control oil pressure
15. Front vertical vibration
16. Rear lateral vibration
17. Rate of oil collection from breather

IV. Test schedule
1. Install engine on test stand and fill engine sump with lube oil. Record amount.
2. Set control bias to 0°F and part power to -200°F.
3. Prime fuel system and check starting fuel flow (nozzle pilot flow) by motoring to a no light-off shutdown. 20-50 cc's required. Check ignition spark during this crank cycle.
4. Disconnect clutch valve electrical connection for free shaft operation. Start engine and observe light-off.
5. Run at idle for 5 min and shut down. Check for oil, fuel, or air leaks. Note and repair. Fill lube oil sump and record amount.
6. Stabilize 20 min at each of the following points free shaft and record a line of data. Make no rapid speed changes. All speeds corrected for ambient. Take vibration signature at point of highest vibration.

Table VIII. (cont)

	N_G	N_o	Comments
6.1	58%	1100	85°F CIT if possible
6.2	74%	1400	85°F CIT if possible
6.3	85%	2200	85°F CIT if possible
6.4	95%	2300	85°F CIT if possible
6.5	100%	2500	85°F CIT if possible (36,936 rpm)
6.6	100%	2880	85°F CIT if possible (36,936 rpm)

Note: Item 6 not required with ceramic regenerators.

7. Stabilize 20 min at each of the following points free shaft and record a line of data. Make no rapid speed changes. All speed corrected for ambient. Take vibration signature at point of highest vibration.

	N_G	N_o	Comments
7.1	58%	Max	85°F CIT if possible
7.2	100%	Max hp	85°F CIT if possible (36,936 rpm)

8. Decelerate slowly to idle. Stabilize 5 min and set idle to 21,500 rpm ± 100 rpm. Record a full line of data after 5 min stabilization at correct gasifier idle speed.
9. Stop engine and remove burner assembly. Inspect burner walls and dome, hot side of regenerators, fuel nozzle, and igniter plug. Record condition.
10. Reconnect clutch valve electrical connection. Start engine and run at idle, check clutch pressure. Should be 0.
11. Unload output to run at 100% lock-up, check and record clutch pressure (155 psig min with 180°F min oil temp). Slowly load dyne to yield 1900°F T_4. Stabilize 5 min. Record N_G, N_o, T_4, T_1, W_f, and front and rear vibration levels.
12. Run the following power transfer performance with 85°F CIT, stabilizing 20 min per point. Adjust T_4 bias and part power to obtain the max allowable fuel flow (135.5 lb/hr at SAE conditions) or the temperature limits shown below.

	Corr N_G	N_o	T_4 max (BOT)	T_6 max
12.1	80%	Max hp	1920°F	1425°F avg
12.2	90%	Max hp	1920°F	1425°F avg
12.3	95%	Max hp	1920°F	1425°F avg
12.4	*100%	Max hp	1920°F	1425°F avg

*Minimum acceptance: 300 hp rated minus 5% with metal regenerators
295 hp rated minus 5% with ceramic regenerators

Table VIII. (cont)

13. Set dyne to obtain 1200 rpm at full throttle. Stabilize at max N_G for 1 min, then make a snap decel to idle to verify decel free from burner blowout. Repeat decel test two times. If burner blowout occurs, contact Engineering for corrective action.
14. Final performance check. Remove T_4 test instrumentation. Reconnect T_4 T/C left front/right rear to one control channel through terminal block and reconnect T_4 T/C right front/left rear to one control channel through terminal block. Recheck 100% N_G max performance and verify bias setting for final data plate stamping. Recheck 80% N_G point and verify part power setting.
15. Stabilize at idle and check for oil, fuel, and air leaks. Correct and recheck as necessary.
16. After test completion, disconnect engine from dyne, remove output flange from engine, and install transmission drive adapter. Run at idle speed to verify the absence of oil leakage at the adapter.
17. Install data plate and stamp the T_4 bias setting on the plate.
18. Log all parts changes, inspection results, adjustments, visual observations, malfunctions, and corrective actions occurring during the test.
19. Remove engine from test stand and send it to assembly floor for final preparation.

Table IX.
Coach engine performance at delivery.

Engine S/N	Horsepower (hp) at SAE conditions	Fuel consumption (lb fuel/hp-hr) at NASA conditions
T5	286.2	0.447
T6	295	0.435
T7	304.3	0.428
T8	293.4	0.442
T9	291.9	0.443
T10*	284.4	0.440
T11	292	0.442
T12	287.8	0.440
T13*	282.8	0.436
T14*	294.5	0.437
T15*	285.3	0.439

*Engine delivered with ceramic regenerators.

The acceptance test data and parts lists for the delivered engines and transmissions were submitted as deliveries were completed. The data obtained during acceptance testing of the 11 GT404-4 engines are shown in Tables X through XX.

Upon completing the acceptance test of Greyhound coach engine S/N T8, engine performance data were obtained and used to develop a typical coach engine performance map. This map is shown in Figure 55.

Although not contractually required in the engine build program, DDA provided installation drawings of the Greyhound coach and transit coach power packages and the GT404-4 operation and service instructions manual, including appropriate information for the engine and the HT740CT and V730CT transmissions. The installation drawings, 23001082 for the Greyhound power pack and 23001083 for the transit power pack, were provided to the respective integration facilities. These drawings establish the configuration of the power packages as delivered and identify installation features for the respective applications. Twenty-five copies of the GT404-4 operation and service instructions manual (SA1431A) were distributed each to Greyhound Lines and to Booz•Allen and Hamilton for use by the respective operating personnel.

Table X.
GT404-4 coach engine acceptance test data
(engine S/N 404TA00000T5, test date 6/16/79).

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100	100	100
GASIFIER SPEED~N_1	RPM	36905	36936	36936
P.T. SPEED ~ N_2	%	95.8	95.8	95.8
P.T. SPEED ~ N_2	RPM	2768	2768	2768
BHP	HP	284.2	286.2	338.2
POWER	KW	211.9	213.4	252.2
BSFC	LB/HP-HR	.469	.468	.447
BSFC	MG/W-HR	285.3	284.7	271.9
FUEL FLOW ~ W_F	LB/HR	133.3	134.0	151.1
FUEL FLOW ~ W_F	KG/HR	60.46	60.78	68.54
T_1	^oF	85.4	85.0	59.0
T_1	^oC	29.7	29.44	15.0
P_1	LB/IN^2 ABS	14.34	14.433	14.696
P_1	KPA ABS	98.870	99.509	101.325
T_4 RIT	^oF	1875	1875	1875
T_4 RIT	^oC	1023.9	1023.9	1023.9
T_6	^oF	1360	1360	1360
T_6	^oC	737.8	737.8	737.8

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Table XI.
GT404-4 coach engine acceptance test data (engine S/N 404TA00000T6, test date 7/6/79).

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100	100	100
GASIFIER SPEED~N_1	RPM	36946	36936	36936
P.T. SPEED ~ N_2	%	89.8	89.8	89.8
P.T. SPEED ~ N_2	RPM	2604	2604	2604
BHP	HP	294	295	347
POWER	KW	219.2	220.0	258.8
BSFC	LB/HP-HR	.454	.454	.435
BSFC	MG/W-HR	276.2	276.2	264.6
FUEL FLOW ~ W_F	LB/HR	133.5	134	151
FUEL FLOW ~ W_F	KG/HR	60.55	60.78	68.17
T_1	^oF	87	85.0	59.0
T_1	^oC	30.6	29.44	15.0
P_1	LB/IN^2 ABS	14.34	14.433	14.696
P_1	KPA ABS	98.87	99.509	101.325
T_4 RIT	^oF	1890	1875	1875
T_4 RIT	^oC	1032.2	1023.9	1023.9
T_6	^oF	1369	1369	1369
T_6	^oC	742.8	742.8	742.8

C-2

Table XII.
GT404-4 coach engine acceptance test data
(engine S/N 4C4TA00000T7, test date 7/30/79).

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100.1	100	100
GASIFIER SPEED~N_1	RPM	36977	36936	36936
P.T. SPEED~N_2	%	99.1	99.1	99.1
P.T. SPEED~N_2	RPM	2853	2853	2853
BHP	HP	294	304.3	356.3
POWER	KW	219.2	226.9	265.7
BSFC	LB/HP-HR	.449	.445	.428
BSFC	MG/W-HR	273.1	270.9	260.3
FUEL FLOW~W_F	LB/HR	132	135.5	152.5
FUEL FLOW~W_F	KG/HR	59.87	61.46	69.17
T_1	^oF	89	85.0	59.0
T_1	^oC	31.7	29.44	15.0
P_1	LB/IN^2 ABS	14.247	14.433	14.696
P_1	KPA ABS	98.229	99.509	101.325
T_4 RIT	^oF	1905	1875	1875
T_4 RIT	^oC	1040.6	1023.9	1023.9
T_6	^oF	1385	1360	1360
T_6	^oC	751.7	737.8	737.8

Table XIII.
GT404-4 coach engine acceptance test data
(engine S/N 404TA00C00T8, test date 9/12/79).

Rec. No. 419

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100	100	100
GASIFIER SPEED~N_1	RPM	36929	36936	36936
P.T. SPEED ~ N_2	%	86.9	86.9	86.9
P.T. SPEED ~ N_2	RPM	2503	2503	2503
BHP	HP	289.3	293.4	345.4
POWER	KW	215.7	218.8	257.6
BSFC	LB/HP-HR	.463	.462	.442
BSFC	MG/W-HR	281.6	281.0	268.9
FUEL FLOW ~ W_F	LB/HR	133.8	135.5	152.5
FUEL FLOW ~ W_F	KG/HR	60.69	61.46	69.17
T_1	^oF	87.1	85.0	59.0
T_1	^oC	30.6	29.44	15.0
P_1	LB/IN^2 ABS	14.313	14.433	14.696
P_1	KPA ABS	98.684	99.509	101.325
T_4 RIT	^oF	1883	1875	1875
T_4 RIT	^oC	1028.3	1023.9	1023.9
T_6	^oF	1415	1409	1409
T_6	^oC	768.3	765.0	765.0

Table XIV.
GT404-4 coach engine acceptance test data
(engine S/N 404TA00000T9, test date 10/22/79).

REC. NO. 235

	UNITS	OBSERVED DATA	CORRECTED DATA SAE	CORRECTED DATA NASA
GASIFIER SPEED~N_1	%	100.1	100.	100.
GASIFIER SPEED~N_1	RPM	36967	36936	36936
P.T. SPEED ~ N_2	%	86.7	86.7	86.7
P.T. SPEED ~ N_2	RPM	2497	2497	2497
BHP	HP	294.7	291.9	343.9
POWER	KW	219.8	217.7	256.4
BSFC	LB/HP-HR	.460	.464	.443
BSFC	MG/W-HR	279.8	282.2	269.5
FUEL FLOW ~ W_F	LB/HR	135.5	135.5	152.5
FUEL FLOW ~ W_F	KG/HR	61.46	61.46	69.17
T_1	^oF	85.7	85.0	59.0
T_1	^oC	29.8	29.44	15.0
P_1	LB/IN^2 ABS	14.157	14.433	14.696
P_1	KPA ABS	97.608	99.509	101.325
T_4 RIT	^oF	1907	1875	1875
T_4 RIT	^oC	1041.7	1023.9	1023.9
T_6	^oF	1431	1407	1407
T_6	^oC	777.2	763.9	763.9

Table XV.

GT404-4 coach engine acceptance test data
(engine S/N 404TA00000T10, test date 2/8/80.

RECORD NO. 542

	UNITS	OBSERVED DATA	CORRECTED DATA SAE	CORRECTED DATA NASA
GASIFIER SPEED~N_1	%	100.0	100.0	100.0
GASIFIER SPEED~N_1	RPM	36926	36936	36936
P.T. SPEED~N_2	%	90.2	100.0	100.0
P.T. SPEED~N_2	RPM	2598	2880	2880
BHP	HP	288.8	284.4	336.4
POWER	KW	215.4	212.1	250.9
BSFC	LB/HP-HR	.459	.461	.440
BSFC	MG/W-HR	279.2	280.4	267.6
FUEL FLOW~W_F	LB/HR	132.6	131.0	148.0
FUEL FLOW~W_F	KG/HR	60.15	59.42	67.13
T_1	^oF	83.9	85.0	59.0
T_1	^oC	28.83	29.44	15.0
P_1	$LB/IN^2 ABS$	14.481	14.433	14.696
P_1	KPA ABS	99.842	99.509	101.325
T_4 RIT	^oF	1880	1875	1875
T_4 RIT	^oC	1026.7	1023.9	1023.9
T_6	^oF	1418	1414	1414
T_6	^oC	770.0	767.8	767.8

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Table XVI.
GT404-4 coach engine acceptance test data
(engine S/N 404TA00000T11, test date 7/17/79).

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100	100	100
GASIFIER SPEED~N_1	RPM	36932	36936	36936
P.T. SPEED ~ N_2	%	88.4	88.4	88.4
P.T. SPEED ~ N_2	RPM	2554	2554	2554
BHP	HP	293	292	344
POWER	KW	218.5	217.7	256.5
BSFC	LB/HP-HR	.461	.463	.442
BSFC	MG/W-HR	280.4	281.6	268.9
FUEL FLOW ~ W_F	LB/HR	135.1	135.1	152.1
FUEL FLOW ~ W_F	KG/HR	61.28	61.28	68.99
T_1	^oF	84	85.0	59.0
T_1	^oC	28.9	29.44	15.0
P_1	LB/IN^2 ABS	14.387	14.433	14.696
P_1	KPA ABS	99.194	99.509	101.325
T_4 RIT	^oF	1875	1875	1875
T_4 RIT	^oC	1023.9	1023.9	1023.9
T_6	^oF	1355	1355	1355
T_6	^oC	735.0	735.0	735.0

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Table XVII.
GT404-4 coach engine acceptance test data (engine S/N 404TA00000T12, test date 8/29/79).

RECORD NO. 679

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100	100	100
GASIFIER SPEED~N_1	RPM	36919	36936	36936
P.T. SPEED ~ N_2	%	90.3	90.3	90.3
P.T. SPEED ~ N_2	RPM	2601	2601	2601
BHP	HP	285.9	287.8	339.8
POWER	KW	213.2	214.6	253.4
BSFC	LB/HP-HR	.459	.460	.440
BSFC	MG/W-HR	279.2	279.8	267.6
FUEL FLOW ~ W_F	LB/HR	131.1	132.5	149.5
FUEL FLOW ~ W_F	KG/HR	59.46	60.10	67.81
T_1	^oF	83.7	85.0	59.0
T_1	^oC	28.7	29.44	15.0
P_1	LB/IN^2 ABS	14.251	14.433	14.696
P_1	KPA ABS	98.256	99.509	101.325
T_4 RIT	^oF	1875	1875	1875
T_4 RIT	^oC	1023.9	1023.9	1023.9
T_6	^oF	1362	1362	1362
T_6	^oC	738.9	738.9	738.9

Table XVIII.
GT404-4 coach engine acceptance test data
(engine S/N 404TA00000T13, test date 10/17/79).

REC. NO. 812

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100.2	100.	100.
GASIFIER SPEED~N_1	RPM	36984	36936	36936
P.T. SPEED ~ N_2	%	97.2	97.2	97.2
P.T. SPEED ~ N_2	RPM	2799	2799	2799
BHP	HP	289.3	282.8*	334.8
POWER	KW	215.7	210.9	249.7
BSFC	LB/HP-HR	.454	.456	.436
BSFC	MG/W-HR	276.2	277.4	265.2
FUEL FLOW ~ W_F	LB/HR	131.2	129.0	146.0
FUEL FLOW ~ W_F	KG/HR	59.51	58.51	66.22
T_1	^oF	86.1	85.0	59.0
T_1	^oC	30.1	29.44	15.0
P_1	LB/IN^2 ABS	14.390	14.433	14.696
P_1	KPA ABS	99.215	99.509	101.325
T_4 RIT	^oF	1900	1875	1875
T_4 RIT	^oC	1037.8	1023.9	1023.9
T_6	^oF	1410	1391	1391
T_6	^oC	765.6	755.0	755.0

* MINIMUM ACCEPTANCE HORSEPOWER WITH CERAMIC REGENERATORS IS 295 HP (RATED) -5% = 280 HP

Table XIX.
GT404-4 coach engine acceptance test data
(engine S/N 404TA00000T14, BU3, test date 11/29/79).

REC. NO. 303

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100	100	100
GASIFIER SPEED~N_1	RPM	36958	36936	36936
P.T. SPEED ~ N_2	%	90.0	90.0	90.0
P.T. SPEED ~ N_2	RPM	2593	2593	2593
BHP	HP	292.8	294.5	346.5
POWER	KW	218.3	219.6	258.4
BSFC	LB/HP-HR	.457	.456	.437
BSFC	MG/W-HR	278.0	277.4	265.8
FUEL FLOW ~ W_F	LB/HR	133.7	134.4	151.4
FUEL FLOW ~ W_F	KG/HR	60.64	60.96	68.67
T_1	^oF	85.4	85.0	59.0
T_1	^oC	29.67	29.44	15.0
P_1	LB/IN^2 ABS	14.391	14.433	14.696
P_1	KPA ABS	99.222	99.509	101.325
T_4 RIT	^oF	1875	1875	1875
T_4 RIT	^oC	1023.9	1023.9	1023.9
T_6	^oF	1356	1356	1356
T_6	^oC	735.6	735.6	735.6

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Table XX.
GT404-4 coach engine acceptance test data
(engine S/N 404TA00000T15, test date 4/9/80).

RECORD NO. 203

	UNITS	OBSERVED DATA	CORRECTED DATA	
			SAE	NASA
GASIFIER SPEED~N_1	%	100.0	100.0	100.0
GASIFIER SPEED~N_1	RPM	36949	36936	36936
P.T. SPEED ~ N_2	%	88.4	88.4	88.4
P.T. SPEED ~ N_2	RPM	2547	2547	2547
BHP	HP	286.5	285.3	337.3
POWER	KW	213.6	212.7	251.5
BSFC	LB/HP-HR	0.456	0.460	0.439
BSFC	MG/W-HR	277.5	279.7	267.3
FUEL FLOW ~ W_F	LB/HR	130.7	131.2	148.2
FUEL FLOW ~ W_F	KG/HR	59.28	59.51	67.22
T_1	^oF	85.9	85.0	59.0
T_1	^oC	29.94	29.44	15.0
P_1	LB/IN^2 ABS	14.182	14.433	14.696
P_1	KPA ABS	97.781	99.509	101.325
T_4 RIT	^oF	1903.4	1875	1875
T_4 RIT	^oC	1039.7	1023.9	1023.9
T_6	^oF	1420.8	1399.5	1399.5
T_6	^oC	771.6	759.7	759.7

Ceramic Regenerators

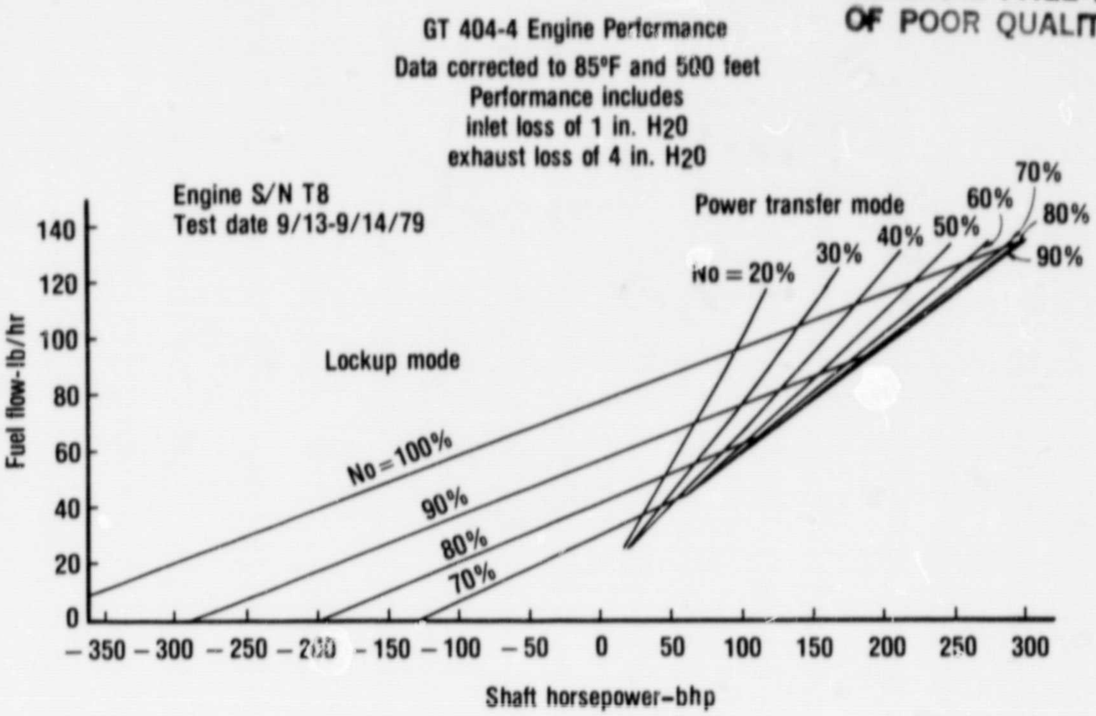

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Figure 55. Typical GT404-4 coach engine performance map.

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APPENDIX B. GREYHOUND AND BALTIMORE TRANSIT COACH INSTALLATION FEATURES

GREYHOUND MC-8 INTERCITY COACH INSTALLATION

General Features

Figure 56 shows the gas turbine powered Greyhound MC-8 intercity coach.

The GT404-4 engine and HT740CT transmission package was configured to replace the standard diesel engine/automatic transmission power plant with minimal change to the production coach configuration. Major modifications included raising the rear floor height 2 in. (0.05 m) to maintain the same ground clearance and rear departure angle and adding a roof scoop to the rear crown section to ensure an adequate supply of clean air, which raised the vehicle height approximately 5 in. (0.13 m). The other change involved location of the engine electronic control boxes within a separate enclosure in the rear baggage compartment. All remaining systems were installed within the envelope of the production coach.

Power Package Mounting and Drive Line

The engine/transmission package is cradle mounted with a three-point system, two heavy-duty isolation type mounts at each side of the transmission input housing, and a single medium-duty mount at the front of the engine block. The package cradle slides into the rear of the coach on cantilevered rails in a

Figure 56. GT404-4 powered Greyhound MC-8 intercity coach.

longitudinal, reverse direction (i.e., front of engine faces the rear bumper). The transmission output drives forward through a short Spicer 1700 series universal drive shaft to the Rockwell full floating type drive axle. The standard differential ratio of 3.70:1 was replaced with 4.33:1 ratio to accommodate the higher output speed of the turbine engine (i.e., 2880 rpm vs 1950 rpm governed diesel speed). During the second half of Phase I of the Intercity Bus Demonstration Program, the ratio was changed to 4.88:1 to achieve improved engine braking on deceleration. In order to achieve full drive shaft travel limits, the bottom drive axle radius rods were extended 0.5 in. (0.013 m) between centers.

The Greyhound power package with mounting cradle installed is shown in Figure 57 on the installation/removal dolly.

Air Intake System

Previous Greyhound field programs resulted in extensive tests to optimize the induction system to provide a large quantity of clean ambient air required for the turbine installation. A roof-mounted fiberglass air inlet scoop is located above the existing roof line and ducted down the rear section of the coach to mate with the air cleaner and inlet plenum assembly. The self-cleaning, single-pass inertial type air cleaner is manufactured by Donaldson Co., sized for a total flow of 3600 SCFM (1.69 m^3/s) and requires a scavenge flow of 10% of total flow for cleaning operation. The cleaner is 94% efficient on AC coarse test dust. The scavenge eductors are powered from engine compressor discharge bleed airflow of approximately 0.4% of engine compressor flow, through a manifold with four 0.055 in (1.4 mm) diameter orifices on each of the two eductor horns, which discharge the dirt and water particles to atmosphere. To eliminate airflow distortion in the narrow plenum section downstream of the cleaner, an inlet bell is attached to the compressor inlet section with a matching center body and bottom fairing as shown in Figure 58.

The complete inlet system from the roof to inlet plenum is lined with a lead-vinyl barrier sheet for noise absorption/attenuation purposes. A flexible silicone rubber boot is mounted above the air cleaner for differential expansion between power package and vehicle structure.

Exhaust System Including Coach Heat

The elimination of the diesel radiator cooling system necessitated using exhaust gas to provide coach heating. The general heating system layout is shown in Figure 59. A stainless steel exhaust gas to water-glycol heat exchanger is installed in one side of the exhaust duct manifold with a separate outlet, as shown in Figure 60.

Exhaust gas is ducted from each of the regenerator outlet ports to the top side of the engine to a common manifold mounted transversely above the engine compartment. Two stainless steel bellows connect the individual ducts to the manifold to provide for thermal expansion and relative power package to vehicle motion. The exhaust gas is diverted through the heater or bypass ducts by two doors mounted to a single shaft. The heater is actuated by an electrically controlled pneumatic cylinder, controlled by the temperature of the 50/50 water-glycol mixture exiting the exhaust heat exchanger. The thermal switch is set to control at a temperature between 180°F-204°F (82°C-96°C).

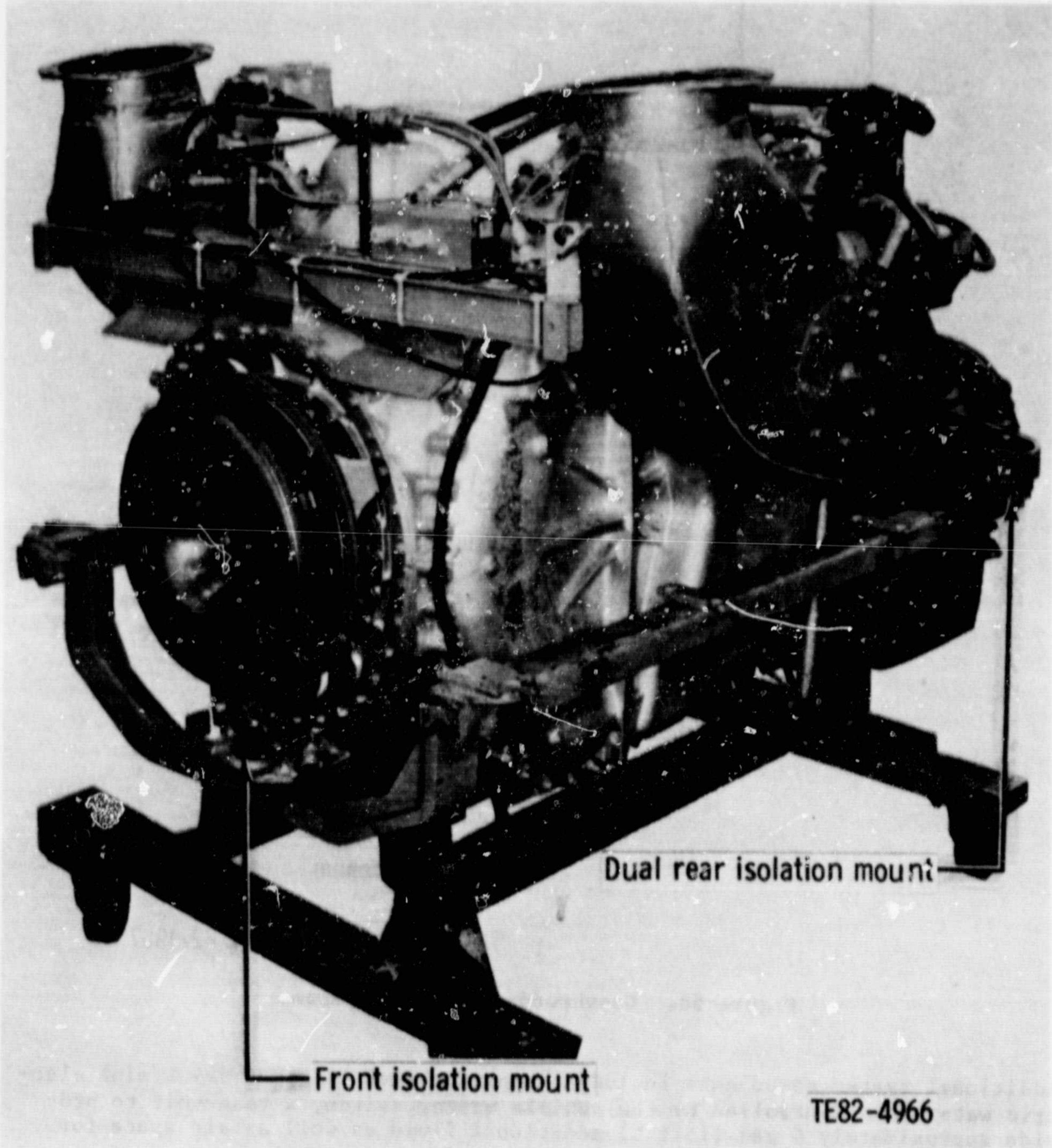

Figure 57. Greyhound power package with mounting cradle installed.

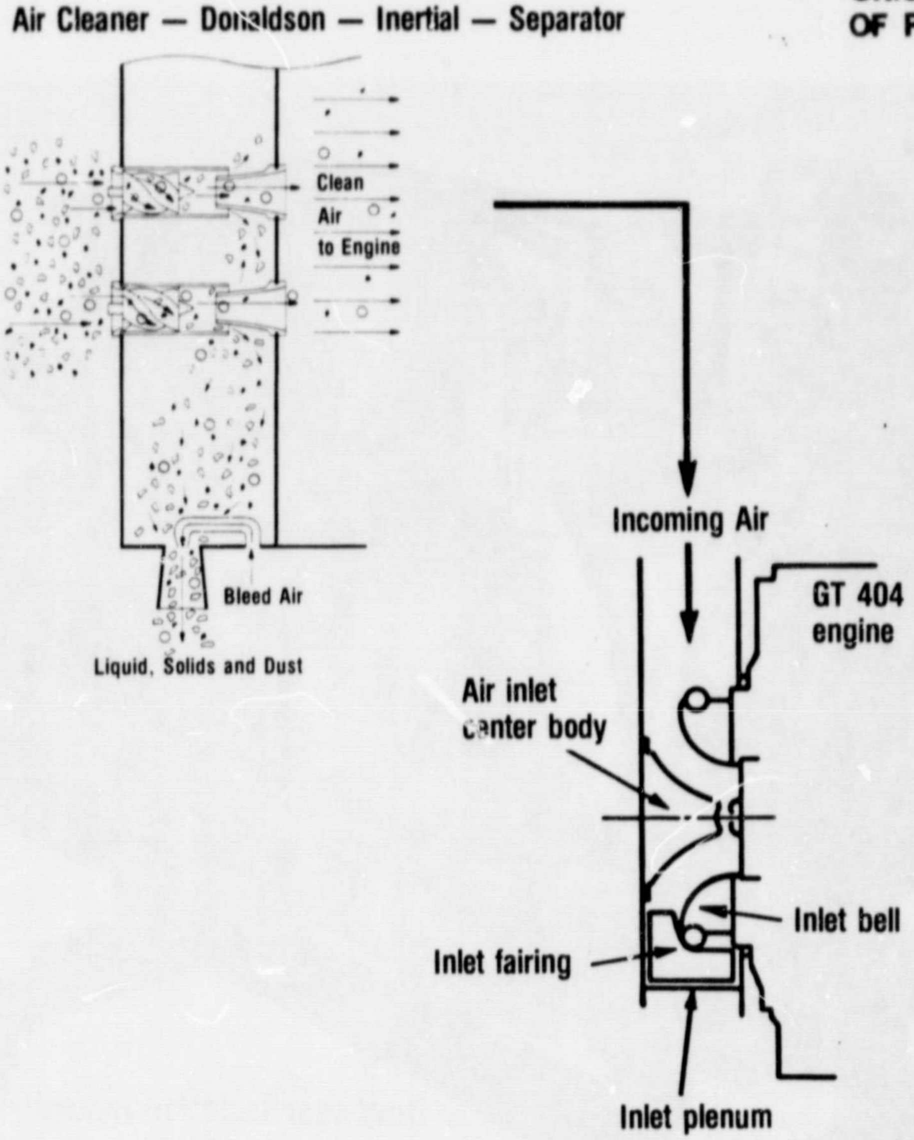

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Figure 58. Greyhound inlet air system.

Additional system components include a constant flow 12 gpm (45.4 L/min) electric water pump controlled by the vehicle master switch, a reservoir to provide approximately 4 gal (15.1 L) additional fluid as well as air space for thermal expansion and pressure relief set to 9 psi (62 kPa) by means of a standard radiator cap on the fill tube.

The upper exhaust system is covered with a 1 in. (0.025 m) thick layer of insulation, held in place with perforated aluminum sheet.

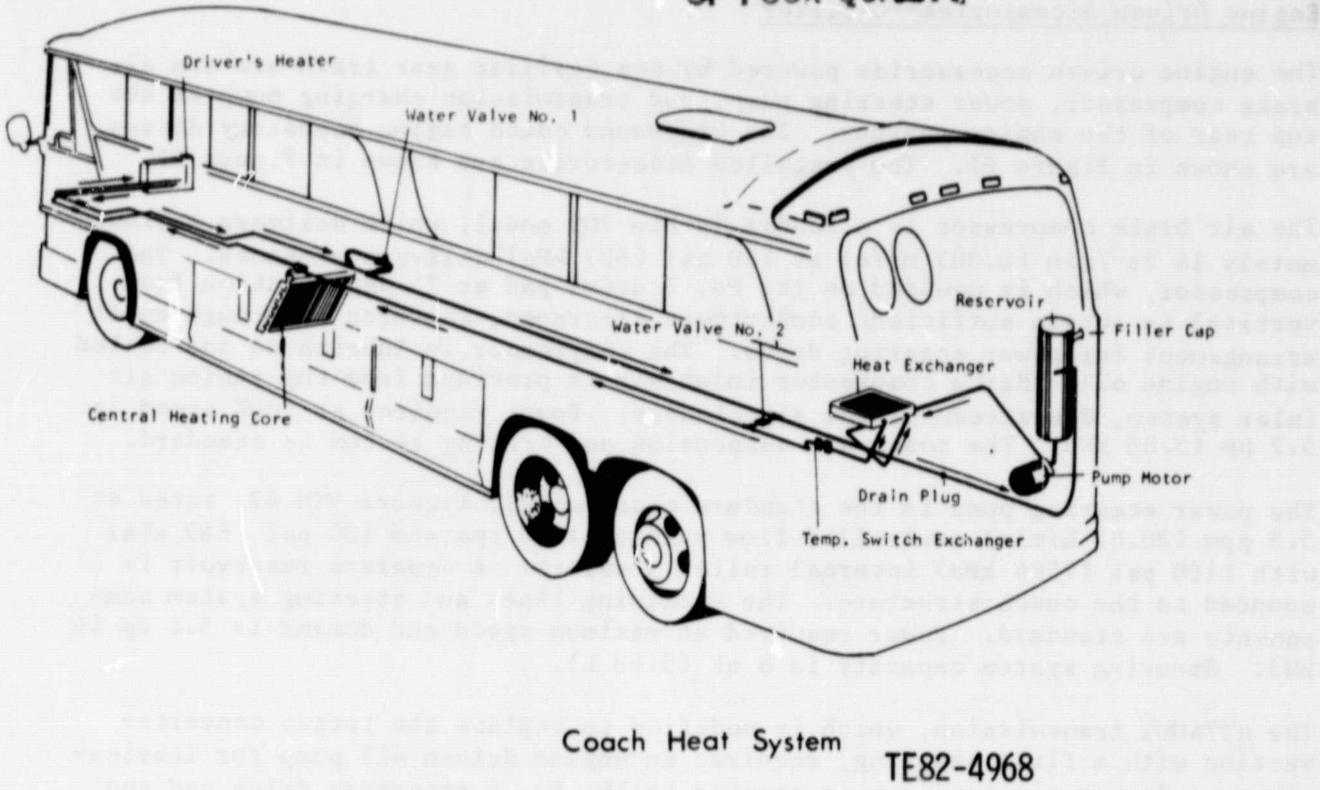

Figure 59. Greyhound coach heat system.

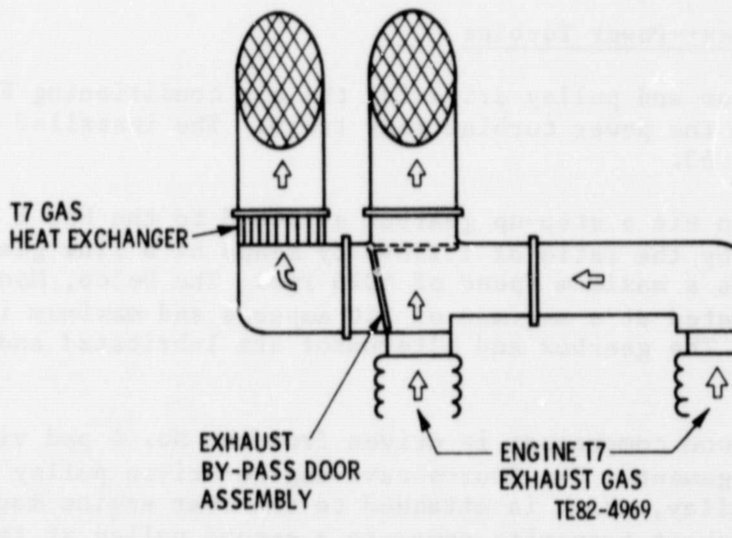

Figure 60. Greyhound exhaust and bypass door arrangement.

The exhaust gas heater system is integrated into the standard coach heating system, including operator controls. One problem with the system was operator use of air conditioning in the winter in addition to the heat mode to provide drier air for a clear windshield. The air conditioning system capacity is capable of overcoming the heater in low ambients.

Engine Driven Accessories--Gasifier

The engine driven accessories powered by the gasifier gear train are the air brake compressor, power steering pump, and transmission charging pump at the top rear of the engine gearbox. The Greyhound coach engine accessory drives are shown in Figure 61. The installed accessories are shown in Figure 62.

The air brake compressor is a Bendix Tu-Flo 700 model, which delivers approximately 14 ft^3/min (0.007 m^3/s) at 120 psi (827 kPa) delivery pressure. The compressor, which is mounted on the No. 3 drive pad at 75 deg rotation from vertical to obtain sufficient compartment clearance, features a through shaft arrangement for power steering drive. The compressor is lubricated and cooled with engine oil. Brake compressor inlet air is provided from the engine air inlet system, downstream of the air cleaner. Power required at 100% speed is 5.2 hp (3.88 kW). The coach air suspension and braking system is standard.

The power steering pump is the standard coach model, Vickers VTM 42, rated at 5.5 gpm (20.82 L/min) controlled flow rate at 1500 rpm and 100 psi (689 kPa) with 1100 psi (7584 kPa) internal relief pressure. A separate reservoir is mounted to the coach structure. The remaining lines and steering system components are standard. Power required at maximum speed and demand is 5.4 hp (4 kW). Steering system capacity is 6 qt (5.68 L).

The HT740CT transmission, which is modified to replace the torque converter section with a fluid coupling, requires an engine driven oil pump for lubrication. A Barnes simplex pump is mounted to the No. 6 accessory drive pad and is capable of a maximum delivery of 16.5 gpm (62.5 L/min) and requires 2.3 hp (1.7 kW) at 150 psi (1034 kPa) delivery pressure.

Engine Driven Accessories--Power Turbine

The coach 28-V alternator and pulley drive for the air conditioning Freon compressor are driven from the power turbine gear train. The installed accessories are shown in Figure 63.

The alternator is driven via a step-up gearbox attached to the No. 1 drive pad. The speed is increased by the ratio of 1:2.895 by means of a ring gear/pinion arrangement, which gives a maximum speed of 6025 rpm. The Delco, Model 50DN, 28-V DC alternator is rated at a maximum of 240 amperes and maximum input power is 17 hp (12.7 kW). The gearbox and alternator are lubricated and cooled by means of engine oil.

The air conditioning Freon compressor is driven from the No. 4 pad via a double pulley-jack shaft arrangement. The four-sheave engine-driven pulley drives a pillow block mounted pulley, which is attached to the rear engine mount pad. A universal type drive shaft transmits power to a second pulley at the rear of the coach, which powers the Freon compressor pulley located in the right rear corner of the engine compartment. The drive ratio is 1:0.526 speed reduction. The Carrier model 05G compressor integral input driven pulley is controlled by an electric clutch. The six-cylinder compressor is rated at 37 ft^3/min (0.017 m^3/s) at 1750 rpm using R12 refrigerant. Estimated maximum power required is 20.3 hp (15.1 kW) at 100% speed.

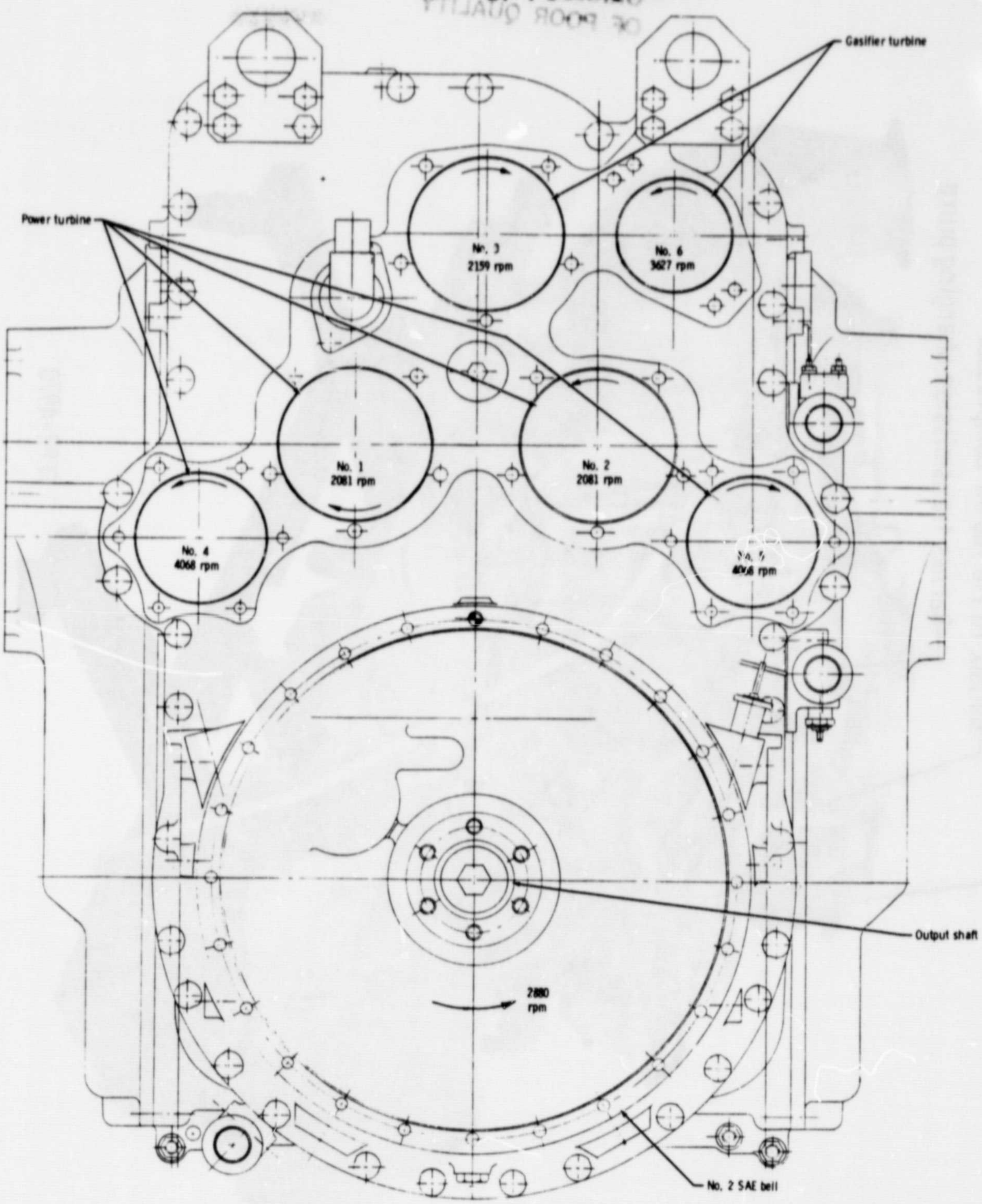

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Figure 61. Greyhound coach engine accessory drives.

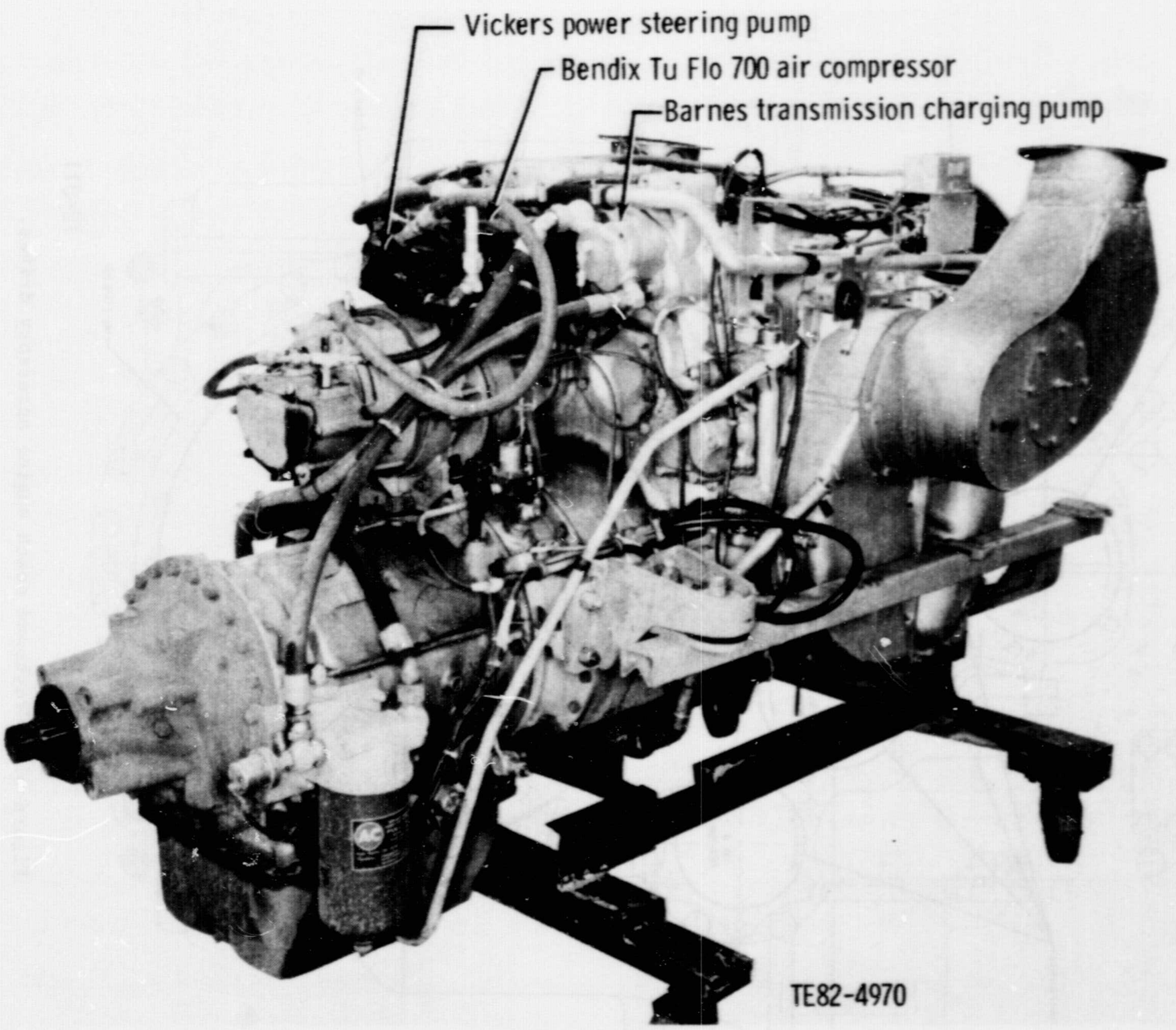

Figure 62. Greyhound engine gasifier driven accessories.

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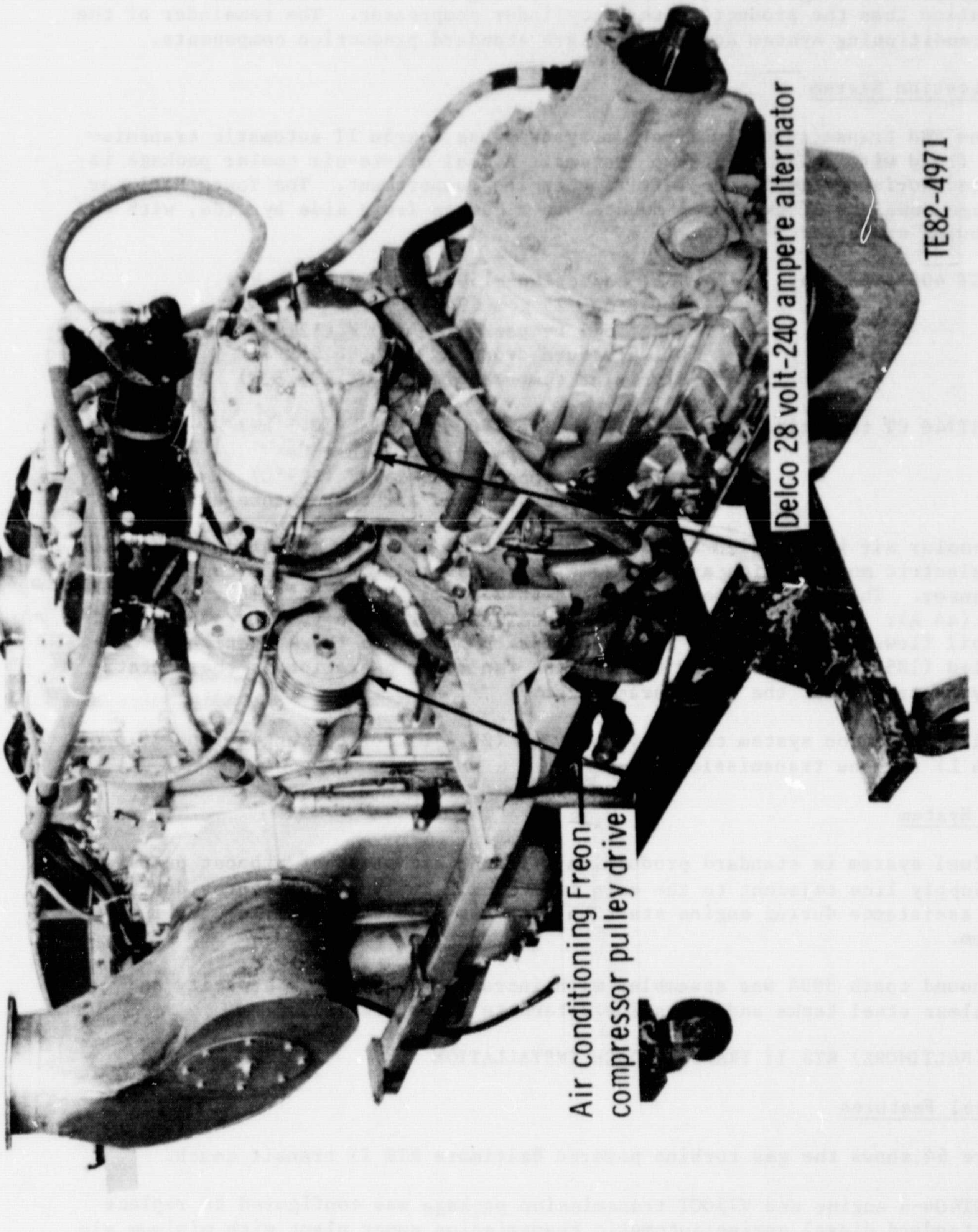

Figure 63. Greyhound engine power turbine driven accessories.

The 05G compressor represents approximately 20% increase in capacity, and the six-cylinder arrangement under partial loading was considerably smoother in operation than the production three-cylinder compressor. The remainder of the air conditioning system and controls are standard production components.

Lubrication System

Engine and transmission lubrication systems use Dexron II automatic transmission fluid with individual sump systems. A dual oil-to-air cooler package is mounted horizontally in the left rear engine compartment. The Young Radiator package consists of two cores mounted in a common frame side by side, with the following criteria:

GT 404-4 engine:	Heat rejection--1500 Btu/min (26.4 kW) Oil flow--25 gpm (94.6 L/min) Inlet oil temperature--250°F (121°C) Oil pressure drop--10 psi (68.9 kPa) Air inlet temperature--100°F (37.8°C)
HT740 CT transmission:	Heat rejection--600 Btu/min (10.5 kW) Oil flow--10 gpm (37.9 L/min) Inlet oil temperature--265°F (129°C) Oil pressure drop and air temperature as above

The cooler air is supplied by an 18 in. (0.46 m) diameter six-blade axial fan and electric motor, which are the same as parts used for the air conditioning condenser. The electric motor is rated at 2 hp (1.49 kW) at 2200 rpm at 26.5 V DC (44 A). The fan provides approximately 1700 ft^3/min (0.8 m^3/s) airflow. The oil flows to both engine and transmission cores are thermostatically controlled (185°F-210°F [85°C-99°C]) and the fan motor operation is thermostatically controlled at the same parameters.

Total lubrication system capacity is 30 qt (28.4 L) for the engine and 19.5 qt (18.4 L) for the transmission.

Fuel System

The fuel system is standard production with the exception of a boost pump in the supply line adjacent to the main fuel tank. The boost pump provides pressure assistance during engine start only and is also used to prime the fuel system.

Greyhound coach 5994 was assembled with increased fuel system capacity and stainless steel tanks and lines for alternate fuels testing.

MTA (BALTIMORE) RTS II TRANSIT COACH INSTALLATION

General Features

Figure 64 shows the gas turbine powered Baltimore RTS II transit coach.

The GT404-4 engine and V730CT transmission package was configured to replace the standard diesel engine/automatic transmission power plant with minimum alteration to the production RTS II coach. The standard diesel engine V-drive

Figure 64. GT404-4 powered Baltimore RTS II transit coach.

transmission is installed in a transverse position; however, a special model diesel engine that is rotated 43 deg counterclockwise from vertical is used to minimize the longitudinal engine compartment dimension. Installation of the turbine engine in the vertical attitude required special rework to fuel system components and plumbing at the top right corner of the engine. In addition, the exhaust system required special treatment to carry the right (inboard) exhaust duct under the power package and up the left side of the engine to meet the rear exhaust exit port.

The major external change to the coach was installation of a cover at the top rear section to house the air conditioning condenser and fan arrangement. Relocation of these components was necessitated by loss of space in the engine compartment resulting from the vertical engine installation attitude and space requirements for the air induction/cleaner system.

<u>Power Package Mounting and Drive Line</u>

The engine/transmission package is cradle mounted and designed to roll into the compartment. The cradle is cantilever mounted to the lower firewall section and supported by means of hanger brackets at the rear of the coach. The cradle and hanger brackets are shown in the rear view of the power package installation (see Figure 65).

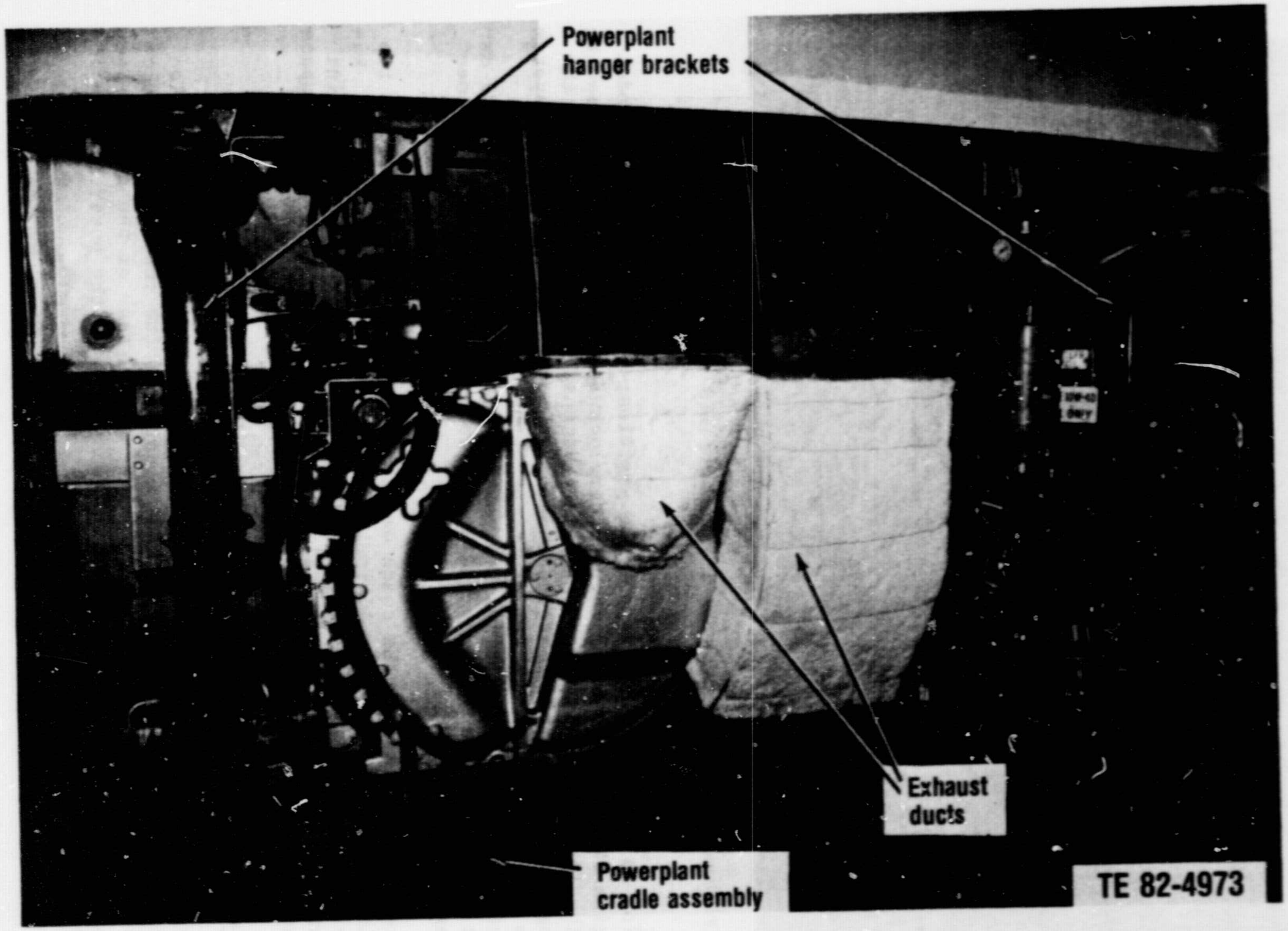

Figure 65. Rear view of transit power package installation.

The engine is supported via pedestals attached to the cradle assembly with main mounts at the engine gearbox and a single smaller support from the bottom front of the engine. A fourth bracket is used at the transmission case to support the overhung moment.

The diesel installation rubber isolation damper mountings are used at all locations.

The V730CT transmission is located in the same position as the V730D, and therefore no change to the drive shaft was required.

The standard diesel coach axle ratio as supplied for conversion was 4.625:1. In order to match the coach top speed with the higher turbine output speed, a 5.375:1 axle was installed in the first coach. Subsequent performance testing indicated the need to change to 5.857:1 ratio for improved acceleration and braking while maintaining acceptable maximum coach speed. All of the turbine coaches were changed prior to being introduced to revenue service.

Air Intake System

The air inlet plenum with inertial cleaner is mounted to the front of the engine at the inlet bell. The air is ducted from a horizontal grill in the left-hand side service door, as shown in Figure 66.

The self-cleaning, single-pass, inertial-type air cleaner, manufactured by Aircraft Porous Media (Pall Corp.), Model AE A244-1, is horizontally installed above the inlet plenum. The cleaner was sized to the GT404-4 engine airflow requirements as follows:

Airflow--total:	3024 SCFM (1.42 m^3/s)
Airflow--engine:	2800 SCFM (1.32 m^3/s)
Airflow--scavenge:	224 SCFM (0.11 m^3/s)
Engine compressor discharge bleed airflow:	0.82% of engine compressor flow
Efficiency:	92% (AC coarse test dust)

The eductor system is powered by an engine compressor discharge bleed arrangement similar to the Greyhound installation. The wider plenum dimension in the transit coach did not require the flow distribution devices used in the Greyhound installation.

The inlet system is treated for noise attenuation and absorption. The inlet duct is lined on the inner surfaces with Scott-Reticulated Foam, No. 3-900, which is 1 in. (0.025 m) thick. The inner surfaces of the plenum are lined with lead-vinyl, Blachford Conaflex U-100.

Exhaust System

The exhaust ducting includes cast elbow sections attached to the regenerator outlet ports. The right-hand exhaust is ducted down and under the engine, then upward and adjacent to the left-hand duct as shown in Figure 65. The exhaust exits through a rectangular-shaped port below the air conditioning module. Insulation is provided by adding Fiberfax to the elbows and 0.5 in.

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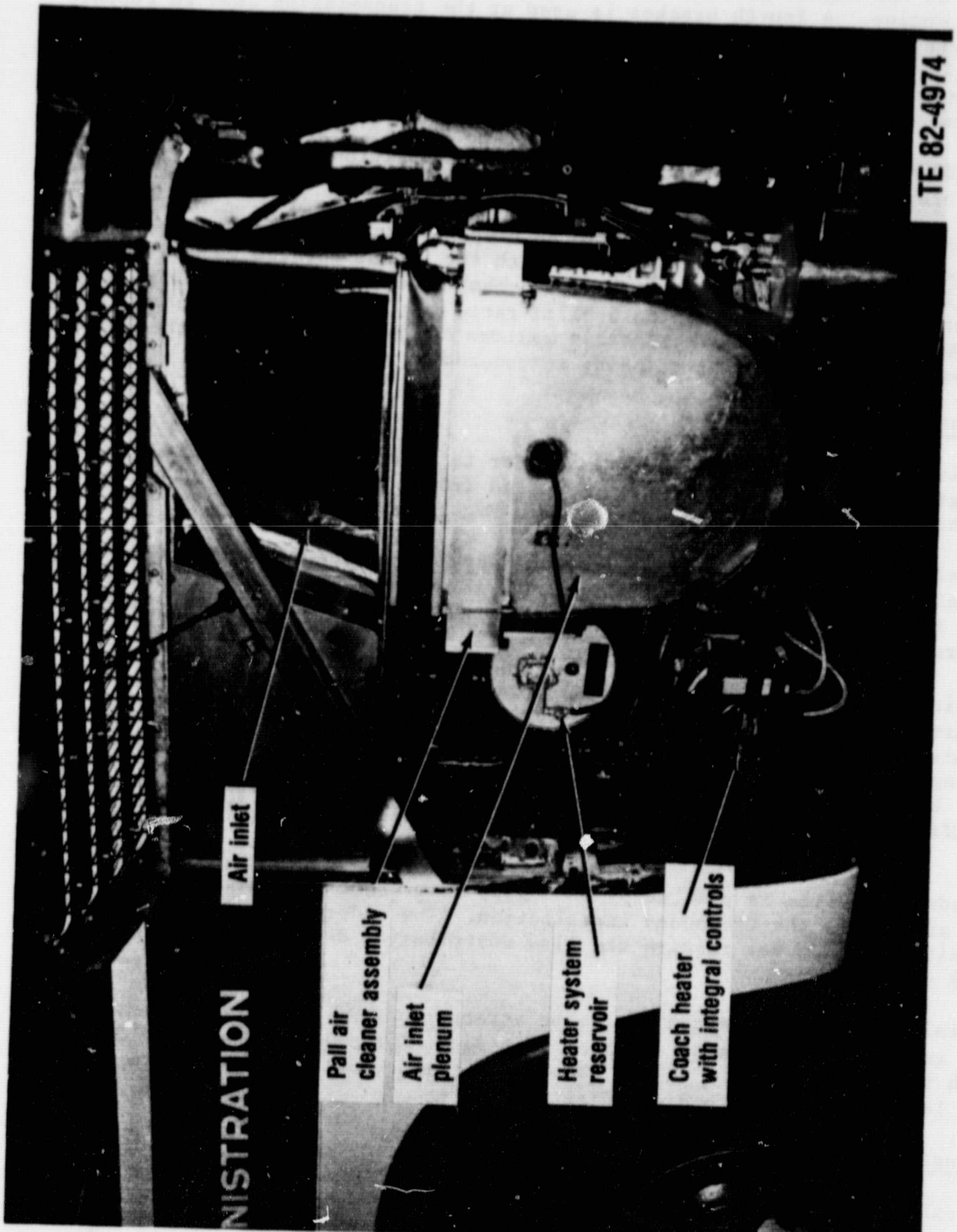

Figure 66. Left side of transit coach engine compartment.

(0.013 m) thick Temp Mat to the duct. To pressure balance the differential in exhaust duct length, a 70 in.^{2} (0.045 m^2) to 50 in.^{2} (0.032 m^2) sheet metal orifice was added to the left-hand duct.

The coach heat is provided by a fuel fired water-glycol system, manufactured by Webasto Inc., Model DRW 2020, rated at 80,000 Btu/hr (23,446 watts). The water-glycol is circulated by means of an electric water pump.

Engine Driven Accessories--Gasifier

The transit coach engine accessory drives are shown in Figure 67.

The gasifier driven accessories consist of the Bendix Tu-Flo 700 Model air brake compressor with through shaft drive to the Vickers power steering pump, mounted on the No. 3 drive pad. These accessories, shown in Figure 68, are the same as those used in the Greyhound installation.

The transmission pump, driven from the No. 6 drive pad, is a Barnes simplex pump. The pump is a higher flow model for use with the V730CT transmission and is rated at maximum speed at a flow of 25 gpm (94.6 L/min) and requires 4.1 hp (3.06 kW) at a delivery pressure of 150 psi (1034 kPa).

Engine Driven Accessories--Power Turbine

A special direct drive pad, No. 7, was provided for the coach alternator since the engine gearbox required redesign to provide the 1-1/2 SAE output housing with opposite (left-hand) rotation for the V730CT transmission (Figure 67).

The Delco alternator, Model 50 DN, Type 600, is oil cooled and is rated at a maximum output of 400 amperes. Nominal rating is estimated at 250 amps, 28 V DC at 17 hp (12.7 kW). Alternator maximum loading is calculated with the air conditioning system loaded.

The No. 4 drive is configured for a pulley drive at 1:2 ratio speed increase for the 38-V Leece-Neville alternator used to power the oil cooler fan motor. The cooler fan is a 7 blade 18 in (0.46 m) diameter, installed to pull ambient air through the engine oil cooler mounted vertically at the right-hand side of the compartment above the transmission.

Air Conditioning Compressor

The air conditioning Freon compressor is the same as that used in the Greyhound installation (Carrier model 05G). The unit is pulley driven at a 1:0.558 ratio to engine output speed and is cradle mounted above the V730CT transmission. The compressor is pulley driven from the transmission power takeoff (PTO), as shown in Figure 68.

Lubrication System

A Young Radiator oil cooler package, with side-by-side vertically mounted cores, is mounted in the right upper section of the engine compartment. The cooler package and specifications are the same as for the Greyhound installation except the transmission cooler capacity was increased to 1000 Btu/min (17.6 kW) heat rejection.

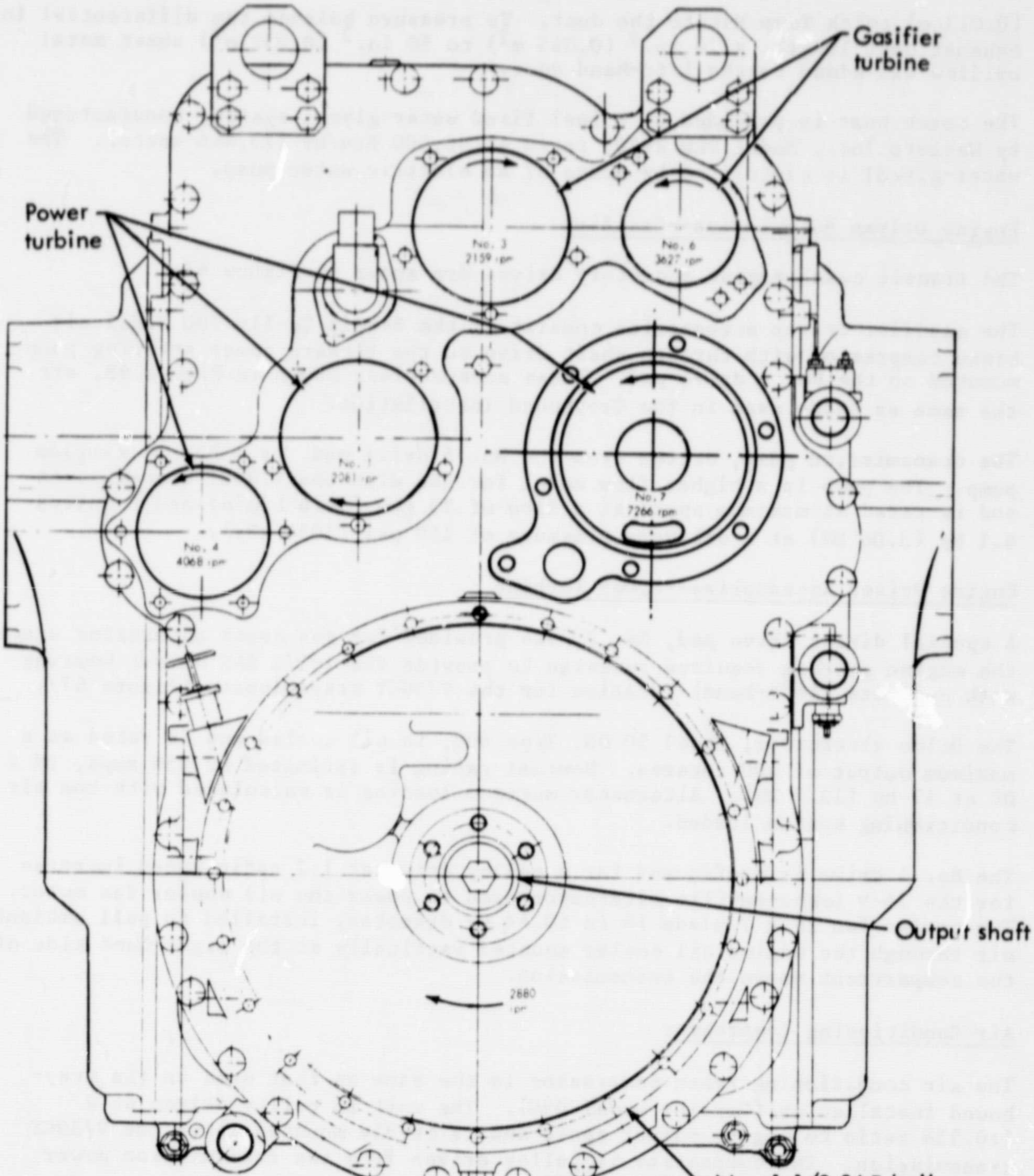

Figure 67. Transit coach engine accessory drives.

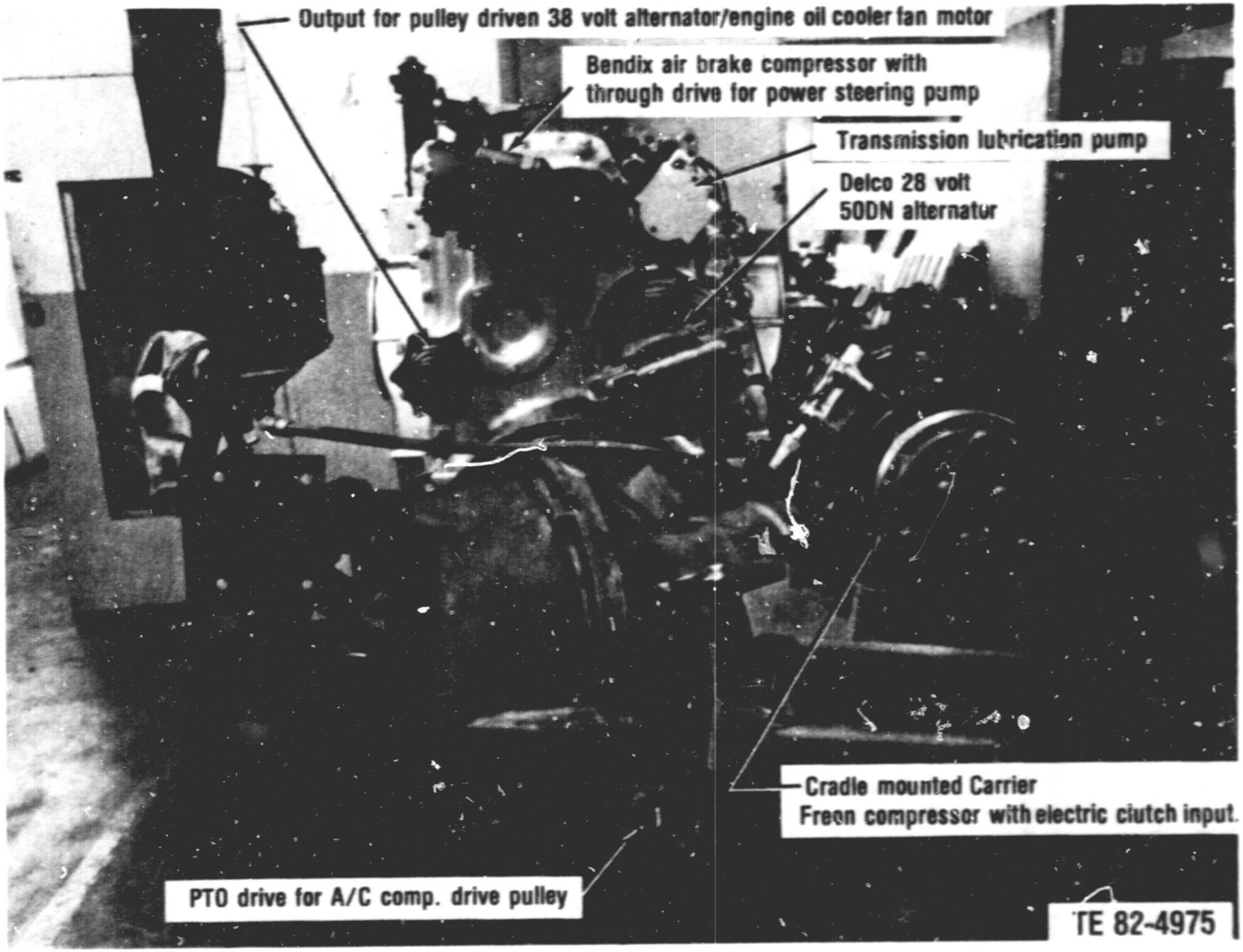

Figure 68. Transit power package--right-hand view partially assembled.

After development testing of the prototype coach, the lubrication cooling system was changed. A new Hayden oil cooler was mounted forward of the engine compartment with a separate electrically driven fan for transmission cooling. The engine and transmission cores of the Young Radiator package were connected in parallel for increased engine cooling capacity.

Cooler fan operation for both coolers is thermostatically controlled.

Fuel System

The engine fuel system components, including diverter valve, manual valve, and two-way and three-way solenoid valves, were relocated to a new arrangement at the top right-hand side of the engine to obtain sufficient coach bulkhead clearance.

A comprehensive temperature survey of engine-mounted control components resulted in the addition of small DC blower motors with ducting directed to supply cooling air to impinge on fuel system components.

APPENDIX C. CHRONOLOGICAL HISTORIES OF GREYHOUND COACH ENGINES AND HT740CT TRANSMISSIONS

ENGINE S/N T5

Date	Activity
1979	
23 March	Initial build instructions for engine T5 issued.
16-18 June	Engine T5 completed acceptance test. Transmission S/N 30576 attached and power package assembled.
19 June	Power package shipped to Motor Coach Industries for installation in Greyhound MC-8 coach S/N 5992.
26 June	Power plant buildup commenced at MCI experimental shop. Coach 5992 rework commenced 1 April 1979.
15-16 July	Coach 5992 reworks completed and trial power plant installation commenced. Insufficient travel with drive shaft required modified upper radius rods to bias drive axle position.
17 July	Initial fireup-static shakedown and road test. Slow vehicle acceleration from rest due gasifier response and second gear start in drive range. Number of oil leaks and cooler fan rotation correction required.
6 August	Coach painting and cleanup completed.
7-9 August	Transmission valve body tuning completed; coach loaded to maximum GVW for coach acceleration tests.
15 August	Testing completed and coach 5992 moved to Pembina, ND, for final checkout--i.e., brake adjustment and wheel alignment, road test and routine vehicle acceptance.
16 August	Coach released by MCI for delivery to DDA for reworks; deadheaded to Chicago.
17 August	Coach serviced in Chicago and delivered to DDA Plant 8. Electronic control assembly and wiring changed to introduce high idle for improved acceleration.
18 August	Transmission modified at DDA Plant 3 to incorporate first gear start for improved acceleration.
21 August	Transmission and controls testing completed at DDA.
22 August	Coach 5992 deadheaded, Indianapolis to Toledo, OH, for noise test program.

Date	Activity
1979	
23 August	Coach delivered to Plumbrook Station for EPA/NASA noise tests (Sandusky, OH), with comparison to standard diesel powered coach.
24 August	Coach deadheaded, Sandusky to Cleveland, OH, revenue run Cleveland to Pittsburgh, PA, and deadheaded to Breezewood, PA.
25 August	Coach deadheaded Breezewood, PA, to Washington, DC, garage.
27 August	Major clean and new coach service at Washington, DC.
29 August	Press release, DOE/Greyhound, Washington, DC.
30 August	Coach 5992 released to revenue service from Washington, DC, to Philadelphia, PA. Coach 5992--2539 mi (4086 km) and 80 hr.
1 September	Coach 5992 experienced loss of alternator power in revenue service. Coach was towed to Washington, DC, for investigation and repair. Failure found to be the loss of the self-locking nut which attaches ring gear to drive shaft on the alternator drive gearbox. Failure attributed to insufficient nut torque at gearbox assembly. Coach 5992--3025 mi (4868 km) and 99.6 hr operation.
27 September	Coach 5992 returned to revenue service after replacement of alternator drive assembly.
28 September	Coach experienced a shutdown in revenue service. Coach would not restart and was towed to Philadelphia for investigation. Coach 5992--3474 mi (5591 km) and 114.4 hr.
2 October	Investigation showed coach operation was normal; it was suspected that the master switch was not recycled prior to restart attempt.
2-3 October	Coach 5992 road tested for shutdowns--random T6 shutdowns at part power condition, part power setting on electronic control reduced to full setting.
4 October	Coach returned to revenue service; north of Baltimore the alternator ceased to function. Coach towed from Baltimore to Washington. Coach 5992--3870 mi (6228 km) and 126.6 hr.
5-10 October	Alternator and drive gearbox removed, all appeared normal. Diode check on alternator indicated failure. Spare alternator shipped from MCI and installed. Power turbine drive train not turning, No. 2 drive gear teeth failure.

Date	Activity
1979	
11 October	Power plant removed, engine T5 to be replaced with engine T8.
30 October	Engine T5 returned to DDA for investigation and repair.
19 November	Teardown inspection completed. No. 2 accessory drive gear failure with extensive secondary damage to mating gear train. Regenerator seals worn, require replacement. Turbine inlet duct requires repair of localized burn area.
	Engine T5 waiting for rebuild authorization.
1980	
11 January	Rebuild instructions issued. Rebuild will be controlled by parts availability, including steel power turbine drive gears.
22 February	Acceptance test completed. Power plant buildup with HT740CT transmission S/N 30576; transmission checked out following removal from coach 5992 in January.
25 February	Installation in coach 5994 completed at DDA and road tested. Coach 5994 to be instrumented for control system, temperature, and electromagnetic interference tests. Coach 5994--954 mi (1535 km) and 35 hr.
26 March	Engine package removed at DDA to repair cracked turbine inlet plenum. Coach alternator changed and drive checked and new fuel valve installed.
31 March	Engine package reinstalled in coach 5994. Road checked--alternator regulator setting increased, test instrumentation removed.
7 April	Coach delivered from DDA to Greyhound Chicago garage. Major cleaning required for Contractors Coordination Meeting. New flexible type transmission dipstick installed. Electrical system check indicated high amperage drain, alternator and damaged batteries replaced (overheated). Alternator stator winding shorted. (Rebuilt unit which was installed 3/26/81.)
14-17 April	Coach 5994 was demonstrated at the Department of Energy, 5th International Symposium on Automotive Propulsion Systems, Dearborn, MI. Coach failed to start and new batteries installed; alternator replaced at Detroit garage. (Suspect failed diode.)
29-30 April	Coach 5994 used for driver and mechanic training at the Chicago garage.

Date	Activity
1980	
12 May	Coach entered revenue service, Chicago/Louisville. Coach 5994--3165 mi (5093 km) and 124 hr. One flameout on deceleration, fuel valve minimum flow increased 3 pph.
13-14 May	Coach used for driver/mechanic training at Louisville, KY.
19 May	Coach 5994 used for public relations demonstration (two local Indianapolis TV stations).
20-21 May	Coach used for driver/mechanic training at Indianapolis and returned to revenue service.
22 May	Defective transmission oil pressure gage replaced in Chicago.
23 May	Coach removed from service due to heater door failure--linkage mechanism adjusted and lubricated.
4 June	Number of engine flameouts--fuel valve minimum flow schedule increased.
10 June	Coach removed from service for major clean and Greyhound public relations demonstration.
12 June	Coach 5994 returned to service. On Chicago-Louisville schedule, engine T5 stopped and coach 5994 was towed to Chicago. Investigation indicated metal particles in the sump and a disconnect between gasifier rotor and the associated accessory drive gears. Coach 5994--13,824 mi (22,247 km) and 384 hr.
17 June	Power plant removed and engine T5 returned to DDA for investigation. Two locating dowels in quill shaft bump-stop dislodged, causing assembly to rotate, which, in turn, shut off the bearing oil supply. Extensive secondary damage to rotating components as well as the gear train.
28 July	Engine reassembled, tested, and shipped to Chicago for reinstallation in coach 5994.
4-7 August	Power plant reassembled, installed, and road tested. T6 shutdowns due to faulty test set connector. Two T4 thermocouples replaced. Overtemperature shutdowns resulted in fuel valve replacement; pressure balance piston fractured.
13 August	Coach 5994 returned to service.
20 August	Minimum flow adjusted after a number of flameouts.

Date	Activity
1980	
25 August	Low power compliant--leaves removed from air inlet debris screen, additional screen to be added to roof scoop opening.
3 September	Improved fuel valve assembly installed at Greyhound garage, Indianapolis.
4 September	Coach 5994 removed from service at Chicago for major cleaning.
6-7 September	Coach deadheaded to Washington, DC.
9-10 September	Coach 5994 used for demonstration at Southeastern Bus Maintenance Forum, Towson, MD.
11 September	Coach returned in revenue service to Chicago.
17-29 September	Noise at left rear side of engine at idle. Alternator drive gear and pinion mesh corrected and returned to service.
2 October	Slow speed complaints corrected by change of speedometer head.
8 October	Brakes overheated--loose right rear trailing wheel air brake chamber replaced at Indianapolis.
16-23 October	Coach removed from service after a number of flameout shutdowns. Fuel nozzle, fuel valve, and pump replaced. Fuel nozzle tested and found to be fouled (coked) on internal passages. Road tested and returned to service.
28 October	Low engine oil pressure complaints--sender relocated from return manifold to filter outlet fitting.
30 October	Coach 5994 routed to Indianapolis for compressor impeller campaign. Coach on hold pending authorization and funding.
1981	
27 March	Coach 5994 reactivated. Gasifier assembly removed, new compressor impeller installed and engine reassembled.
30 March	Coach road tested--engine operation satisfactory but brakes require maintenance.
2 April	Coach 5994 deadheaded--Indianapolis to Chicago. Engine T5/transmission S/N 30576 removed.

Date	Activity
1981	
24 April	Engine returned to DDA--to be used for spare parts to support the coach programs. Coach 5994--29,802 mi (47,961 km) and 832 hr. Coach to be repowered with updated engine T6.

Engine T5: Installed vehicle miles--32,718 mi (52,654 km)
Installed vehicle hours--923
Total engine hours--964

ENGINE S/N T6

Date	Activity
1979	
24 April	Initial build instructions issued.
6 July	Engine T6 completed acceptance test. Power package assembled with HT740CT transmission S/N 29804.
12 July	Power package shipped to Motor Coach Industries for installation in Greyhound coach 5991 (MC-8 coach S/N 2303 from 404-3 field test program).
10 September	Transmission S/N 29804 returned to DDA for first gear start modification. Modified transmission S/N 30575, shipped to Motor Coach for installation in coach 5991.
17 September	Alternator drive gearbox assembly returned to DDA for update following failure of gearbox assembly on engine T5/coach 5992.
26 September	Electronic control assembly updated by Woodward Governor Co. and shipped to MCI for T6/5991 installation. Power transfer schedule raised for two-speed idle system.
1 October	Updated transmission S/N 29804 shipped to MCI for installation in coach 5991.
9 October	Transmission S/N 30575 returned to DDA after use on engine T6 as power plant assembly mock-up; transmission requires rework of coupling input seal area.
15-17 October	Engine T6/transmission 29804 installation completed and coach 5991 road tested. High input coupling lockup speed and rough shift encountered. CDP (compressor discharge pressure) modulator valve and spring changed. Coach 5991 front suspension and brakes reworked.

Date	Activity
1979	
14 November	Final inspection completed and coach 5991 released by MCI for deadhead trip to Greyhound (Chicago). Coach experienced transmission shift problems and overheat. Transmission oil level reduced and thermostat plumbing corrected at Fargo, ND.
19 November	New bus service at Chicago including new wheels/tires and replacement of defective Freon compressor unloader valve assembly.
21 November	Coach 5991 entered initial revenue service. Coach 5991--1189 mi (1913 km) and 34 hr. Run aborted due to no heat; operator used A/C instead of heat mode. During heater system checkout, the engine lost power and would not shift out of second gear. A defective (shorted) road speed governor was replaced.
30 November	Grinding noise from differential and/or drive shaft. Differential assembly removed and overhauled. Drive shaft balance checked and realigned.
12 December	Coach 5991 returned to service. En route to Washington, DC, a number of T6 shutdowns were experienced and the coach was removed from service at Toledo, OH. Coach 5991 was deadheaded to Detroit for electronic control adjustment by DDA representative.
14 December	Near Washington, DC, the engine lost oil pressure--two quarts of oil were added and the coach driven to the terminal. Further investigation confirmed loss of oil pressure. Engine T6 was removed to check oil pump drive gear fit at Johnson & Towers, Inc. (DDA Baltimore Distributor Facility). Coach 5991--2216 mi (3566 km) and 62 hr.
1980	
31 January	Engine found to have loose oil pump drive input gear nut--engine repaired and rebuilt to gearbox assembly, build delayed for steel power turbine drive gears.
14 February	Power plant reinstalled in coach 5991.
15 February	Road test indicated drive line vibration--drive shaft indexing corrected.
19 February	Coach 5991 returned to revenue service.

Date	Activity
1980	
28 February-4 March	Road speed governor activated, low idle incorporated and control adjusted. Road test resulted in erratic engine clutch operation. Electronic control replaced, coach retested and returned to service.
6-11 March	Coach 5991 failed to start in Washington and later in Philadelphia. Electronic control replaced and tested; coach returned to service. ECA had damaged capacitor and was returned to the vendor for investigation and repair.
13 March	Transmission overheated in service--three quarts overfull, oil burnt and grit in sump. Coach 5991--5141 mi (8273 km) and 161 hr.
14 March	Transmission S/N 30575, overhauled on 2/26/81 shipped from DDA to Washington (ex-coach 5994 on 1/9/81--transmission overheat).
7 April	Power plant removed, transmission S/N 29804 replaced with S/N 30575. Transmission 29804 returned to Indianapolis for investigation and repair; fourth range clutch damaged due to overheat as a result of overfill condition. Dipsticks recalibrated.
15 April	Power plant reinstalled in coach 5991. Road test resulted in harsh coupling lockup. Change of lockup valve, which had a scored bore, did not significantly improve shift quality.
18 April	Replacement valve body shipped to Washington.
25-28 April	Transmission repaired and fuel leak at fuel nozzle main pressure line fitting corrected; coach 5991 returned to service.
4 May	Noise and vibration complaint was out-of-phase drive shaft, which was reindexed.
30 May	Coach 5991 removed from service for low power complaints. No problem could be found during road test.
6-20 June	Coach 5991 routed from Washington to Chicago for scheduled change of operating region. Further low power complaint on initial service run. Large quantity of leaves found in air intake debris screen. Chassis dynamometer test indicated 40 hp increase with clean inlet. Coach held out of service pending investigation results of engine T5 (coach 5994) failure investigation (bump-stop pin failure 6/12/81).

Date	Activity
1980	
17 July	Engine T6 removed for bump-stop campaign. Coach 5991--14,253 mi (22,937 km) and 406 hr.
23-25 July	Engine T6 received at DDA for bump-stop campaign--pins found to be loose--bump-stop replaced, engine reassembled and returned to Chicago.
1 August	Power plant reinstalled and road tested; coach 5991 returned to service.
19 August	Engine T6 failed to start or run due to T6 overtemperature shutdowns. Combustor removed and left-hand regenerator hot face found to be damaged (smeared). Coach 5991--17,127 mi (27,563 km) and 474 hr.
1-2 September	Power plant removed and engine T6 shipped to DDA. Teardown revealed one segment of carbon was missing from the left-hand hot seal.
20 October	Engine rebuilt and current updates incorporated acceptance test completed and returned to Chicago.
21-27 October	Power plant rebuild started--controls used to service engine T5 (coach 5994). Coach test satisfactory.
28-30 October	Coach sent for major clean. Overtemperature shutdowns at body shop. Fuel valve changed, road test, and release to service.
1-5 November	Coach removed from service at Indianapolis due to low pressure and high engine oil consumption. Unused drain port plug on alternator had fallen out. Plug reinstalled, coach road tested and returned to service.
9 November	No coach heat--water pump motor brushes replaced.
11 November	Too much heat--coach return air thermostat switch replaced.
16-18 November	Coach removed due number of flameouts. Fuel valve with increased minimum flow installed at Indianapolis.
23-24 November	High idle speed complaint--road test normal and coach returned to service at Indianapolis.
1-3 December	Coach removed from service at Indianapolis due to complaints of high closed throttle speeds and excessive service brake requirement. Gasifier idle speed reduced 1000 rpm to 20,500 rpm and coach returned to service.

Date	Activity
1980	
4 December	Coach removed from service at Louisville due to driver complaints. Coach 5991 returned to DDA for corrective action. A reduction in program scope will remove coach 5991 from the demonstration program.
1981	
24 March	Coach 5991 reactivated and fueled at DDA, Indianapolis.
25 March	Coach 5991 deadheaded to Greyhound garage, Chicago.
15 April	Engine T6/transmission S/N 30575 power plant removed from coach 5991 for use in coach 5994. Coach 5991 to be terminated. All turbine components to be removed and coach to be sold as is. Coach 5991--27,234 mi (43,829 km) and 756 hr.
29 April	Engine T6/transmission 30575 installed in coach 5994. (Replaced engine T5 and transmission S/N 30576; engine T5 returned to DDA for spare parts and transmission S/N 30576 stored as a used spare in Chicago.) Coach 5994 axle ratio changed from 4.33:1 to 4.88:1. Coach 5994--29,802 mi (47,961 km) and 832 hr. Overtemperature on startup--fuel nozzle replaced due to internal carbon formation.
5 May	Installation and updates completed, including electronic control with decreased idle dump speed, two-speed idle system, updated fuel valve with steel pin, and adjustable low oil pressure switch. Rough 1/2 and 2/1 shifts during road test. Valve body and spring/shim changes to transmission not successful. Suspect worn second gear clutch.
11 May	Power plant removed from coach 5994; transmission S/N 30575 replaced with spare unit 30576 (previously removed from coach 5994). Coach 5994--29,869 mi (48,069 km) and 836 hr.
15 May	Power plant reinstallation completed and coach 5994 road tested. Released to revenue service after oil cooler air side cleaning and vehicle brake check. Coach 5994--29,882 mi (48,090 km) and 837 hr.
16 May	Coach removed from service for bad brakes in Chicago.
17 May	Coach removed from service for bad brakes in Indianapolis--front wheel brakes overhauled due to excessive wear and cracked left-hand wheel drum.
19 May	Coach 5994 removed from service--power steering fluid leak at loose line (quick disconnect fitting).

Date	Activity
1981	
20-21 May	Coach rejected for rough shifts at Indianapolis. Lockup pressure switch changed, coach road tested and returned to service.
29 May - 5 June	Coach 5994 removed from service in Louisville due to flameouts, minimum flow adjustment inadvertently made to coarse adjustment screw. New fuel valve and T4 thermocouples installed, coach road tested and returned to service.
16-17 June	Removed from service due to hot engine oil warning. Oil cooler air passages cleaned and coach 5994 returned to service.
17-23 June	Coach road failed due to alternator failure; alternator and regulator replaced. Shutdowns on road test; idle speed increased and coach returned to service.
5-8 July	Shutdowns at Lexington, KY--coach towed to Louisville.
9 July	Road test indicated intermittent electrical power loss to control system. Electronic control assembly replaced, coach road tested and returned to service. Investigation on removed ECA indicated no problems and coach circuit breaker and/or wiring considered suspect.
10 July	Coach removed from service at Chicago due to program termination. Coach 5994--38,566 mi (62,065 km) and 1085 hr.
	Power plant removed from coach 5994.
24 August	Engine T6 returned to DDA.

Engine T6: Installed vehicle miles--35,998 mi (57,933 km)
Installed vehicle hours--1009
Total engine hours--1168

ENGINE S/N T7

Date	Activity
1979	
14 May	Initial build instructions issued.
30 July	Engine completed acceptance test. Power package buildup with HT740CT transmission S/N 30579.

Date	Activity
1979	
3 August	Power package shipped to Motor Coach Industries; scheduled for installation in Greyhound coach S/N 5993.
17 September	Alternator drive gearbox assembly returned to DDA for update following failure analysis of unit removed from T5/coach 5992.
26 September	Electronic control assembly updated by Woodward Governor Co. and returned to MCI for T7/5993 installation. Power transfer schedule raised for two-speed idle system.
26 October	Initial fireup and road test of coach 5993. Transmission oil leak at input (coupling) end.
1 November	Replacement HT740CT transmission S/N 30578 shipped to MCI.
9-12 November	Power plant removed from coach 5993 at MCI; transmission S/N 30579 replaced by S/N 30578. Transmission dipstick recalibrated to reduce overfill condition.
19 November	Coach 5993 delivered to MCI, Pembina, for adjustment and final inspection.
20 November	Leaking transmission S/N 30579 returned to DDA; suspect porosity in coupling casting. Input coupling casting porosity weld repaired and casting impregnated. (Transmission installed on engine T9 for use in coach 5992, 2/13/80.)
27 November	Coach 5993 released by MCI--deadheaded delivery to Greyhound (Chicago). Coach heating system inoperative due to failed main core water valve, which was replaced in Chicago. New bus service completed in Chicago.
6 December	Coach 5993 released to initial revenue service--1339 mi (2155 km) and 52 hr. Coach routed to Washington, DC, via Cleveland/Pittsburgh.
9 December	Coach arrived at Washington, DC--coach cleaned for public relations photo session.
12 December	Inaugural run to Philadelphia, PA. Coach 5993 shut down north of Baltimore and would not restart. Towed to Washington garage--fuel nozzle, fuel valve, and pump replaced due to low start flow. Coach 5993--2224 mi (3579 km) and 79.6 hr.
	Subsequent investigation by Woodward Governor Co. found a loose internal fitting in the fuel valve which limited travel of the torquemotor arm and start fuel flow.

Date	Activity
1979	
15 December	Coach 5993 returned to service.
17 December	Engine T7 experienced loss of oil pressure. Power plant removed for investigation and repair at DDA distributor--Johnson & Towers, Inc., Baltimore. Coach 5993--3290 mi (5295 km) and 112 hr.
1980	
10 January	Engine T7 oil pump bevel drive gear nut found to be loose. Engine repaired and rebuilt with two cast and one hardened cast power turbine accessory gears. Power plant rebuilt and returned to Greyhound for installation.
14 January	Engine started but coach not road tested. Power plant removed for return to DDA distributor for installation of all-steel power turbine accessory drive gears.
13 February	Power plant returned to Greyhound.
15 February	Power plant reinstalled in coach 5993. Coach road tested and released to revenue service.
25 February	Two shutdowns in service; ECA adjusted, part power (-200) and T4 bias reduced 20 deg to 120 deg.
26 February	Five shutdowns in service; fuel valve min flow increased 3 lb/hr and high idle system deactivated.
28 February	Coach 5993 returned to service.
5 March	Coach 5993 experienced high engine oil temperature warning in revenue service. Problem traced to shorted signal wire at switch and corrected. Check of engine oil indicated the addition of 3-4 qt of SAE 30 diesel oil. Engine sump drained and flushed. New filter element installed.
6 March	Coach 5993 returned to service.
17 March	Transmission S/N 30578 downshift inhibitors reset and coach 5993 returned to service.
19 March	On return trip from Philadelphia, driver heard a noise and the engine shut down. The engine would not restart and was towed to Washington. The gasifier turbine was found to be seized. Coach 5993--10,514 mi (16,921 km) and 332 hr.
24 March	Engine T7 removed from coach 5993 for return to DDA for investigation and repair; received at DDA on 3/28/81. Engine T8 replaced T7 in coach 5993.

Date	Activity
1980	
2 April	Teardown investigation started. Severe engine damage due to burst rotors. Power turbine pinion gear fretted due to loose fit, suspected to be the result of inadequate assembly torque.
1 May	Engine T7 reassembly authorization awaiting NASA approval.
15 August	Reassembly authorization received. Parts procurement initiated.
1 October	Build instructions issued.
20 November	Engine T7 assembly and acceptance test completed. All NASA approved modifications and updates incorporated.
25 November	Engine T7/transmission S/N 30578 reassembled into power plant and installed in coach 5993 at DDA and road tested. Coach 5993--51,571 mi (82,995 km) and 1436 hr.
26 November-3 December	Two-speed idle system, activated by transmission coupling lockup signal, installed and cold ambient engine oil dump on start system incorporated.
4 December	Coach 5993 delivered to DDA Plant 3 for coupling lockup improvement. Initial testing indicated failure of the speed sensor pitot vanes. Coach 5993 was returned to Plant 8 for transmission replacement.
11 December	Power plant removed at DDA Plant 8; failed transmission S/N 30578 replaced with spare Chicago transmission S/N 30579. Coach 5993--51,710 miles (83,218 km) and 1452 hr.
18 December	Coach 5993 returned to Plant 3 for evaluation and adjustment following power plant installation and road test.
1981	
5-29 January	Transmission S/N 30579 instrumented for coupling lockup tests. Coupling lockup speed adjusted to 1150 input rpm, which improved shift quality and acceleration rate.
30 January	Coach 5993 returned to DDA Plant 8 for additional control system tests.
2-20 February	Two-speed idle system set up to accommodate reduced power transfer idle dump settings for improved engine braking range with automatic transmission downshifts. A series of performance tests were conducted to determine fuel valve minimum flow setting during deceleration.

Date	Activity
1981	
23-26 February	Coach 5993 deadheaded to Greyhound garage, Louisville, KY, for complete brake and suspension overhaul; coach returned to DDA.
27 February - 2 March	Fuel valve bench calibration and road tests at DDA Plant 8.
3-6 March	Coach 5993 turbine and diesel performance comparison tests at General Motors Proving Ground, Milford, MI. Loaded coach acceleration and deceleration tests with automatic and manual shifts. Tests on incline and skid pad also conducted for tractability and dynamic stability comparison.
9 March - 16 April	Fuel valve tests and modification action. Additional tests for fuel temperature effect on valve performance and minimum flow setting durability. Engine compartment airflow restricted on static coach due to fouled oil cooler assembly.
20-24 April	Engine oil cooler fan motor failed. Used motor (ex-coach 5991) shipped from Chicago and installed at DDA. Cooler air side cleaned.
27 April	Coach 5993 road tested and released to Greyhound Indianapolis, for revenue service. Coach 5994--55,236 mi (88,893 km) and 1588 hr.
28 April	Low engine oil pressure indications on deceleration. Pressure switch setting lowered and returned to service after road test.
5 May	Road test on coach 5993 at Chicago following complaints of rough transmission shifts; found acceptable and coach not removed from service.
17-19 May	Coach 5993 instrumented with magnetic tape recorder to obtain a profile of engine speed and temperature cycles. Express type run, Chicago/Louisville, and local run data, Louisville/Indianapolis, recorded.
29 May	Coach brakes examined at Chicago during routine maintenance check and found in satisfactory condition.
7-8 June	Coach removed from service at Indianapolis after a number of flameout shutdowns. Fuel nozzle replaced and bypass fuel rerouted to secondary filter inlet. Road test satisfactory. Coach 5993--69,368 mi (111,636 km) and 1942 hr.

Date	Activity
1981	
9-11 June	Coach rejected at Louisville due to flameouts. Fuel valve coarse adjustment turned instead of minimum flow. Fuel valve and pump replaced. Coach road tested and returned to service. Coach 5993--69,496 mi (111,842 km) and 1948 hr.
11-12 June	Coach 5993 shut down in Louisville on revenue run and would not restart. New batteries installed and low idle speed increased.
17 June	High engine oil temperature reading. Oil temperature sender replaced and oil cooler air passages cleaned at Chicago.
22-23 June	High engine oil temperature road failure. Oil cooler fan motor brushes replaced and coach returned to service after road test.
27 June - 1 July	Air conditioning system failure--problem traced to Freon compressor seals. Compressor assembly removed from coach 5992 and installed in 5993; A/C system serviced.
1 July	Coach would not start due to low batteries. Batteries replaced, coach road tested and released to service.
6-8 July	Coach 5993 road failed at Rushville, IN; towed to Indianapolis. Fuel nozzle replaced due to carbon buildup; bench check confirmed blocked pilot orifice. Combustor assembly and igniter replaced. Coach road tested and returned to service.
10 July	Coach 5993 parked at Chicago due to program termination. Coach 5993--75,943 mi (122,217 km) and 2118 hr.
August	Power package removed at Chicago.
11 September	Engine T7 returned to DDA for termination action.

Engine T7: Installed vehicle miles--34,886 mi (56,143 km)
Installed vehicle hours--1014
Total engine hours--1063

ENGINE S/N T8

Date	Activity
1979	
19 July	Initial build instructions issued.
12 September	Engine T8 completed acceptance test. Unit prepared for shipment, less HT740CT transmission, which required incorporation of first gear start. The electronic control assembly and alternator drive gearbox to be modified and shipped separately.
19 September	Package shipped to Motor Coach Industries--tentatively scheduled for installation in the fourth Greyhound coach S/N 5994.
26 September	Updated electronic control for T8 shipped to MCI.
11 October	Engine T8 shipped from MCI, Winnipeg, to Washington, DC, garage to replace engine T5 removed from coach 5992 on 10/11/81. Transmission S/N 30576 reworked to incorporate improved input seal.
23 October	Engine T8/transmission S/N 30576 package installed in coach 5992--road test satisfactory. Coach 5992--3870 mi (6228 km) and 126.6 hr.
24 October	Coach 5992 returned to revenue service.
29 October	Coach removed from service for major clean. Two-speed idle system and modified electronic control installed.
1 November	Coach 5992 participated in the first International Automotive Fuel Economy Research Conference, Washington, DC, and returned to revenue service.
25-26 November	A number of T6 automatic shutdowns encountered in revenue service--electronic control adjusted.
1 December	Electronic control adjusted and No. 2 power turbine drive gear inspected.
4 December	Electronic control adjusted; T6 control box and T4 thermocouples replaced and coach road tested.
5 December	Coach 5992 returned to service.
14 December	Coach removed from service after inspection of the No. 2 power turbine accessory drive gear exhibited excessive tooth wear. Coach 5992--14,995 mi (24,130 km) and 471.6 hr. Power plant removed for gear update at DDA distributor, Johnson & Towers, Baltimore.

Date	Activity
1980	
10 January	Power plant sent to DDA distributor. Engine T8 rebuilt with induction hardened cast iron gears at No. 1 and No. 2 positions and cast iron No. 4 gear.
15 January	Engine torn down at distributor facility to change to No. 2 steel gear.
17 January	Power package reassembled and returned to Greyhound.
18 January	Reinstallation in coach 5992 completed. During road test the engine experienced increased noise level, erratic operation, and underspeed shutdown. Coach towed to garage for removal. Coach 5992--15,025 mi (24,180 km) and 473 hr.
21 January	Power plant removed and complete package to be trucked directly to DDA Indianapolis. Engine T8 to be replaced by engine T9 (ex-coach 5994, following gear update at DDA).
25 January	Power plant received at DDA. Investigation revealed a missing outer bearing race on the power turbine second-stage cluster gear. Engine reassembly to incorporate updated power turbine accessory gears. Transmission S/N 30576 sent to DDA Plant 3 for spin check of mechanical integrity.
24 March	Engine assembled and acceptance test completed. Shipped to Washington garage for coach 5993.
31 March - 8 April	Power plant assembly in process. Transmission S/N 30578 installed. Fuel valve changed (original unit used on T9, coach 5992). Transmission downshift inhibitors reset, coach 5993 road tested and released to service. Coach 5993--10,514 mi (16,920 km) and 332 hr.
16-17 April	Coach heat malfunction--loose main water valve to relay wire fixed. Fuel valve minimum flow adjustment increased. Engine oil pressure sender changed due to low oil pressure signals at deceleration idle speed.
22 May	Coach 5993 removed from service to participate in U.S. Congress Travel and Tourism caucus.
30 May	Coach 5993 routed Washington to Chicago for change of operating region.
1-2 June	In service.
3-4 June	Body work and transmission dipstick update.
5-9 June	In revenue service.

Date	Activity
1980	
10-12 June	Coach used for public relations purposes.
13-15 June	In revenue service.
16-20 June	Coach 5993 removed from service following bump-stop failure on coach 5994/engine T5 on 6/12/80. Leaves removed from intake and oil changed to check magnetic drain plug. Coach used to establish acceleration and braking capability on flat road.
23-27 June	Coach rear drive axle change from 4.33:1 to 4.88:1 ratio. Coach on hold until T5 engine failure investigation. New electronic control assembly installed in preparation for additional engine braking tests.
8-11 July	Power plant removed for return of engine T8 to DDA for bump-stop pin inspection.
16 July	Bump-stop assembly changed. Turbine inlet duct replaced--two sections broken out. Engine reassembled and check run.
15 August	Engine T8 returned to Chicago for reinstallation in coach 5993.
19-27 August	Power plant reassembled and installed. Road test completed. Start problem with neutral safety switch, which was replaced. Coach released to service.
10-12 September	Lower power complaint; leaves removed from intake debris screen. Throttle linkage adjusted. Coach road tested and returned to service.
18 September	Coach removed from service for installation of updated fuel valve. Minimum flow increased following one flameout on road test and coach 5993 returned to service.
3 October	Several flameouts in service--minimum flow increased on fuel valve. Engine oil temperature and pressure sender/gage system updated.
13 October	Report of fumes in bus not substantiated--coach left-hand rear sash lock not operative.
23-24 October	Low power complaint--leaves removed from intake duct and screen added at roof scoop.
30 October - 2 November	Coach removed from service for engine compressor impeller campaign; coach deadheaded to DDA, Indianapolis. Coach 5993--51,571 mi (82,995 km) and 1436 hr.

Date	Activity
1980	
4-11 November	Power plant removed for repair of engine T8. New impeller, turbine inlet plenum repair, burner replacement, fuel nozzle cleaning, and regenerator overhaul required.
	Coach 5993 repowered with overhauled engine T7.
	Engine T8 scheduled to replace T9 (impeller failure) in coach 5992 at Louisville, KY.
25 November	Engine T8 found to have low power during acceptance test--engine removed to assembly floor for investigation and corrective action. Unit placed on hold due to financial constraints.
1981	
20 March	Engine T8 reactivated--to be used as Greyhound spare. Turbine inlet plenum updated and right-hand outboard regenerator seal replaced.
10 April	Engine acceptance test completed.
24 April	Spare engine T8 shipped to Greyhound as spare unit.
8 August	Engine T8 returned to DDA following termination of DOE demonstration program.

Engine T8: Installed vehicle miles--52,212 (84,027 km)
Installed vehicle hours--1450
Total engine hours--1546

ENGINE S/N T9

Date	Activity
1979	
13 August	Initial build instructions issued.
22 October	Acceptance test completed. Unit built up for shipment less the HT740CT transmission, alternator drive assembly (used for Engine T5), and the throttle sensor assembly.
25 October	Engine package only shipped to Motor Coach Industries for installation in Greyhound coach 5994. Power plant buildup with HT740CT transmission assembly S/N 30575.

Date	Activity
1979	
3 December	Starting problems on initial fireup at MCI. J3 connector shorted (pin B to ground).
6 December	Initial road test completed. Coach 5994 instrumented for performance tests and temperature survey.
1980	
8 January	Coach 5994 completed final acceptance test at Pembina, ND; released for deadhead run to Chicago.
9 January	Transmission overheat failure south of Minneapolis. Coach returned to garage. Coach 5994--954 mi (1535 km) and 35 hr.
15 January	Coach 5994 towed from Minneapolis to DDA, Indianapolis, for repair.
22 January	Power plant removed for transmission investigation and repair as well as power turbine accessory drive gear campaign.
13 February	Engine T9 rebuilt with steel power turbine accessory gears. HT740CT transmission S/N 30579 installed along with accessories, mounting cradle, and exhaust ducts from engine T8.
14 February	Complete package shipped to Washington garage for installation on coach 5992. Coach 5992--15,025 mi (24,180 km) and 473 hr.
19 February	Installation completed; coach 5992 road tested and released to service.
25 February	Random shutdowns in service--electronic control part power adjusted down.
27-28 February	Road speed governor check--loss of engine clutch control function. Temporary fix at electrical harness clutch valve connector.
4 March	Clutch connector replaced, engine compressor surge, electronic control adjusted.
14-18 March	Test on transmission downshift inhibitors--3-2 shift adjusted down. Metal particles found in transmission sump at adjustment.
23 March	Transmission overheat in service. Transmission almost 1 gal overfull. Level corrected and dipstick remarked.

Date	Activity
1980	
27 March	Overtemperature shutdowns on start--suspect fuel valve. Particles in transmission sump confirmed to be pitot vane material. Out of service for fuel valve and transmission replacement. Coach 5992--20,791 mi (33,460 km) and 652 hr.
2 April	Fuel valve removed from T8 (coach 5993) for use on engine T9. The failed valve was returned to DDA--bench check confirmed bent torque motor arm. Torque motor replaced and valve bench checked serviceable.
12-13 April	Two round trips to Philadelphia due to breakdown in communications regarding defective transmission condition (pitot failure).
17-18 April	Power plant removed from coach 5992 and transmission S/N 30579 sent to DDA distributor (Johnson & Towers, Inc.) in Baltimore for repair. Transmission lockup valve removed for use in coach 5991. Coach 5992--21,364 mi (34,382 km) and 669 hr.
28-30 April	Transmission assembly returned to Greyhound, power plant rebuilt.
1-19 May	Power plant reinstalled--road test indicated random overtemperature shutdowns and harsh shifts. Fuel valve and electronic control changed. Transmission reworked to lower coupling lockup and eliminate momentary engine output stall.
20 May	Coach 5992 returned to service--electronic control adjusted down to eliminate engine surge.
31 May	Coach 5992 removed from service due to excessive transmission oil consumption. Coupling housing oil leak--high in reverse (highest regulated main oil pressure).
5-17 June	Power plant removed from coach 5992. Transmission S/N 30579 removed and replaced with unit S/N 29804, shipped from Indianapolis 6/9/80. Power plant reinstalled and road test satisfactory. Coach 5992--23,886 mi (38,440 km) and 766 hr.
18-20 June	Coach 5992 loaded with turbine program spares and deadheaded to Chicago. New transmission dipstick installed and coach placed on hold pending engine T5 failure investigation. Coach 5992--25,419 mi (40,908 km) and 793 hr.
8 August	Power plant removed for engine bump-stop campaign. Fuel valve assembly removed for use on engine T5 (coach 5994).
14-25 August	Engine T9 returned to DDA--both bump-stop pins found to be loose. Bump-stop assembly replaced, reassembled, and shipped to Chicago, less fuel valve assembly.

Date	Activity
1980	
27-29 August	Power plant reassembled and installed upgraded fuel valve. T6 shutdowns due to defective T6 control assembly, which was replaced. 5992 road tested and to be released to service following major clean.
1-5 September	Coach released to service--power surges reported by operators. One T4 thermocouple, T1 sensor, and upgraded fuel valve assembly installed.
7-9 September	Similar surge reports received--three other T4 thermocouples, electronic control, and fuel nozzle checkout at Indianapolis.
12-17 September	Additional power surge reports--burner pattern suspect and combustor assembly from transit engine T11 installed. High gasifier speed cycling encountered and electronic control assembly replaced. Engine oil level 2 qt overfull--corrected. High engine oil temperature--fan motor control components replaced and coach returned to service.
18-19 September	Engine oil overheat in service--coach towed to Chicago. Fan motor brushes suspect and complete motor assembly replaced.
29-30 September	Coach 5992 major clean and service.
8-9 October	Transmission overheat road failure--sump approximately 2 gal overfull. Level corrected and lockup valve adjusted; coach returned to service at Indianapolis.
17-23 October	Transmission adjusted lockup valve for rough shift. Air conditioning condenser fan motor replaced due to failed bearing. Road tested and released to service.
29 October	Engine T9 failed in Louisville--compressor impeller burst during trip to garage for service. Coach 5992--41,311 mi (66,483 km) and 1195 hr.
3-4 November	Power plant removed for return to DDA for investigation and repair. Subsequent investigation revealed subsurface oxide inclusions in impeller casting with resultant fatigue failure. Secondary engine damage was extensive. Engine rebuild placed on hold pending program funding review.
1981	
23 March	Coach 5992 towed to Chicago for removal from program. Engine T9 to be used for spare parts in support of program.

Engine T9: Installed vehicle miles--27,240 mi (43,838 km)
Installed vehicle hours--758
Total engine hours--768

SUMMARY OF GREYHOUND ENGINE/COACH MILES (KM) AND HOURS

404-4 engine S/N	Installed miles (km)	Installed hours	Total hours
T5	32,718 (52,654)	923	964
T6	35,998 (57,933)	1009	1168
T7	34,886 (56,143)	1014	1063
T8	52,212 (84,027)	1450	1546
T9	27,240 (43,838)	758	768
Total 5	183,054 (294,595)	5154	5509

MC8 coach S/N	Revenue service miles (km)	Revenue service hours	Total operating miles (km)	Total operating hours
5991	25,886 (41,659)	717	27,234 (43,829)	756
5992	38,736 (62,339)	1116	41,311 (66,483)	1195
5993	70,939 (114,165)	1914	75,943 (122,218)	2118
5994	35,049 (56,405)	945	38,566 (62,065)	1085
Total 4	170,610 (274,568)	4692	183,054 (294,595)	5154

TRANSMISSION S/N 29804

Date	Activity
1979	
12 July	Power package shipped to MCI.
10 September	Unit returned to DDA for first gear start modification.
1 October	Unit shipped to MCI.
17 October	Unit installed into coach No. 5991. Unit would not upshift from first.
19 October	Investigation revealed misassembled 1-2 shift valve.
22 October	Complaint of harsh lockup engagement. Investigation deferred.
25 October	Vehicle sent to paint shop.
1 November	Harsh lockup engagement resolved by CDP actuator replacement.

Date	Activity
1979	
14 November	Vehicle released from MCI for deadhead run to Greyhound, Chicago.
15 November	Investigated transmission overtemp and blowing oil at Fargo, ND. Found mismarked oil level dipstick resulting in 2 1/2 gal overfill.
19 November	New coach service at Chicago.
21 November	Coach 5991 released to revenue service--run aborted due to heater problem. During checkout, unit would not shift out of second gear.
26 November	Shift problem traced to defective engine road speed governor switch.
30 November	Grinding noise from drive line--differential overhauled.
12 December	Coach returned to revenue service.
12 December	Coach arrived Washington, DC, and lost engine oil pressure. Power plant removed for engine oil pump investigation.
1980	
14-18 February	Power package reinstalled in coach 5991. Road test indicated severe drive line vibration--drive shaft alignment corrected.
19 February	Coach 5991 returned to service.
28 February - 11 March	Coach out of service due to engine control problems.
13 March	Transmission overheated in revenue service--3 qt overfull with burnt oil and grit in sump.
7 April	Power plant removed and transmission S/N 29804 replaced with unit S/N 30575 (overhauled 2/26/81 and shipped to Washington 3/14/81). Transmission S/N 29804 returned to DDA.
14 April	Transmission received--damaged in transit; pan crushed into hydraulic controls. Piece of outer lip seal missing, which probably caused clutch oil leak and slipping of fourth range clutch. Unit to be overhauled.
9 June	Unit completed spin test and shipped to Washington to replace S/N 30579 in coach 5992. Removed from service due to regulated main oil pressure leak on 5/31/81.

Date	Activity
1980	
17 June	Power package reinstalled and road tested normal.
18-20 June	Coach 5992 deadheaded with turbine spares, Washington to Chicago, for change in operating region. New dipstick assembly installed at Chicago. Coach 5992 placed on hold pending investigation of engine failure in coach 5994.
8 August	Power plant removed for engine campaign at DDA.
27-29 August	Power package reinstalled, coach 5992 road tested and returned to service.
8-9 October	Transmission overheat road failure at Lafayette, IN. Transmission sump approximately 2 gal overfull--level corrected; coach delivered to Plant 3 for lockup valve adjustment and coach returned to service at Indianapolis.
22 October	Transmission controls adjusted to provide proper 1-2 and 2-1 shift characteristic.
29 October	Engine failed in Louisville, KY--burst engine impeller.
4 November	Engine returned to DDA.
1981	
23 March	Coach 5992 with transmission S/N 29804 towed to Chicago--coach to be terminated and transmission held as a spare unit.
13 July	Greyhound coach demonstration program terminated.

TRANSMISSION S/N 30575

Date	Activity
1979	
10 September	Transmission S/N 30575 shipped to MCI to replace S/N 29804, which is to be returned for first gear start modification.
9 October	Transmission returned to DDA following use as mock-up to rework coupling input seal surface.
20 November	Transmission S/N 30575 returned to MCI for use in coach 5994.
28 November	Power package installation completed in coach 5994.

Date	Activity
1979	
6 December	Coach completed initial road tests.
28 December	Report of upshift malfunction during final acceptance test at MCI--Pembina, ND; engine road speed governor circuit disconnected.
1980	
8 January	Coach released for deadhead run to Chicago for new coach service.
9 January	Transmission overheat failure south of Minneapolis. Oil leaking from coupling input area following return to garage.
15 January	Coach 5994 towed to DDA, Indianapolis.
22 January	Power package removed for transmission failure investigation and repair as well as engine update. Transmission S/N 30575 replaced by S/N 30576 in coach 5994 on 2/25/81.
28 February	Transmission rebuilt and held as spare unit.
14 March	Unit shipped to Washington, DC, to replace S/N 29804 in coach 5991.
7 April	Power plant removed and unit S/N 29804 returned to DDA.
15 April	Transmission S/N 30575 installation completed; incorporated revised hold regulator valve spring.
16 April	Coach 5991 road tested; all functions normal except harsh coupling lockup at 2200 rpm. Change of lockup valve due to scored bore did not correct high lockup rpm.
18 April	Replacement valve body shipped to Washington.
24 April	Lockup clutch valve body installed and calibration completed; however, coach held out of service due to engine fuel leak.
28 April	Coach 5991 released to service.
4 May	Noise and vibration complaint corrected by proper phasing of drive shaft joints. Transmission overfull; one gallon drained to correct sump level.
30 May	Coach out of service for low power complaints.

Date	Activity
1980	
6-_0 June	Coach routed to Chicago for change of operating region. Low power complaint attributed to engine intake restriction. Coach 5991 held out of service pending failure investigation of coach 5994 (engine bump-stop pins).
17 July	Power plant removed to return engine to DDA for campaign action.
25 July	Engine returned to Chicago.
1 August	Power plant reinstalled, coach 5991 road tested, and returned to service.
29 August - 2 September	Engine failed to start--engine removed and returned to DDA.
20 October	Engine regenerator system repaired, updated, tested and returned to Chicago.
27 October	Installation completed and road test normal. Coach 5991 to be major cleaned.
30 October	Start problems--engine control change and coach 5991 returned to service.
1-5 November	Coach removed from service in Indianapolis due to low engine oil pressure. Plug reinstalled in coach alternator, coach road tested and returned to service.
4 December	Coach removed from service at Louisville due to driver complaints of excessive vehicle braking requirements. Coach 5991 returned to DDA for corrective action. Program reduction will result in phase-out of coach 5991.
1981	
24 March	Coach reactivated at DDA and deadheaded to Chicago garage.
15 April	Power plant removed for use in coach 5994.
29 April	Power plant installed in coach 5994; unit 30575 replaced S/N 30576, which will be held as serviceable spare. Axle ratio changed from 4.33:1 to 4.88:1.
5 May	Rough 1-2 and 2-1 shifts during road test. Valve body and spring/shim combinations did not alleviate problem; suspect worn second range clutch pack.

Date	Activity
1981	
11 May	Power plant removed and transmission S/N 30575 replaced by S/N 30576. Transmission held in Chicago awaiting disposition instructions.
13 July	Greyhound coach demonstration program terminated.

TRANSMISSION S/N 30576

Date	Activity
1979	
19 June	Power package shipped to MCI for installation in Greyhound coach 5992.
17 July	Installation completed and initial fireup and road test at MCI. Slow acceleration from rest due to engine inertia and second gear start.
7-9 August	Loaded coach acceleration tests and coupling clutch lockup engagement adjusted.
15-16 August	Coach 5992 completed acceptance test and released by MCI, Pembina, ND. Coach deadheaded to DDA, Indianapolis.
18-21 August	Two-speed idle system incorporated for improved acceleration. Transmission modified to incorporate first gear start.
22-24 August	Coach completed noise tests at EPA facilities at Sandusky, OH.
30 August	Coach 5992 released to revenue service; Washington, DC/Philadelphia inaugural run.
1-27 September	Coach removed from service due to alternator drive failure. Drive replaced and returned to service.
28 September - 3 October	Coach controls problem investigation at Philadelphia.
4 October	Alternator failure in service--coach towed to Washington, DC, garage.
5-8 October	Investigation revealed failure of engine power turbine accessories drive gear train.

Date	Activity
1979	
11 October	Power plant removed for engine replacement. Transmission reworked to replace coupling input seal assembly.
23-24 October	New engine with transmission S/N 30576 installed in coach 5992 and road tested. Coach returned to service.
2 November	Transmission lockup clutch recalibrated and returned to service.
14 December	Coach 5992 removed from service for engine accessory drive gear campaign (excessive wear).
1980	
18 January	Reinstallation completed. Engine failed during road test of coach 5992.
21 January	Complete power package removed and returned to Indianapolis. Transmission shipped to Plant 3--precautionary teardown inspection conducted.
18 February	Transmission S/N 30576 reassembled and returned to Plant 8.
25 February	Power package installation completed in coach 5994 at DDA. Coach road tested and instrumentation for performance testing to be installed.
26 March	Power package removed at DDA for engine repair.
31 March	Package reinstalled in coach 5994 and road tested.
7 April	Coach delivered to Chicago for use at the Contractors Coordination Meeting, Detroit, MI.
29-30 April	Coach 5994 used for Greyhound training, Chicago.
12 May	Coach 5994 entered revenue service, Chicago/Louisville.
13-14 May	Coach used for Greyhound training, Louisville.
20-21 May	Coach used for Greyhound training, Indianapolis.
12 June	Coach engine road failed in service. Power package removed and engine returned to DDA for investigation and repair.
4-7 August	Power package reinstalled and coach road tested. Engine controls changed.
13 August	Coach 5994 returned to service.

Date	Activity
1980	
4-7 September	Coach cleaned and deadheaded to Washington, DC.
9-10 September	Coach used at bus maintenance forum, Towson, MD.
11 September	Coach returned to revenue service.
22 October	Coach engine maintenance at Indianapolis; transmission hold regulator adjusted to correct shift schedule.
30 October	Coach 5994 routed to Indianapolis for DDA engine campaign.
1981	
27 March	Coach 5994 reactivated at DDA--engine updated.
2 April	Coach deadheaded to Chicago for power package removal. Transmission 30576 replaced by 30575; S/N 30576 to be held as spare unit.
11 May	Unit S/N 30576 replaced S/N 30575 in coach 5994; suspect worn second range clutch pack in removed unit.
15 May	Road test completed--revised trimmer springs installed. Coach 5994 returned to revenue service.
20-21 May	Coach removed from service at Indianapolis for rough shifts. Engine two-speed idle switch changed, coach road tested and returned to service.
13 July	Coach 5994 removed from service due to termination of demonstration program.

TRANSMISSION S/N 30578

Date	Activity
1979	
10 May	Transmission shipped to DDA, Plant 8.
22 August	Transmission returned to Plant 3 to incorporate first gear start.
10 September	Transmission shipped to MCI to replace S/N 30579.
9 October	Unit returned to DDA for clutch hub polishing.

Date	Activity
1979	
2 November	Unit shipped to MCI to replace S/N 30579, which was found to be leaking at the input section during initial testing of coach 5993.
12 November	Unit checked for 1-2 shift valve assembly which required correction. Power package installed in coach 5993.
19 November	Road test indicated power turbine stall--transmission coupling lockup speed raised to 1000 rpm. High transmission oil temperature and fluctuating regulated main pressure. Dipstick recalibrated and oil level corrected.
21 November	Coach delivered to MCI, Pembina, for final acceptance testing.
27-29 November	Coach 5993 released for deadhead run to Chicago for new bus service.
6 December	Coach released to revenue service; Chicago to Washington, DC.
12 December	Entered service Washington/Philadelphia.
17 December	Coach removed from service due to loss of engine oil pressure--power plant removed for corrective action as well as engine gear campaign.
1980	
15 February	Power plant reinstalled in coach 5993, coach road tested and returned to service.
17 March	Transmission downshift inhibitors reset and returned to service.
19 March	Major engine failure in revenue service.
24 March	Power package removed for engine replacement.
31 March - 8 April	Replacement engine package installed, power plant reinstalled, coach 5993 road tested and released to service.
30 May	Coach 5993 transferred to Chicago from Washington.
4 June	Transmission dipstick changed from ribbon to flexible type.
16-20 June	Coach used for performance tests.
23-27 June	Rear axle ratio changed from 4.33:1 to 4.88:1.

Date	Activity
1980	
11 July	Power plant removed to return engine to DDA for bump-stop campaign.
15 August	Engine returned to Greyhound, Chicago.
19-27 August	Power plant reinstalled; coach 5993 road tested and returned to service.
23 October	Shift linkage adjusted.
30 October - 2 November	Coach 5993 removed from service for engine compressor campaign--delivered to DDA, Indianapolis.
11 November	Power plant removed at DDA for engine campaign.
25 November	Rebuilt engine and transmission S/N 30578 installed in coach 5993 and road tested. Two-speed idle system installed and cold oil dump system installed.
4 December	Coach 5993 delivered to Plant 3 for coupling lockup recalibration. Initial testing indicated failure of transmission speed sensor pitot vanes. Coach returned to Plant 8 for transmission replacement.
11 December	Unit S/N 30578 replaced with Unit S/N 30579.
1981	
January	Unit at DDA Plant 3 awaiting disposition and funding; transmission to be used for spare parts as a result of program reduction to two coaches.
13 July	Greyhound demonstration program terminated.

TRANSMISSION S/N 30579

Date	Activity
1979	
3 August	Power package shipped to MCI--scheduled for installation in Greyhound coach 5993.
10 September	Transmission returned to DDA to incorporate first gear start. Oil leak at input section at removal from engine at MCI. Quality problem with surface finish on coupling input journal.

Date	Activity
1979	
1 October	Transmission shipped to MCI for installation in coach 5993 (to replace unit S/N 30578).
26 October	Installation completed and road test on coach 5993. Oil leaking from input section of transmission.
9 November	Power plant removed and transmission S/N 30579 replaced by S/N 30578.
20 November	Transmission returned to DDA for corrective action; to be held as spare unit. Input coupling porosity weld repaired and casting impregnated.
1980	
3 January	Transmission function checked and sent to Washington as spare unit.
16 January	Unit returned to DDA for use in coach 5994.
14 February	Rebuilt engine and transmission S/N 30579 shipped to Washington as a complete package for coach 5992 replacing transmission S/N 30576.
19 February	Package installation completed, coach 5992 road tested and released to service.
14-19 March	Transmission downshift inhibitors checked; 3-2 shift adjusted down. Metal particles found in sump during changes.
23 March	Transmission overheated in service; sump approximately 5 qt overfull. Level corrected and dipstick recalibrated. Pieces from sump confirmed to be speed sensor pitot vane material. Coach placed on hold for transmission replacement.
12-13 April	Two round trips to Philadelphia due to breakdown in communications regarding defective transmission condition (pitot failure).
17-18 April	Power plant removed from coach 5992 and transmission S/N 30579 sent to DDA distributor (Johnson & Towers, Inc.) in Baltimore for repair. Transmission lockup valve removed for use in coach 5991.
28-30 April	Transmission assembly returned to Greyhound and power plant rebuilt.

Date	Activity
1980	
1-19 May	Power plant reinstalled--road test resulted in engine overtemperature shutdowns and harsh shifts. Transmission reworked to lower coupling lockup and eliminate momentary engine output stall.
31 May	Coach 5992 removed from service due to high transmission oil consumption. Leak at input area and increases with pressure (i.e., greatest leakage rate in reverse).
5 June	Power package removed and transmission S/N 30579 replaced with S/N 29804.
16 June	Transmission shipped to Chicago via coach 5992--unit to be sent to distributor for repair.
25 July	Unit repaired at distributor.
8 August	Unit shipped to Chicago garage as spare.
11 December	Unit returned to DDA Plant 8 for coach 5993. Transmission S/N 30579 replaced S/N 30578 (failed pitot); coach sent to Plant 3 for transmission lockup calibration.
1981	
5-29 January	Transmission instrumented for coupling lockup tests. Lockup adjusted to 1150 rpm for improved shift quality and vehicle acceleration rate. Coach returned to Plant 8 for additional controls tests.
3-6 March	Diesel and turbine coach comparison tests at GM Proving Ground, Milford, MI.
27 April	Coach 5993 returned to revenue service, Indianapolis.
5 May	Rough shift complaint--Chicago; unit road tested and found to be acceptable.
18 May	Coach used for express and local duty cycle profile recording, Chicago-Louisville-Indianapolis.
10 July	Coach routed to Chicago on final run.
13 July	Greyhound demonstration program terminated.

APPENDIX D. CHRONOLOGICAL HISTORY OF MTA (BALTIMORE) TRANSIT COACH ENGINES AND V730CT TRANSMISSIONS

ENGINE S/N T10

Date	Activity
1979	
13 March	Initial build instructions issued.
6 July	Engine proof tested with metal regenerators and shipped to Transmission Test Group at Plant 3 for acceptance testing six V730CT automatic transmissions.
13 December	Engine returned to Plant 8 for teardown, rebuild to latest configuration, including ceramic regenerator system.
1980	
8 February	Acceptance test completed. Engine and transmission assembly and power plant buildup.
12 February	Engine T10 and V730CT transmission S/N 11122 shipped to Modern Engineering Service, Troy, MI.
1 July	Power plant returned to DDA for bump-stop campaign.
9 July	Power plant shipped to Modern Engineering following bump-stop replacement. Tentatively assigned for installation in coach 3318.
1981	
27 January	Engine returned from Modern Engineering. Engine T10 removed from program; to be used for spare parts. Replaced by engine T11.
19 February	Gasifier section removed from engine T10 updated and shipped to MTA, Baltimore, for use in coach 3321, engine S/N T12.
28 April	Engine rebuild commenced; to be used as spare for MTA transit coach program.
11 May	Engine acceptance test completed.
13 May	Engine shipped to MTA, Baltimore, as transit coach program spare.

Engine T10: No coach installation
Total engine hours--108.0

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ENGINE S/N T11

Date	Activity
1979	
12 June	Initial build instructions issued. This engine to be configured with metal regenerator system. Unit to be used for rework of fuel manifold system to obtain installation clearance with transit coach firewall.
17 July	Engine completed acceptance test. Power plant buildup with V730CT transmission, S/N 11121 commenced.
7 August	Power plant package shipped to Modern Engineering. Package to be used for engineering design and installation configuration definition in MTA coach S/N 3319.
12-15 November	Initial engine fireup and static testing conducted.
29 November - 5 December	Instrumentation installed for road test.
10-14 December	Initial coach road test completed.
1980	
16 January	Engine road test on coach 3319 completed at Modern Engineering. Additional testing required for evaluation of engine and transmission oil cooler operation as well as engine compartment temperatures under higher ambient conditions. Auxiliary heater system and A/C system not operational.
12-14 March	Coach 3319 driven to Baltimore via TRC (Transportation Research Center--East Liberty, Ohio), to install instrumentation for monitoring lubrication systems and compartment temperatures. High oil temperatures observed on trip (i.e., 230°F [110°C] engine oil at 30°F [-1.1°C]). Coach delivered to Baltimore for painting and decal application.
24 March	Starter contacts welded together at MTA and starter remained energized after run switch turned off. Starter and starter relay replaced. Coach 3319--1036.5 mi (1668 km), 37.5 hr
31 March	Coach 3319 returned to Modern Engineering from Baltimore. Heater system okay but engine oil temperature was high. Heat/A/C and cooler system rework required.
7-10 April	Coach 3319 participated in demonstration at the Contractors Coordination Meeting, Dearborn, MI.
24 April	Separate transmission oil cooler installed in bay forward of coach exit door for improved cooling system.

Date	Activity
1980	
26 April	Coach 3319 driven to Baltimore for display. High engine compartment temperatures from exhaust duct gas leaks. Heater system unserviceable.
29 April	Coach participated in MTA 10th anniversary ceremony.
5 May	Coach 3319 returned to Modern Engineering to correct cooling problems. Transmission oil cooler temperature switch failed en route.
7 May - 25 June	Transmission cooler fan switch replaced. The engine oil cooler capacity was increased by using the redundant transmission core plumbed parallel to the engine core. A new seven-blade fan used at higher speed to increase airflow. Low capacity blower motors used with ducting to control areas and louvres added to service doors to reduce engine compartment temperatures.
26 June	Coach 3319 delivered to TRC for performance and systems testing to be followed by endurance testing as administered by Booz.Allen & Hamilton, Inc. Heat and A/C systems not operational.
10 July	Engine T11 removed from coach 3319 for return to DDA and replaced with engine T14. Engine T14 was campaigned for bump-stop condition and incorporates ceramic regenerator for evaluation test program. Coach 3319--4401 mi (7097 km) and 158.3 hr.
4 September	Bump-stop inspection commenced at DDA, as well as other pertinent engine updates.
17 September	Transmission S/N 11121 returned to DDA Plant 3 for inspection.
3 November	Engine T11 completed acceptance test.
5 November	Engine T11 shipped to TRC, East Liberty, OH, as spare engine.
3 December	Relay panel updated on T11 (spare engine).
1981	
19 January	Engine T11 shipped from TRC to Modern Engineering for installation in MTA coach 3318 with transmission S/N 11122; replaced engine T10.
4 March	Installation completed, coach 3318 road tested.
11 March	Coach acceptance testing completed at Modern Engineering.

Date	Activity
1981	
17 March	Coach heating system failed on delivery of coach from Modern Engineering to TRC, due to wiring and plumbing problems--unit repaired.
18 March	Coach driven to Baltimore via TRC.
19 March	Coach at MTA, Baltimore--transmission coupling lockup clutch slow to release during deceleration with output stalling momentarily. Coach to be prepared by MTA for revenue service operation.
27 March	Drive axle differential ratio change in process.
2 April	Transmission S/N 11122 lockup valve body changed to correct output stall condition.
3 April	Final checkout and cleanup prior to release.
6 April	Electronic control assembly changed to new unit which incorporates low idle dump. Engine found to be cycling at high idle condition. Control "borrowed" from coach 3321 (Engine T12) to correct problem. Hi/Lo idle switch wiring corrected.
7 April	Coach S/N 3318 released by DDA and available for service after completion of all final engine and transmission adjustments, settings, and updates. Coach 3318--1018 mi (1638 km) and 27 hr.
7 April	Available for service.
9 April	Road call issued. Driver complained engine stalling out momentarily on occasions. Driver training problem; engine not stopping. Output stalls momentarily on rapid stop due to slow decoupling of transmission lockup clutch--requested transmission service to adjust lockup clutch to release sooner. Coach continued in service on 10 April.
13 April	Held out of service for transmission adjustment of lockup clutch--released back to service same day.
14-23 April	Available for service.
23 April - 1 May	Down for engine problem. Would not start. Replaced L.H. regenerator seals and ceramic disk--inboard hot seal had worn excessively and damaged ceramic disk. Coach 3318--1834 mi (2952 km) and 102 hr.
1-4 May	Available for service.

Date	Activity
1981	
4 May	Down for air system leak--not substantiated; ran driver training in PM.
5-6 May	Available for service.
6 May	Down for low oil pressure due to oil pump drive gear slipping on shaft. Engine removed from coach and rear gear case removed. Replaced driving gear and shaft and oil pump with mating driven gear. (Positive lock type with Woodruff key.) Updated clutch assembly installed. Coach 3318--2409 mi (3877 km) and 136 hr.
20 May	Down for Freon leak in A/C line.
21-26 May	Available for service.
26 May	Down for brake grab and throttle pedal linkage spring failure.
1 June	Available for service.
1-3 June	Available for service.
3 June	Out-of-service for transmission control adjustments.
4-8 June	In-service road call 6/4/81 for hot transmission oil light, A/T oil cooler fan stopped. Found loose connection in wire from thermo-switch.
8-11 June	Down for no A/C; also 2-speed throttle spring failed. Replaced spring--A/C condenser mounting brackets failed permitting condenser to shift and be damaged. Removed condenser for repair. Made new brackets and remounted.
11-12 June	Available for service.
12-15 June	Down for no vehicle marker lights and water from A/C condenser dripping on rear seat passengers--drain plugged.
15-16 June	Available for service.
16 June	Road call--engine shut down and would not start. Severe ceramic regenerator disk damage, both right and left hand, hot side. Coach 3318--4411 mi (7099 km) and 251 hr.
17 June	Parked awaiting decision on whether to repair or replace engine.

Date	Activity
1981	
2 July	Parked--program suspended.
19 August	Coach 3318 shipped from MTA, Baltimore, to Mid-West Rebuilders, Owasso, MI, for diesel engine retrofit.

Engine T11: Installed miles--8812 mi (14,181 km)
Installed hours--409
Total engine hours--432

ENGINE S/N T12

Date	Activity
1979	
6 July	Initial build instructions issued; engine assembled with metal regenerator disks.
29 August	Acceptance testing completed. Power plant package assembled with V730CT transmission S/N 11561.
31 August	Package shipped to Modern Engineering, Troy, MI.
13 September	Package returned to examine position of the alternator drive gear--gear corrected.
17 September	Package reshipped to Modern Engineering (spare--not assigned).
12 November	Updated T1 sensor (spare engine).
1980	
7 February	Fuel valve assembly returned to DDA for update.
27 February	Starter reworked for improved mechanical contacts and updated fuel valve installed.
6 March	Updated dipstick and transmission mounting bolts installed.
7 March	Engine T12/transmission S/N 11561 shipped to Baltimore (MTA garage) for turbine training school activities.
24 July	Engine T12 returned to DDA for bump-stop campaign and upgrade from metal to ceramic regenerator system.
30 July	Performance test check run.

Date	Activity
1980	
31 July	Power package reassembled.
4 August	Engine T12/transmission S/N 11561 package shipped to Modern Engineering--coach not assigned.
13 October	Power package returned to DDA from Modern Engineering for compressor impeller update.
15 October	Package shipped to TRC to replace engine T15, which was removed from coach 3321 following failure of power turbine labyrinth seal on 10/2/81. Coach 3321--3666 mi (5900 km) and 79.6 hr.
22 October	Engine T12 fired up following installation in coach 3321 at TRC. Hunting start and erratic T4--updated 2-speed idle electronic control and modified fuel valve installed.
28 October	Engine shutdown after starter drop-out on overtemperature; changed four T4 thermocouples--start okay; however, high idle unstable; old type electronic control installed. Heater and air conditioning system modifications and test prior to service release.
3-4 December	Cold weather engine lube oil dump system installed.
8-10 December	Coach 3321 moved to Cleveland via Detroit following systems update (heat and A/C rewiring).
11 December	Coach 3321 delivered to MTA, Baltimore; heater system failed en route.
1981	
9-27 January	Coach 3321 heater system repaired. Engine turbine plenum change required.
23 March	Gasifier module replaced with updated module from T10 (turbine inlet plenum with floating ring design). Coach 3321--4584 mi (7377 km) and 116 hr.
25 March	Coach 3321 released by DDA and available for service after completion of all final engine and transmission adjustments, settings, and updates. Coach 3321--4734 mi (7619 km) and 130 hr.
26 March	Down, no A/C--R.H. ventilating blowers blown. Replaced blowers--released to service.
27 March	Down, no heat--water leak. Fixed and released to service.

Date	Activity
1981	
30 March - 1 April	Available for service.
1-9 April	Down, no A/C--R.H. ventilating blowers blown again. Replaced blower, which blew again. Found blowers wired wrong, corrected wiring and blowers worked okay.
9 April	Changed engine fuel valve and electronic control to updated components and released to service.
10-15 April	Available for service.
16 April	Road failure in afternoon appeared to be an intermittent shutdown problem--no corrective action; could not substantiate problem.
21-24 April	Down on road failure on first trip--power transfer clutch not operating. Changed clutch valve. No change--ECA change corrected problem. Released to service. Coach 3321--6543 mi (10,530 km) and 225 hr.
24-29 April	Available for service.
29 April - 1 May	Down--Freon line in A/C system failed; Freon line leak.
4 May	Driver training in AM. Completed 125 hr burner inspection in PM.
5-13 May	Available for service.
13-22 May	Down for failure to start. L.H. regenerator seal failed due to excessive carbon wear. Replaced seal and disk. Coach 3321--7122 mi (11,462 km) and 290 hr.
22-29 May	Available for service.
29 May - 3 June	Down for A/C--added Freon.
3 June	Available for service.
4-9 June	Down for A/C--added Freon.
9-11 June	Available for service.
11 June	Down for A/C--added Freon.

Date	Activity
1981	
12-16 June	Used in service without A/C.
16-19 June	Down for A/C--found Freon leak. Condenser brackets broken and condenser leaking. Also found major leak in suction line. Repaired condenser and remounted with new brackets and resoldered suction line.
19-23 June	Available for service.
23-25 June	Road call for high engine oil temp. Cooler fan stopped, 38 V alternator drive V-belt broken. Replaced and released to service after changing engine oil and oil filter.
25-30 June	Available for service.
30 June	Hot engine oil light warning--cooler fan not operating due to excessive brush wear.
2 July	Fan motor replaced and coach 3321 moved to the ready line. Coach parked--program suspended. Coach 3321--10,978 mi (17,667 km) and 462 hr.

Engine T12: Installed miles--7312 mi (11,767 km)
Installed hours--382
Total engine hours--421

ENGINE S/N T13

Date	Activity
1979	
7 August	Initial build instructions issued. Engine to be assembled with ceramic regenerator disks.
17 October	Engine completed acceptance test. Package buildup in process.
23 October	Engine T13/V730CT transmission S/N 11489 package shipped to Modern Engineering, Troy, MI. Engine scheduled for installation in MTA coach 3321.
1980	
7 February	Fuel metering valve changed and regenerator drive gear rivet integrity checked. New engine oil dipstick installed. (Fuel valve "borrowed" from engine T14.)

Date	Activity
1980	
27 February	Starter motor solenoid contacts updated.
15 April	Installation of T13 package in coach 3321 completed and initial static fireup.
17 April	Initial road test completed okay; heat and A/C systems completion and checkout required, as well as corrections to engine compartment cooling.
May/June	Coach 3321 update in process; separate transmission cooler, louvred rear service door, twin A/C condenser/fan setup, and seven-blade engine oil cooler fan. Engine change scheduled for bump-stop campaign on T13.
10 July	Engine T13 removed at Modern Engineering for return to DDA for bump-stop campaign. Engine to be replaced by engine T15/transmission S/N 11488. Coach 3321--75 mi (121 km) and 3.5 hr.
16 July	Bump-stop campaign at DDA--bump-stop changed.
18 July	Engine T13/V730CT transmission S/N 11489 shipped to Modern Engineering for installation in MTA coach 3320.
10 November	Initial static fireup in coach 3320 at Modern Engineering. Coach still on jacks, so road test not conducted.
1981	
10 February	Coach 3320 road test at Modern Engineering--all okay except transmission oil cooler fan switch failed.
12 February	Coach 3320 driven to DDA for compressor impeller and turbine inlet plenum change. Relay panel updated. Coach 3320--447.5 mi (720 km) and 20.1 hr.
2 March	Updated T13 checked out in coach 3320 at DDA. Updated fuel valve and electronic control installed. Fuel nozzle, 3-way solenoid, and T4 thermocouples replaced. Coach heating system failed.
4 March	Coach 3320 driven from DDA to TRC with no heat--fixed loose wire.
9 March	Coach 3320 driven from TRC to MTA, Baltimore. Repaired fuel nozzle main line due to cracked flare and leaking. Incorrectly installed heater system bleed line fixed--heater system performance improved.
12 March	Coach 3320 differential ratio changed to 5.857:1.

Date	Activity
1981	
24-26 March	Transmission S/N 11489 lockup spring change to improve lockup engagement--transmission adjusted and road tested.
27 March	Coach 3320 released by DDA after completing all final engine and transmission adjustments, setting, and updates. Coach installation--1231 mi (1981 km) and 44 hr.
30 March	Not available for service--MTA adding radio, fare box, etc.
31 March - 1 April	Down for A/C compressor seal failure.
2-6 April	Available for service.
6 April	Down for driver complaint of engine stalling out momentarily on occasions. Driver training problem--problem not substantiated. Did find low batteries--adjusted voltage regulator up 3 V.
7 April	In service.
8 April	Down for driver complaint of no A/C--not substantiated. Coach used for driver training.
9-21 April	Available for service.
21 April	Down for destination sign failure.
22 April	Road failure in service--engine shutdown due to flameout. Fuel valve minimum fuel flow adjusted 3 pph and released back to service.
23-27 April	Available for service.
27-29 April	Removed from service after morning rush hour run for check of rough transmission shifts--adjusted lockup clutch coupling engagement setting.
29 April - 1 May	Available for service
1-4 May	Available for service.
4-15 May	On static display at Baltimore, MD, Convention Center.
15 May	125-hr burner inspection performed. Updated electronic control and low oil pressure switch installed.

Date	Activity
1981	
16-25 May	Available for service. Had intermittent low battery problem during this period, which was found caused by bad voltage regulator.
25-31 May	Down for investigative inspection of right and left hand regenerator disks and seals to attempt determination as to why this regen hardware was causing no problem when regenerators on 3318 and 3321 had failed. Total regenerator hardware time--267 hr. Coach 3320--4044 mi (6508 km) and 241 hr.
1-2 June	Completed engine installation after investigative inspection of right and left hand ceramic regenerator disks and seals.
2-5 June	Available for service.
5 June	Down for 2-speed idle not working--spring failed, replaced spring and released coach for service in PM.
5-8 June	Available for service.
8 June	Down for 2-speed idle working intermittently--replaced idle relay and coach released in PM.
8-9 June	Available for service.
9 June	Coach rejected for vapors in passenger compartment--relocated G/B breather hose and coach released to service in PM.
9-12 June	Available for service.
12-13 June	Down for A/C condenser leaking--mounting brackets broken and condenser damaged. Removed and repaired condenser and replaced with new brackets. Also replaced 2-speed idle switch on transmission.
15-16 June	Available for service.
16 June	Road call for stopping; could not confirm on road test. Adjusted min fuel flow and released.
17-25 June	Available for service.
25 June	Down for repair of destination sign.
26-30 June	Available for service.
30 June	Road failure--lost power steering function.

Date	Activity
1981	
1 July	Power steering line chafed through due to improper installation. Line replaced and coach returned to service at noon.
2 July	Coach 3320 in revenue service. Coach parked in PM due to program suspension. Coach 3320--7125 mi (11,466.5 km) and 406 hr.

Engine T13: Installed miles--7200 (11,587 km)
Installed hours--410
Total engine hours--465

ENGINE S/N T14

Date	Activity
1979	
21 August	Initial build instructions issued; to be configured with ceramic regenerator disks.
14 November	Engine T14 completed acceptance test. A crack in the rear gearbox casting required replacement and retest.
29 November	Retest completed. Additional performance map and noise tests scheduled per NASA request.
12 December	Engine testing completed. Power package assembled with V730CT transmission S/N 11564.
14 December	Power package shipped to Modern Engineering. Power plant scheduled for installation in MTA coach 3320 (third coach for conversion).
1980	
18 January	Fuel valve plumbing updated; also regenerator ring gear rivets inspected and repaired.
2 February	Fuel valve assembly removed for use on engine T13.
27 February	Starter solenoid contacts upgraded. Fuel valve, previously removed on 2 February, was replaced.
16 June	Engine T14 package returned to DDA from Modern Engineering for bump-stop inspection campaign.

Date	Activity
1980	
2 July	Bump-stop pins found to be undersize and bump-stop assembly was replaced. Gearbox ball bearings changed.
3 July	Package T14/transmission S/N 11564 shipped to TRC for use in coach 3319 to replace engine T11, which was removed for bump-stop campaign.
16 July	Coach 3319 brakes overhauled at TRC.
18-23 July	Installation completed in coach 3319 [coach 3319--4401 mi (7097 km) and 158.3 hr]. Road test was satisfactory. Standard ECA removed and new unit with varible "idle dump" installed, for coach transit cycle endurance testing.
26 August	Fuel valve replaced--number of overtemperature shutdowns during start as well as erratic T4 on starts.
25 September	Fuel valve replaced due flameouts during deceleration. Minimum flow setting increased 3 pph.
1 November	Engine T14 removed from coach 3319 due to damage to left-hand regenerator disk caused by a loose T6 cavity insulation liner--engine returned to DDA for repair. Coach 3319--9109 mi (14,659 km) and 352 hr.
13 November	Teardown and inspection for liner failure commenced. The following additional updates were incorporated: o improved compressor impeller o turbine inlet duct with floating ring o gasifier support outer shield with welded tablocks (The left-hand disk and both inboard regenerator seals were replaced.)
24 November	Engine T14 test completed. Unit shipped to Transportation Research Center (TRC) for reinstallation in coach 3319.
3 December	Electronic control adjusted to T14 settings.
10 December	Transmission S/N 11564 lockup clutch chattered on engagement following incorporation of the two-speed idle system. Coupling teardown showed overheated clutch plates which were replaced at TRC.
18 December	Engine T14/transmission S/N 11564 reinstalled in coach 3319 at TRC. Cold-start dump valve system installed. Road test was satisfactory. Transmission lockup shift point adjusted to 1200 rpm for smooth engagement.

Date	Activity
1981	
5 January	Heater system (WEBASTO) failed.
15 January	Heater system repaired following receipt of parts. Transmission clutch coupling will not lock up, considered to be the result of attempting to move coach 3319 with frozen brake system. Power plant removed and transmission S/N 11564 replaced by S/N 11561.
30 January	Heater system failure--WEBASTO burner section burned up, requiring replacement.
3 February	Transmission coupling stalling out in high idle. Controls swapped with the removed unit and operation returned to normal.
18 February	Coach 3319 experienced a number of flameout shutdowns during start. Burner assembly removed and showed extensive damage in the area of the dilution holes. Problem considered to be the result of salt/gravel ingestion during extended endurance testing at TRC. Coach 3319--13,226 mi (21,285 km) and 526 hr.
16 March	Coach 3319 towed from TRC to Modern Engineering for update to latest standards on coach wiring and heat/A/C systems.
1 April	Gasifier module removed from engine T14 at Modern Engineering for return to DDA for investigation following burner failure 2/18/81.
6 April	Gasifier module teardown completed at DDA. Gasifier rotor replaced due to heavy trailing edge tip erosion. Turbine inlet duct cracked--reworked unit installed, which incorporates floating ring design.
16 April	Gasifier module returned to Modern Engineering for reinstallation in engine T14.
24 April	Left-hand regenerator assembly removed for gas path examination. Gasifier module installed. Engine T14 statically fired and found to be normal.
1 May	Coach 3319 road tested. Two-speed idle system wiring corrected.
5 May	Coach 3319 delivered to MTA, Baltimore, from Modern Engineering. Coach to be prepared for revenue service.
11 May	Coach 3319 road test and adjustments.

Date	Activity
1981	
13 May	Coach 3319 released to service. Coach--13,924 mi (22,408 km) and 540 hr.
13-21 May	Available for service.
21 May	Down for transmission failure. Will not shift out of first gear. Coach 3319--15,295 mi (24,615 km) and 595 hr. Transmission S/N 11561--4745 mi (7636 km) and 189 hr.
21-31 May	Down for transmission change. Package removed. Transmission S/N 11561 removed and sent to DDA distributor for repair (Johnson & Towers, Inc.) Lockup clutch failed--considered to be result of high lockup point, and low oil level caused overheating. Transmission S/N 11121 installed. Failed unit repaired and returned to MTA as a spare.
1-3 June	Completed transmission control adjustments after installation of new transmission (lockup valve body changed to lower lockup to 1000/1200 rpm).
4-12 June	Available for service.
12 June	Down for no A/C and hot transmission oil. Reset A/C circuit breaker and cleaned oil cooler. Lost A/C compressor belt during road test and replaced.
13-16 June	Available for service.
16 June	Road call for flickering low oil pressure light--added oil and released.
17 June	Available for service.
18 June	Would not start--low batteries, had low charging rate. Replaced batteries and voltage regulator.
19-22 June	A/C condenser brackets broken--condenser shifted and was damaged. Removed, repaired, and replaced with new brackets. Engine burner removed for routine inspection. Coach 3319--17,054 mi (27,446 km) and 676 hr.
22-29 June	Available for service.
29 June	Engine won't start--damaged L.H. ceramic regenerator disk.
30 June	Vehicle parked awaiting L.H. disk from factory.

Date	Activity
1981	
2 July	MTA transit coach program suspended. Coach 3319--18,053 mi (29,053 km) and 721 hr.

Engine T14: Installed miles--13,652 mi (21,971 km)
Installed hours--563
Total engine hours--595

ENGINE S/N T15

Date	Activity
1979	
27 August	Build instructions issued--ceramic regenerator configuration.
1980	
9 April	Engine T15 completed acceptance test. Power package buildup with V730CT transmission S/N 11488.
11 April	Power package shipped to Modern Engineering for coach installation--MTA fifth coach not yet assigned to program.
16 June	Power package returned from Modern to DDA for engine bump-stop inspection campaign.
7 July	Bump-stop assembly changed. Engine rebuilt and package reassembled.
8 July	Package returned to Modern Engineering for installation of MTA coach 3321 to replace engine T13, which requires bump-stop campaign.
24 July	Package engine T15/transmission S/N 11488 installed in MTA coach 3321 at Modern Engineering (replaced T13/11489). Coach 3321--26 mi (42 km) and 3.5 hr.
15 August	Fuel valve changed at Modern Engineering. Overtemperature on start was corrected. Coach delivered by Modern Engineering to TRC; heat and air conditioning system failed.
22 August	Coach 3321 delivered to MTA, Baltimore, for paint work.

Date	Activity
1980	
9-10 September	Coach 3321 participated in Eastern Bus Maintenance Forum, Towson, MD. Engine T15 experiencing high T4 (turbine inlet) temperature and low power.
12 September	Engine T15 repaired at Baltimore. Left-hand regenerator disk and hot seal replaced due to carbon damage. Coach 3321--936 mi (1506 km) and 20 hr.
16 September	Coach driven from Baltimore to TRC. Heat and A/C system failure. Transmission oil cooler fan switch failed.
25 September	Coach 3321 heat and A/C systems repair. Updated fuel valve and electronic control installed for two-speed idle system. Coach 3321--1521 mi (2448 km) and 43 hr.
1 October	Engine T15 failed to start--electronic control asssembly changed (single-speed idle type). Coach 3321--2539 mi (4086 km) and 53 hr.
8 October	Coach 3321 lost power and power turbine found to be seized. Engine T15 removed for return to DDA and replaced by engine T12 at TRC. Coach 3321--3617 mi (5821 km) and 79.6 hr.
12 October	Engine T15 strip examination commenced at DDA. Power turbine front labyrinth seal fractured at hub.
1981	
11 February	Engine T15 retired from transit coach program; to be used for spare parts.

Engine T15: Installed miles--3591 mi (5779 km)
Installed hours--76
Total engine hours--150

SUMMARY OF MTA TRANSIT COACH/ENGINE MILES (KM) AND HOURS

404-4 engine S/N	Installed miles (km)	Installed hours	Total hours
T10	0	0	108
T11	8,812 (14,181)	409	432
T12	7,312 (11,767)	382	421
T13	7,200 (11,587)	410	465
T14	13,652 (21,971)	563	595
T15	3,591 (5,779)	76	150
Total 5	40,567 (65,285)	1,840	2,171

MTA RTS coach S/N	Service miles (km)	Service hours	Total miles (km)	Total hours
3318	3,393 (5,460)	224	4,411 (7,099)	251
3319	4,129 (6,645)	178	18,053 (29,053)	721
3320	5,894 (9,485)	362	7,125 (11,466)	406
3321	6,244 (10,049)	332	10,978 (17,667)	462
Total 4	19,660 (31,639)	1096	40,567 (65,285)	1,840

TRANSMISSION S/N 11121

Date	Activity
1979	
7 August	Power package shipped to Modern Engineering for configuration engineering and installation in MTA coach S/N 3319.
12 November	Initial static startup in coach 3319.
10-14 December	Initial road test completed.
1980	
16 January	Acceptance test completed.
25 January	Final coach modifications continued at Modern Engineering.
12 March	Coach driven to Baltimore Mass Transit Administration (BMTA) for paint and decals. Complaint of lockup clutch chatter received.
31 March	Coach driven from BMTA to Modern Engineering. Occasional 1-2 and 2-3 and lockup shift chatter noted. Cooler capacity was marginal. Cooler out temperature was 224°F, cooler in 237°F, with 52°F ambient.

Date	Activity
1980	
1 April	Lockup engagement adjusted and revised trimmer springs incorporated. Leaking air bleed valve on transmission supply pump repaired.
7-10 April	Coach 3319 at CCM Demonstration, Dearborn, MI.
18-25 April	Transmission oil cooler relocated to bay forward of rear exit door for improved cooling.
26 April	Coach driven to MTA, Baltimore.
2 May	Coach utilized for dedication ceremonies at Baltimore.
5 May	Lockup override valve modification incorporated. Lockup shift point adjusted for 900-1050 rpm engagement. Vehicle driven to Modern Engineering for correction of deficiencies.
20 May	Instrumented road test indicated inadequate engine cooling capacity. Additional modifications in process.
26 June	Coach driven to Ohio Transportation Research Center (TRC).
30 June - 3 July	Driver training at TRC
10 July	Power pack removed at TRC for engine inspection at DDA. Unit replaced by S/N 11564 in coach No. 3319.
13 July	Unit at DDA Plant 8--awaiting teardown authorization.
17 September	Unit shipped to Plant 3 for inspection.
11 October	Unit disassembled for inspection. No distress found. Awaiting disposition instructions.
1981	
March	Controls used on transmission S/N 11122, coach 3318. Transmission to be reassembled as a spare unit.
April	Transmission rebuilt--awaiting functional test.
22 May	Unit shipped to MTA, Baltimore, to replace failed unit S/N 11561 in coach 3319; would not shift out of first range on 5/21/81.
27 May	All functions during road test in coach No. 3319 normal except lockup engaged at 1200-1500 rpm and was sluggish in disengaging.

Date	Activity
1981	
28 May	Investigated lockup malfunction; polished lockup control valve and incorporated orifice enlargement modification to separator plate.
1 June	Replaced lockup valve body assembly.
2 June	Adjusted lockup engagement point to 1000 rpm and eliminated sluggish disengagement.
3 June	Test instrumentation removed and coach 3319 released to service.
29 June	Coach 3319 out of service--engine regenerator problem.
2 July	MTA transit coach program suspended.

TRANSMISSION S/N 11122

Date	Activity
1980	
12 February	Power package shipped to Modern Engineering as a spare unit.
1 July	Power plant returned to DDA for engine campaign.
9 July	Power plant shipped to Modern Engineering; tentatively scheduled for installation in MTA coach S/N 3318.
1981	
23 January	Engine T10 removed and T11 installed for use in coach 3318.
4 March	Installation completed and initial road test conducted.
11 March	Coach 3318 final road test completed.
17-19 March	Coach delivered to MTA, Baltimore, via TRC.
20 March	Investigated high lockup engagement speed at 1600 rpm and sluggish lockup clutch disengagement. Coach being prepared for revenue service.
2 April	Replaced CDP valve and lockup valve body and adjusted lock-up calibration.
7 April	Coach 3318 released to revenue service.

Date	Activity
1981	
13 April	Investigated sluggish lockup clutch disengagement. Adjusted lockup clutch, and coach returned to service.
23 April - 1 May	Coach out of service due to engine regenerator replacement. Road tested and returned to service.
6-20 May	Coach out of service--loss of engine oil pressure. Power plant removed--engine repaired, reinstalled, tested, and returned to service.
3 June	Coach road tested to evaluate performance. All functions normal except lockup engaged at 1200-2400 rpm. Unit was 1 gal overfull.
4 June	Investigated overheated transmission complaint during revenue service. Unit was 1/2 gal overfull. Cooler fan was inoperative.
8 June	Cooler fan electrical control switch connector found disconnected. Unit performed acceptably after correction.
8-11 June	Coach 3318 out of service for coach problems (air conditioning condenser and throttle pedal mechanism).
16 June	Engine failure in service--regenerator damage, parked awaiting repair decision.
2 July	MTA transit coach program suspended.

TRANSMISSION S/N 11488

Date	Activity
1980	
11 April	Power package shipped to Modern Engineering--not assigned. Fifth coach not scheduled from MTA, Baltimore.
16 June - 8 July	Power package returned to DDA for engine campaign (bump-stop inspection). Package reassembled and shipped to Modern Engineering for use in coach 3321, which requires campaign action.
24 July	Installation in coach 3321 completed and coach road tested. Coach system rework required to heat and A/C system.
15 August	Coach 3321 delivered to TRC for checkout.

Date	Activity
1980	
22 August	Coach driven to Baltimore Mass Transit Administration for painting and decals.
29 August	Painting and detailing continued.
2 September	Transmission operation normal during road test. Transmission cooler fan sending unit required replacement.
9 September	Coach displayed for Transit Coach Maintenance Forum.
11-15 September	Power package removed for regenerator repair. Transmission separator plate EX118882 installed to change 1-2 shift from modulated to fixed shift point.
16 September	Coach 3321 delivered to TRC from Baltimore for acceptance test. Transmission oil cooler thermal switch failed--switch replaced.
17-30 September	Coach system updates and test at TRC.
1-22 October	Engine failed to start--power turbine found seized. Power package removed and engine replaced.
23-28 October	Engine controls problems--components replaced and coach systems update and test continued.
8-10 December	Coach moved to NASA Lewis, Cleveland, for demonstration.
11 December	Coach 3321 delivered to MTA, Baltimore, for axle change, brake overhaul, and coach systems update.
1981	
19 March	Coach function tested--2 gal of oil drained from transmission to correct sump level.
23-24 March	Engine updated and road test normal.
25 March	Coach 3321 released to revenue service.
26 March	Available for service.
27 March	Heater system repaired.
30-31 March	Available for service.
1-9 April	Coach heat and A/C system repaired--engine controls updated and coach returned to service.

Date	Activity
1981	
21-24 April	Out of service to correct engine control problem.
29 April - 1 May	Coach out of service for air conditioning repair.
13-22 May	Coach 3321 out of service to repair engine regenerator.
29 May - 2 June	Air conditioning repair.
3-4 June	Coach road tested to evaluate transmission operation; all normal except lockup engaged at 1600-2300 input rpm. Adjusted down to 1200-1300 rpm engagement and coach released to service.
4-9 June	Air conditioning rework.
11 June	Out of service--air conditioning.
12-15 June	In service without A/C.
16-18 June	A/C system repaired.
24 June	Coach 3321 out of service for alternator drive belt failure.
30 June - 2 July	Out of service. Engine oil cooler fan motor repaired. Coach released but parked due to transit coach program suspension.

TRANSMISSION S/N 11489

Date	Activity
1979	
23 October	Power package shipped to Modern Engineering; scheduled for installation in MTA coach S/N 3321.
1980	
14 April	Installation completed and engine static fireup.
17 April	Initial coach road test completed. Additional coach system updates required.
10 July	Power plant removed for engine return to DDA for campaign. Transmission S/N 11489 replaced by S/N 11488.

Date	Activity
1980	
18 July	Power package with transmission S/N 11489 returned to Modern Engineering for installation in coach S/N 3320.
15 August	Power package installed in coach 3320.
9 October	Transmission separator plate, P/N EX118882, installed to change 1-2 shift from modulated to fixed shift point.
10 November	Initial static fireup in coach 3320.
1981	
10 February	Initial road test satisfactory, except transmission oil cooler fan control thermal switch failed, requiring replacement.
12 February	Coach driven to DDA for engine update.
4 March	Coach driven to Ohio Transportation Research Center (TRC) for acceptance testing.
13 March	Coach driven to Baltimore Mass Transit Administration (BMTA) for revenue service preparations.
25 March	Coach road tested at BMTA. All functions were normal.
26 March	Incorporated revised lockup control valve spring. Adjusted lockup engagement to 1100 rpm. Cooler line leakage repaired.
27 March	Coach 3320 released to revenue service.
27 April	Harsh downshift complaints were investigated. Downshift characteristics were good but lockup engaged at 2000 rpm.
28 April	Installed lockup control valve spring. Incorporated enlarged separator plate orifice.
29 April	Lockup engagement point adjusted. Coach released for revenue service.
25 May	Coach removed from service for engine inspection.
2 June	Coach road tested after engine inspection. Transmission functioned normally, lockup engaged at 1100-1400 rpm. Coach released for revenue service.
4 June	Investigated overheated transmission complaint. No trouble was found during inspection. Coach released for revenue service after road test.

Date	Activity
1981	
30 June	Investigated overheated transmission complaint. Source of complaint could not be isolated. Coach road tested. Power steering leak; line replaced.
1 July	Coach released to service.
2 July	Coach parked due to MTA transit program suspension.

TRANSMISSION S/N 11561

Date	Activity
1979	
31 August	Power package shipped to Modern Engineering.
13 September	Package returned to DDA for engine gear inspection.
17 September	Package returned to Modern Engineering as a spare unit.
1980	
6 March	Longer transmission mounting bolts installed.
7 March	Package shipped from Modern Engineering to MTA, Baltimore, for training school activities.
24 July	Package returned to DDA for engine campaign.
4 August	Package shipped to Modern Engineering as unassigned unit.
13 October	Package returned to DDA for engine update. Transmission S/N 11561 held at Plant 8 as a spare.
1981	
30 January	Unit installed in coach 3319 at TRC to replace unit S/N 11564, which failed coupling lockup when vehicle attempted to move with frozen brakes.
4 February	Transmission coupling stalling out in high idle. Valve body and CDP activator removed from S/N 11564 and installed into S/N 11561. Lockup function was normal.
6 February	Coach 3319 returned to endurance testing at TRC.
18 February	Endurance testing terminated due to engine combustor failure (salt ingestion).

Date	Activity
1981	
16 March	Coach 3319 towed from TRC to Modern Engineering.
1-16 April	Engine gasifier module returned to DDA for inspection and repair.
24 April	Engine statically fired for checkout.
1 May	Road test completed.
5 May	Coach 3319 delivered to MTA, Baltimore, to be prepared for revenue service.
11 May	Coach road tested and adjustments made.
13 May	Coach 3319 released to revenue service.
19 May	Coach road tested to evaluate transmission operation. All functions normal except lockup engaged at 1800 rpm. Lockup adjustment deferred due to lack of available lift facilities. Coach released for revenue service.
20 May	Coach experienced loss of transmission downshift during Baltimore to Annapolis revenue service.
21 May	Investigated lost downshift functions. Transmission oil heavily oxidized and oil level 2 gal low. Unit removed and replaced by S/N 11121.
12 June	Unit sent to Baltimore area DDA distributor for teardown inspection.
15 June	Unit disassembled for analysis. Lockup clutch plates burned. Output governor seized due to contaminated oil.
16 June	Unit reassembled and returned to MTA as spare unit.
2 July	MTA transit coach program suspended.

TRANSMISSION S/N 11564

Date	Activity
1979	
14 December	Power package shipped to Modern Engineering scheduled for installation in Baltimore MTA coach 3320.

Date	Activity
1980	
16 June	Power package returned to DDA for engine campaign (bump stop).
3 July	Power package shipped to TRC for installation in MTA coach 3319, which requires engine campaign action.
18 July	Coach road tested after installation. Installed transmission separator plate P/N EX118882 to change 1-2 shift from modulated to fixed point control to improve dynamic braking.
24 July	Fuel consumption testing was conducted.
1 August	Performance testing conducted with 5.857:1 axle ratio.
22 August	Lockup clutch adjusted from 1150 rpm engagement to 900 rpm to improve engine braking.
24 August	Endurance testing resumed.
1 November	Power package removed for repair of engine at DDA--regenerator damage.
24 November	Engine repaired and returned to TRC.
7 December	Power plant reinstallation completed.
10 December	Transmission S/N 11564 lockup clutch chattered on engagement following incorporation of two-speed idle system, power package removed. Coupling teardown showed overheated clutch plates, which were replaced at TRC.
18 December	Power plant reinstalled in coach 3319 at TRC. Cold start dump valve system installed. Road test was satisfactory. Transmission lockup shift point adjusted to 1200 rpm for smooth engagement.
1981	
15 January	Transmission clutch coupling will not lock up; considered to be the result of attempting to move coach 3319 with frozen brake system. Power plant removed and transmission S/N 11564 replaced by S/N 11561.
4 February	Valve body and CDP actuator removed from S/N 11564 for installation in S/N 11561. Transmission S/N 11564 returned to DDA.
27 February	Unit at DDA awaiting disposition.
2 July	MTA Transit Coach program suspended.