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Dept. of Energy/Dept. of Transportation Gas Turbine Transit Bus Demonstration Program

Program Plan
April 1978

Prepared For
U.S. Department of Energy
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Conservation and Solar Applications
Division of Transportation Energy Conservation
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ABSTRACT

This document is the program plan for a cooperative project of the Urban Mass Transportation Administration (UMTA) of the Department of Transportation and the Division of Transportation Energy Conservation (TEC) of the Department of Energy to test and evaluate the use of gas turbine engines in transit buses. UMTA is responsible for furnishing buses from UMTA grantees, technical direction for bus/engine integration, and coordination of operational use of buses in selected cities. TEC is responsible for providing gas turbines, data acquisition/reduction services, and management for the complete project.

The project will be carried out in three phases. In Phase I, prototype turbine engines will be used. One turbine-powered bus and diesel-powered bus will be tested at a test facility to obtain baseline data. Five turbine-powered buses will be evaluated in revenue service in one city. In Phase II, preproduction turbine engines will be used. One turbine-powered bus and diesel-powered bus will be baseline tested and ten turbine-powered buses will be evaluated in two cities. In Phase III, production gas turbine engines will be used. Only the turbine-powered bus will run baseline tests in this phase. Ten turbine-powered buses will be evaluated in two cities.

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1.0 INTRODUCTION

1.0 INTRODUCTION

This document is the "Program Plan" for a comprehensive project to demonstrate and evaluate the operation of gas turbine engines in transit buses in revenue service. The program is being conducted through the cooperative efforts of agencies of the Federal Government, local governments, and industry. It is directed toward implementing national environmental and energy goals.

The program was initiated by the U.S. Department of Energy (DOE) to accelerate commercialization of automotive gas turbines, and is the result of over five years of development experience with gas turbine engines.

DOE's interest in this program stems primarily from an increasing concern over the transportation sector's impact on issues of national concern, such as:

- Environmental pollution
- Energy conservation
- Natural resource depletion
- Dependence on foreign sources for petroleum fuel
- U.S. balance of payments to foreign petroleum fuel sources.

The transportation sector consumes about 25 percent of the total energy in the United States and well over 50 percent of its petroleum energy. Trucks and buses alone consume approximately 30 percent of the nation's highway transportation fuel. Imported petroleum, which was only 3.4 million barrels per day in 1970, increased to 6.0 million barrels per day in 1975 and by 1985, if left unchecked, could conceivably reach 12 to 15 million barrels per day at a projected cost to the American public of $57 to $71 billion annually.

Introduction into the transportation sector of an advanced propulsion system with potential advantages of improved fuel economy, alternate fuel capabilities, reduced exhaust emissions, and lower noise and vibration will have a direct beneficial impact on national issues. The turbine-powered transit bus operational experience gained from this program can provide an important technical base for determining the viability of the gas turbine engine as an alternate highway transportation powerplant.

The program is being sponsored jointly by the U.S. Department of Energy (DOE) and the U.S. Department of Transportation (DOT). The Urban Mass Transportation Administration (UMTA) is directing DOT's participation in the program.

UMTA's interest in this program stems primarily from the belief that mass transportation is part of the solution to the increasingly urgent urban problems of congestion, pollution, and energy conservation. In order to compete with the private automobile, mass trnasit must be more convenient, reliable, comfortable, safe, economical, and environmentally acceptable.

The gas turbine engine offers to the transit industry potential advantages of reduced maintenance requirements and improved fuel economy. The resultant lower life cycle cost make the turbine an attractive alternative power source. In addition, it offers improved overall reliability, cleaner exhaust emissions, greater engine braking capability, and virtually vibration-free operation.

The sections that follow in this program plan define the:

- Program objectives—both primary and ancillary
- Program background—both DOE and DOT
- Technical approach—implementation of the three phases of the program
- Organization—program participants, their roles and responsibilities
- Schedules and milestones
- Financial—plans and documents that will be necessary to budget resource requirements
- Program control—plans and documents that will be necessary to implement and control the program.

2.0 PROGRAM OBJECTIVES

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The primary objective of the "Gas Turbine Transit Bus Demonstration Program" is to provide the transportation industry with a demonstration program producing performance and operational data on the gas turbine propulsion system under actual service conditions.

Specifically, the program is designed to evaluate the benefits of gas turbine powered buses used in revenue service, acquire operational data on gas turbine powered buses that may be applicable to other automotive gas turbine engine programs, and provide a catalyst to advance highway vehicle gas turbine technology from the research and development stage to commercial operations.

The program will test the performance, driveability, reliability, and fuel economy of developed gas turbine power systems in actual bus operations, and provide a mechanism for collection and dissemination of information concerning gas turbine engine engineering and operational experience to industry and the public.

3.0 BACKGROUND

3.0 BACKGROUND

3.1 GENERAL

For over a decade the Federal Government has been actively engaged in efforts to develop and accelerate improvements in transportation vehicle propulsion systems. The main thrust of these efforts has been directed toward reducing exhaust emission pollutants, and in the past three years toward reducing energy consumption. In addition to continuing activities focused on near-term efficiency improvements in presently available propulsion systems and operations, a major pursuit has been the development of advanced propulsuion systems for intermediate and long-term improvements.

One of the most promising advanced propulsion systems is the gas turbine engine. The gas turbine not only offers potential for reductions in noxious emissions and fuel consumption, but also could provide operators with improvements in performance and vehicle maintenance cost.

Development of the gas turbine engine as a potential power source for automotive vehicles began in the early 1950's. In 1976 only three manufacturers in the United States—Chrysler Corporation, Detroit Diesel Allison Division (DDAD) of General Motors Corporation, and Industrial Turbines International (ITI), a consortium—were actively engaged in the development of small (150 HP to 650 HP) gas turbines that could realistically be considered engines for application to automobiles, trucks, and buses. The reported engine status of these small turbine engine developers are listed in Figure 3-1.

The Chrysler engine evolved as a passenger car engine. In 1962 this engine was extensively field-tested in 50 prototype automobiles. The development of this engine is continuing, with U.S. Government financial aid, in areas that can best be described as "advanced technology."

The ITI consortium engine is in the 450 HP to 600 HP range and is being designed as an eventual replacement for truck diesel engines. It is in the initial, unproven stages of development and prototype engines will not be available

FIGURE 3-1
Activities Involved in Developing
Improved Gas Turbine Engines

Chrysler Corporation	ERDA Baseline Engine (150 HP) and Upgraded Engine (123 HP) under active development, 2-shaft regenerative
Detroit Diesel Allison	300 HP, 400 HP and 500 HP, 2-shaft regenerative engine under active development for bus, truck, industrial application
Industrial Turbine International (Air Research/Mack/KHD)	Comprehensive program for truck and industrial applications, 450-600 HP range

for 2 to 3 years. Production engines could not be available for several years after the prototypes.

The DDAD turbine engine has been designed as an alternative for the diesel engines manufactured by that firm, and gas turbine engines have currently developed to a state where volume production can be seriously considered.

In addition to research and development engines, nearly 100 DDAD gas turbines have been field-tested in trucks, transit coaches, intercity coaches, marine craft, and industrial electrical generator sets and air compressors. Since 1972 test engines in 24 trucks of ten different makes have operated in widely divergent service in all parts of the country. In addition, eight Greyhound intercity coaches powered by gas turbines have operated throughout the country. In the most recent of these applications, the turbine engine has demonstrated greatly improved reliability and fuel consumption rates compared with earlier turbines. In fact, the fuel consumption in the intercity coaches was nearly competitive with that of the diesel engine.

In the early 1970's, under the Urban Mass Transportation Administration (UMTA) Transbus program,* three DDAD gas turbine engines were installed in the Transbus prototype

* Booz, Allen & Hamilton Inc., Transbus Engineering Test Program, TR 77-003, December, 1977.

coaches manufactured by the Truck and Coach Division of General Motors. This engine was selected for testing in Transbus because of the gas turbine's apparent advantages and demonstrated potential in heavy trucks. During this program the turbine engine demonstrated its potential as a viable transit coach powerplant by exhibiting the following advantages over the conventional diesel engine in transit coach application:

- Reduction of installed weight and volume
- Elimination of cooling radiator, fan, and attendant piping
- Cleaner exhaust emissions
- Lower noise level
- Reduced or low vibration operation
- Reduced lubricating oil consumption
- Good reliability
- Improved vehicle performance for power rating
- Greater engine braking capability
- Superior cold weather starting.

However, fuel consumption demonstrated in the program was higher than contemporary diesel engines. The extended periods of idle and extensive part-load operations, both inherent to transit coach service, account for a measure of the high fuel consumption. However, improvements have been made since these coaches were evaluated and further improvements are scheduled for reducing brake specific fuel consumption (BSFC) in the transit coach duty cycle.

Because of the gas turbine's apparent advantages and demonstrated success in heavy trucks, an in-depth survey* of gas turbine engine manufacturers was conducted

* Booz, Allen & Hamilton Inc., Gas Turbine Engine Application in Transit Coaches, TR 77-001, March, 1977.

to determine the suitability of the turbine engine for transit coach application. The following sections trace the development of the only gas turbine engine found to be sufficiently developed to be considered for near-term volume production and subsequent application to transit coach service.

3.2 GAS TURBINE ENGINE DEVELOPMENT AT DDAD

For over 20 years DDAD (independently and with government assistance) has been energetically developing gas turbine engines to compete in many commercial applications with piston diesel engines. Specifically, they have concentrated on applications in large trucks and buses, although field evaluation has included construction equipment, marine equipment, and electrical power generation units. DDAD's goals were to develop a practical, cost-effective turbine engine to meet the requirements of large, heavy-duty ground vehicles. This program has resulted in a family of three engines covering the power range from 300 HP to 500 HP (SAE rating). The smallest of these engines is designated as the GT-404, and engines incorporating the latest design changes with improved performance are designated as the -4 series.

The GT-404 gas turbine, is a two-shaft, regenerative gas engine featuring a power transfer system. A rigid block assembly, constructed of cast iron, serves as the main structural support member for the engine. It houses, in a modular fashion, the burner, gasifier section, power section, regenerators, and the reduction and accessory drive gearing. The modular design, shown in Figure 3-2, allows easy service and unit replacement of the various sections. The engine controls are electronic and are remotely mounted from the engine block itself. The engine is available with a rated maximum output shaft speed of 2880 rpm.

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* Booz, Allen & Hamilton Inc., Gas Turbine Engine Application in Transit Coaches, TR 77-001, March, 1977.

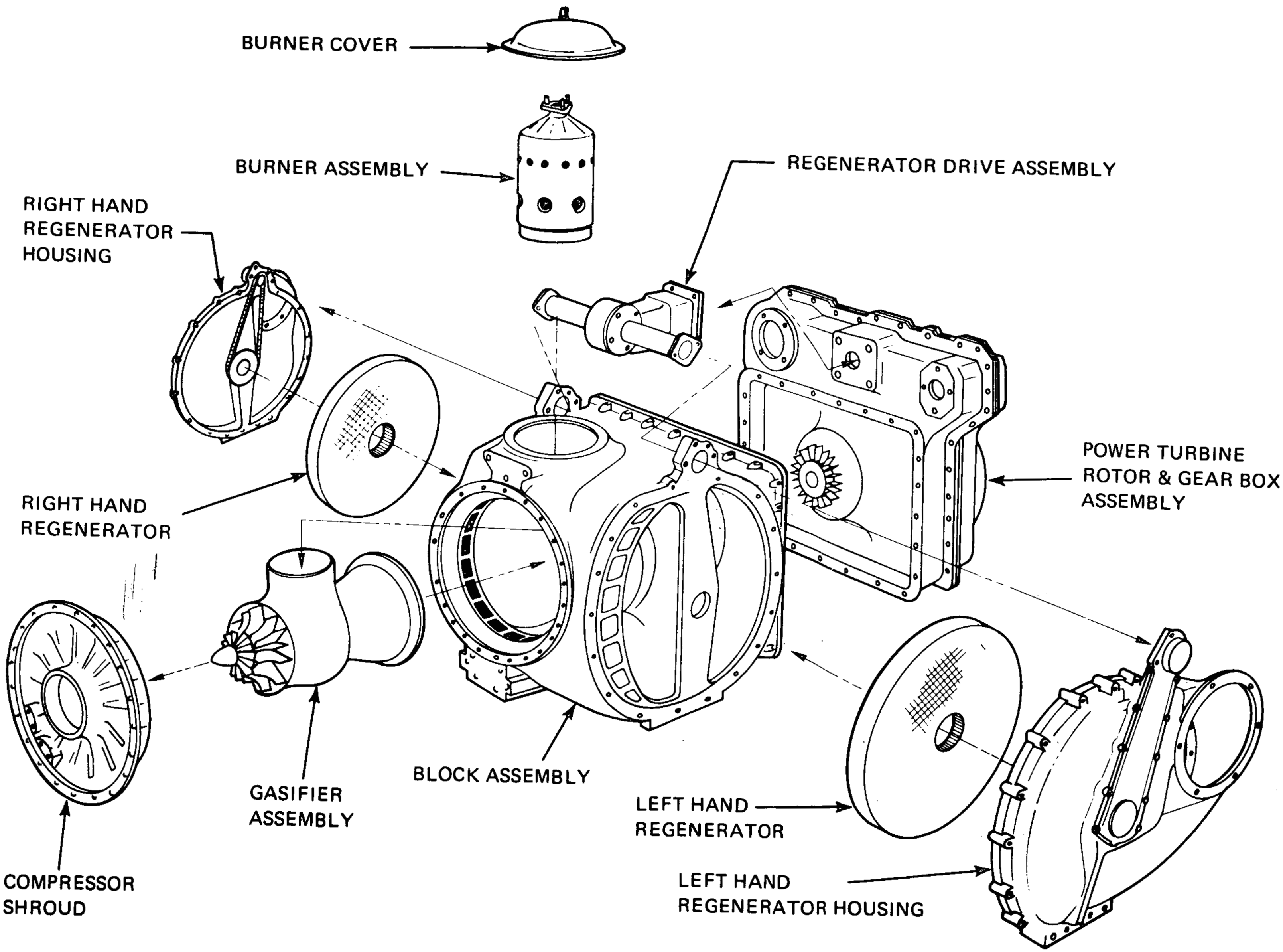
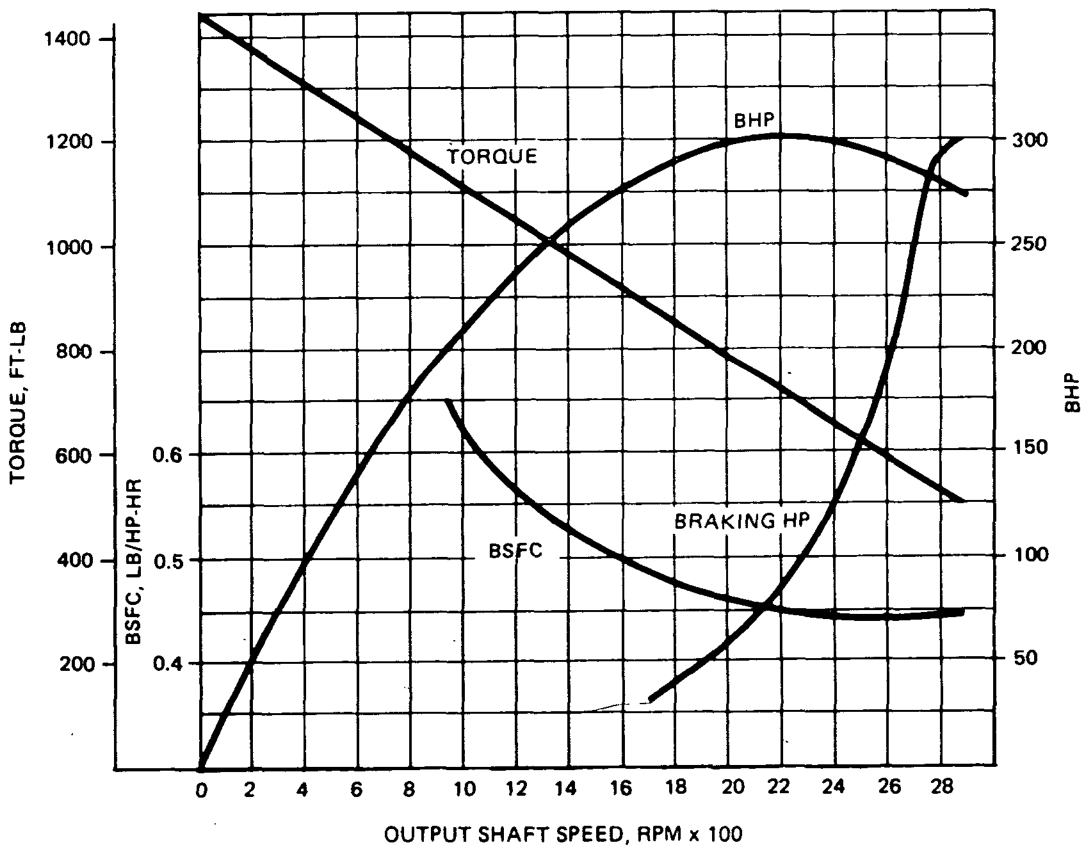


FIGURE 3-2
Modular Construction of GT-404
Gas Turbine Engine

The GT-404 engine's normal dry weight of 1750 pounds is approximately 650 pounds lighter than a comparable diesel engine, the DDAD 8V-71, and its basic size is very similar. On an average vehicle-installed basis, this weight savings advantage is about 1000 pounds, and the GT-404 can be installed in virtually any vehicle accommodating the 8V-71.

The performance capabilities of the now obsolete GT-404-3 engine are shown on the characteristic curve in Figure 3-3. The GT-404-4 will have similar performance but with improved fuel economy and durability. Maximum torque is produced at power turbine (output shaft) stall (0 rpm) condition. With the high torque rise characteristic, fewer number of transmission gear ranges are required—generally five or less in trucks, and four or less in buses. With an automatic transmission, a torque converter is not required and a fluid-coupling can be used. The dynamic braking capability of the engine is equal to the rated power at maximum output shaft speed and is effective in each transmission gear range.

FIGURE 3-3
Performance Capabilities of GT-404-3 Engine



The GT-404 engine consumes only about 1 quart of lubricating oil per 20,000 to 30,000 miles compared with about 1 quart per 800 miles for a diesel engine in transit coach service. In addition, the turbine engine oil requires changing every 250,000 miles compared with 9,000 miles for the transit coach diesel engine. This results in savings for the turbine engine.

The GT-404 engine emits less noise than a comparable diesel engine. Results of an exterior noise test on trucks, conducted to the SAE test standards, demonstrated that the noise level of the GT-404 engine is 11 dBA lower than a standard diesel powered truck. This 11 dBA lower reading represents nearly a three-fourths reduction in sound pressure over that of a diesel. Development effort is continuing toward a still further reduction of the noise level to meet future noise attenutation requirements.

Major pollution elements in transit coaches would be minimized with the GT-404 engine through highly efficient, low-pressure, continuous burning with large amounts of excess air resulting in almost 100 percent combustion. The odor is virtually undetectable, exhibiting only a slight kerosene odor at engine idle, and exhaust smoke is virtually undetectable.

The gas turbine's ability to start quickly at low temperature is superior to any conventional diesel powerplant. The GT-404 engine has demonstrated its ability to start, without aids, in temperatures well below 0°F. However, batteries must be reasonably well-charged and diesel fuel #1 must be used (diesel fuel #2 begins to solidify at about +20°F).

The GT-404 engine does not require a water-based cooling system because it is internally cooled by the excess air passing through the engine and by the lubricating oil which is cooled through a small oil-to-air heat exhanger. The elimination of a water-based cooling system greatly decreases engine maintenance and downtime, thereby reducing a major maintenance cost area in transit coaches.

The gas turbine engine, in general, requires less maintenance than a diesel engine because of fewer wearing parts and almost vibration-free operation. All moving elements in the basic turbine engine are rotary in motion, compared with reciprocating components in diesel engines. No water hoses or pipes, drive belts, or other elements that tend to be unreliable are used. Use of self-cleaning inertial air filters, absence of the liquid cooling system, absence of a manifold exhaust system, extended brake life, and expected extended life of components will contribute to reduced maintenance costs and will significantly increase vehicle availability.

The fuel system of the GT-404 engine can operate on a wide range of petroleum-based fuels including: diesel #1, diesel #2, furnace oil, JP fuels, kerosene, and gasoline. The diesel fuels are most commonly used because of their higher energy content and current ready availability. Gasoline is the least preferred fuel because the lead additive tends to deposit and foul the turbine, nozzles, and regenerators, thereby reducing engine performance. When synthetic or other fuels become available in quantity, the fuel handling and control system of the GT-404 can be modified to accommodate these fuels.

3.3 DDAD ENGINE FIELD TESTS

DDAD has manufactured approximately 100 GT series gas turbines for field evaluation in trucks, buses, boats, electrical power generation units, and other applications. These engines include the GT-404 and GT-505 in both the -2 and -3 configurations.

Pilot models of the engine began going into service in 1972 for extensive field evaluation. The engines have been tested in 24 trucks from ten manufacturers, eight motor coaches from MCI-Greyhound, coaches from GMC Truck and Coach Division, Transbus prototypes, various watercraft, and industrial applications.

Consignment engines were operational with Greyhound on the East Coast and West Coast, Binswanger Trucking in Los Angeles, Freightliner Corporation and Consolidated Freightways in Portland, Acadian Marine Rentals in New Orleans, Terminal Transport in Atlanta, Gardner-Denver in Quincy, Illinois, a Hatteras yacht operating in the waters of New Jersey, GMC Truck and Coach Division of General-Motors in Pontiac, Michigan, and Detroit Diesel Allison in its Indianapolis-based field-test vehicles.

The major effort at DDAD, in the development of the GT-404 engine, has been directed toward heavy-duty trucks. The field experience with turbine engines in transit coaches has been the Transbus prototypes, and several transit coach engineering models assembled by Truck and Coach Division of General Motors. The most extensive coach experience with turbine engines is in the Greyhound fleet. However, it must be recognized that the duty cycle and service requirements for intercity coaches, such as those operated by Greyhound, are substantially different from transit coaches.

The eight GT-404 turbine powered Greyhound coaches have logged well over one million miles since mid-1975 and several have been refitted with -3 engines. These particular -3 engines were capable of operating at 0.51 BSFC as compared with 0.54 BSFC of the -2 engines used in the Transbus prototypes. The last of the -3 engines with the latest burner improvements, and other developments, lowered the BSFC to 0.45. Even without the latest engine modifications, the fuel penalty sustained by Greyhound has averaged slightly over 1 mpg for the turbine engine compared with the diesel The Turbine engine also virtually eliminated engine overheating and other cooling system-related problems, which account for 50 percent of Greyhound's road failures with diesel engines. Brake life on the turbine powered Greyhound coaches was extended by more than 50 percent due to the engine's regenerative braking system. Elimination of engine vibration-induced cracks in refrigerant lines and fittings improved air conditioning system reliability in turbine powered coaches, and elimination of engine vibrations and reduction of the powerplant weight improved coach structural integrity. The largest number of engine problems Greyhond experienced with the turbine engines were with the various electrical controls.

3.4 DDAD ENGINE COST PROJECTIONS

Figure 3-4 shows projected costs of incorporating turbine engines in transit coaches. The established baseline 1973 bus fleet data is shown in the first column of the figure. The 1976 coaches, however, are different in some major respects from the "typical" coach of the 1973 transit fleet. In addition, fuel costs have increased at a rate far higher than "normal" inflation. (Other costs, such as labor, overhead, and repair parts have escalated at the same relative rate since 1973 and have been carried over in the cost projection.) The second column of the

FIGURE 3-4
Changes in Maintenance, Servicing, and Consumables Cost for Complete Replacement of Fleet

CATEGORIES	BASELINE BUS FLEET (1973) ¢/MILE	BUS AS BUILT IN 1976 (1976 DOLLARS)		MATURE TURBINE (GT404-4 PI) IN 1976 BUS (1976 DOLLARS)	
		¢/MILE	BASIS	¢/MILE	BASIS
REPAIRS TO REVENUE EQUIPMENT:					
– ACCIDENTS	1.39	1.72	SAME	1.72	SAME
– POWER PLANT	1.83	2.27	8V-71	1.22	REDUCED MAINTENANCE
– BODY AND DOORS	1.68	2.08	SAME	2.08	SAME
– SUSPENSION/CHASSIS/ REAR AXLE/DRIVE TRAIN	1.47	1.82	SAME	1.82	SAME
– BRAKES	1.13	1.79	FMVSS 121 SYSTEM	1.60	REGENERATIVE ENGINE BRAKING
– TRANSMISSION	.82	1.26	V-730 MORE COMPLEX	1.26	SAME
– ELECTRICAL, STARTER, GENERATOR	1.11	1.38	SAME	1.38	SAME
– AIR CONDITIONING	.64	.79	SAME	.99	A/C SAME, ELECTRIC OR OTHER HEATING SYSTEM WILL COST MORE
– FRONT AXLE/STEERING	.49	.69	POWER STEERING	.69	SAME
– AIR SYSTEM	.37	.51	INCREASED CAPACITY FOR FMVSS 121 BRAKE SYSTEM	.51	SAME
TOTAL FOR REPAIRS	10.93	14.31		13.27	
FUEL	3.60	8.86	HIGHER FUEL COST	9.82	INCREASED FUEL CONSUMPTION
OIL	.16	.20	SAME	.01	REDUCED OIL CONSUMPTION
TIRES	1.28	1.98	INCREASED PERFORMANCE	1.84	REDUCED VEHICLE WEIGHT
TOTAL COST	15.97	25.35		24.94	

SOURCE: BOOZ, ALLEN APPLIED RESEARCH: BASELINE BUS COSTS BASED ON 1973 APTA OPERATING COST DATA, A SURVEY OF 16 MAJOR PROPERTIES, AND ENGINEERING ESTIMATES, WHICH UTILIZE TEST DATA, COMPONENT MANUFACTURER'S DATA, AND JUDGEMENT BASED ON OBSERVATIONS OF VEHICLES AND DRAWINGS OF EQUIPMENT. 1973 COSTS UPDATED TO 1976 DOLLARS IN 2ND AND 3RD COLUMNS.

figure reflects the projected cost of operating a "typical" 1976 model transit coach. The third column of the figure reflects the projected cost of operating a "turbine-powered" 1976 production coach in the 1976 operating environment.

In making operating cost projections for new coaches and engines, the data sources available are:

- Booz, Allen experience with the coach system, or component, on prototype vehicles, if the system or component is new
- Transit industry experience, if the component is the same as on current buses
- Engineering judgment and supplier claims if the component is new to the industry.

3.5 DDAD PRODUCTION ENGINE COST IMPACTS

Production cost and selling price are not directly relatable. Selling price is a function of production cost plus market conditions, profit margin, and the time selected by the manufacturer over which tooling and production engineering costs are written off. It is, therefore, unrealistic in this analysis to attempt to predict selling price. However, since DDAD has made available anticipated production costs for the turbine engine, based on 1976 dollars, production cost estimates are possible and are shown in Figure 3-5.

FIGURE 3-5
Production Cost Comparison
Assuming Equal Amortization of Manufacturer Start Up Costs*
(1976 Dollars)

SYSTEM CATEGORIES	1976 PRODUCTION BUS**	TURBINE ENGINE 1976 BUS
• BODY STRUCTURE, DOOR AND GLAZING	10,527	10,527
• SUSPENSION, INCLUDING AXLES AND STEERING	7,705	7,705
• ENGINE	6,465	8,081
• DRIVELINE AND SUPPORT SYSTEMS (not affected by engine)		
– Transmission Accessories/Mounts/Wheels/Drive Shafts/Misc.	13,511	13,511
• DRIVELINE AND SUPPORT SYSTEMS (affected by engine)		
– Exhaust/Aspiration Air/Cooling	1,175	250
• ELECTRICAL	1,544	1,544
• AIR CONDITIONING/HEATING	4,772	5,877
• INTERIOR TRIM	4,292	4,292
• SEATS	3,948	3,948
• DESTINATION SIGNS/BUMPERS/MISC.	8,083	8,083
SUBTOTAL	62,022	63,818
G&A AND PROFIT (10%)	6,202	6,382
TOTAL	68,224	70,200

*THESE ARE COST, NOT PRICE, ESTIMATES

**CURRENT PRODUCTION BUS USED AS A BASELINE IS A FULLY EQUIPPED 1976 MODEL BUS, AND NOT NECESSARILY TYPICAL OF ALL FLEET IN USE.

SOURCE: BOOZ, ALLEN APPLIED RESEARCH

The turbine engine in the early years of production is projected to cost 20 to 25 percent more than the 8V-71 diesel engine. The projected production cost of a turbine engined transit coach, however, is projected to be $70,000 in 1976 dollars, or only 2.9 percent more than $68,224 for the typical diesel-powered coach currently in production.

3.6 DDAD ENGINE SURVEY CONCLUSIONS

The operational cost impact analysis indicates that transit coaches equipped with the production improvement gas turbine engines (GT-404-4 PI) will be essentially equal in total operating cost to current diesel-powered transit coaches, without including any added value for:

- BSFC performance gain potential beyond 1983
- Multifuel capability
- Ability to accommodate future synthetic or alternative fuels
- Improved operational performance
- Conformance with environmental standards
- Perceived environmental improvement
- Reduced noise
- Reduced gaseous emissions
- Elimination of exhaust odor and smoke.

The tangible and intangible value/benefit of these attributes can, based on currently proposed regulations, lower the operating cost of a turbine-powered transit bus by well over 1 cent/mile.

If the current government regulatory trends continue into the 1980's, the above factors will become increasingly important and realistic monetory value could be assigned to these benefits offered by the gas turbine engine. The current higher fuel consumption of the gas turbine could continue to be a disadvantage of the engine, particularly if the cost of fuel continues to escalate at a faster rate than other costs. The multifuel capability and the ability to burn less expensive lower grade middle-distillate fuels may offset this disadvantage, especially if nonpetroleum-based fuels become readily available.

Beyond 1983, the fuel consumption of the gas turbine engine will continue to improve relative to the diesel engine. Increasing emission controls for diesel engines will result in a more complex engine, with escalating cost and declining fuel economy, while development of improved technologies in all gas turbine component areas indicate that gas turbine fuel economy will continue to improve. In fact, by the mid-1980's gas turbine fuel economy should equal that of the diesel engine at most speed/load ranges (with the exception of idle).

The major factors indicated by the cost impact analysis are the improved reliability and reduced maintenance costs of the gas turbine engine, offsetting the increased fuel consumption. The turbine engine used in the analysis was the DDAD GT-404-4 PI model. This improved engine, with a rated MTBO of 10,000 hours, is tentatively scheduled for volume production in 1983, which is the earliest reasonable date to expect widespread use of turbine engines in transit coaches.

The procurement cost of the turbine engine, as stated previously, will initially be about 20 percent higher than the contemporary diesel engine. As the production volume of the engine is increased, the cost of the engine should be reduced and may be comparable with the diesel engine. Cost of the diesel, moreover, may be adversely affected by additional equipment required as a result of environmental regulations. The anticipated fuel consumption improvements will be attained by increasing the TIT and possibly variable inlet geometry. The higher TIT will necessitate incorporating improved materials in the nozzles and turbine blades and may also require blade cooling. These changes and the additional complexity of the variable inlet mechanism will increase the cost of the engine somewhat, but it must be presumed that the competitive nature of the engine market will maintain the selling price of the gas turbine within a range commensurate with the advantages it has to offer for vehicular power.

4.0 TECHNICAL APPROACH

4.0 TECHNICAL APPROACH

4.1 GENERAL

The "Gas Turbine Transit Bus Demonstration Program" is designed to take advantage of progressive engine and coach improvements. The basic program plan consists of three distinct phases to coincide with expected engine development, as identified in Figure 4-1. Coach development will also occur within the time frame of the program, with Advanced Design Buses as the current design for the first phase, and Transbuses as the specified coach for subsequent phases of the demonstration.

In each phase, a fleet of gas turbine-powered coaches will be tested in revenue service for a period of one year, while one gas turbine-powered coach is durability tested at a proving grounds for 15 months. A diesel-powered coach will also be tested at the proving grounds to provide an identical comparative data base for performance and durability.

The gas turbine engine used in this program will be the Detroit Diesel Allison Divison GT-404 engine. It was determined that the GT-404 is the only gas turbine engine likely to be in production, and competitive with the diesel engine for transit coach service, within the next decade.*

In-city demonstration coaches will be borrowed from selected transit authorities who have procured the transit coaches through the UMTA Capital Grants Program for continuing use in their fleet after this program. The coach being retrofitted for proving grounds testing may be procured from the manufacturer exclusively for use in the program, or may be borrowed from the operating fleet of the demonstration city for the duration of the proving grounds testing program. The unmodified diesel-powered coach being run as a baseline at the proving grounds may be procured from the manufacturer under the program subcontract exclusively for this program. Spare parts will also be procured from the manufacturer for proving grounds tests.

* Booz, Allen & Hamilton Inc., Gas Turbine Engine Application in Transit Coaches, TR 77-001, March, 1977.

FIGURE 4-1
Basic Program Plan - Three Phases

PHASE I - PROTOTYPE ENGINES

Subcontractors

Detroit Diesel Allison
Coach Manufacturers
Proving Grounds
Demonstration City Operating Property #1

Vehicle Summary

Proving Grounds:	1 Diesel Advanced Design Bus
	1 Turbine Advanced Design Bus
Demonstration City #1:	5 Turbine Advanced Design Buses

PHASE II - PRE-PRODUCTION ENGINES

Subcontractors

Detroit Diesel Allison
Coach Manufacturers
Proving Grounds
Demonstration City Operating Properties #2 and #3

Vehicle Summary

Proving Grounds:	1 Diesel Transbus
	1 Turbine Transbus
Demonstration Cities #2 and #3:	5 Turbine Transbuses each

PHASE III - PRODUCTION ENGINES

Subcontractors

Detroit Diesel Allison
Coach Manufacturers
Proving Grounds
Demonstration City Operating Properties #4 and #5

Vehicle Summary

Proving Grounds:	1 Turbine Transbus
Demonstration Cities #4 and #5:	5 Turbine Transbuses each

At the close of each phase, the operating property of the demonstration city may choose to retain the demonstration coaches as repowered with gas turbine engines, or the coaches may be refurbished with diesel engines.

4.2 PHASE I

Phase I will involve the acquisition of gas turbine engines, Advanced Design Bus conversions, in-city revenue service demonstration, and proving grounds tests.

4.2.1 Acquisition and Integration of Engines and Coaches

DOE will procure six prototype gas turbine engines and modified V-730 transmissions from Detroit Diesel Allison Division. The engines and transmissions will be acceptance tested to ensure that the hardware is in accordance with the procurement specifications before being delivered to a coach manufacturer for integration into coaches of his manufacture.

A coach manufacturer will be selected in a competitive procurement for engine installation engineering and coach repowering under the direction of Booz, Allen. Repowered coaches will be tested and inspected according to detailed acceptance procedures prepared by Booz, Allen before shipment for revenue demonstration or endurance track testing.

Six coaches will be acquired for turbine engine integration. A diesel (baseline) coach may be procured from the manufacturer to be used at the proving grounds.

4.2.2 In-City Revenue Service Demonstration

The demonstration site selections will be based on capability, environment, and cost.

The operating property of each candidate demonstration city must be capable of performing a successful demonstration. First, they should be operating sufficient quantities of the bus manufactured by the successful engine/bus integration contractor. They must commit to furnish these coaches to the program in such quantity and for such time as is required for repowering with gas turbine engines and acceptance testing before they are returned to the city for the actual demonstration project.

A factor in the site selection may be the candidate's willingness to furnish a coach for gas turbine endurance testing.

They must express a desire to participate and management must be willing to dedicate the personnel and equipment required for the demonstration. Further, each candidate operating property must possess technical and operating personnel who can be trained and who will maintain and operate the turbine powered coaches in a manner that is conducive to the success of the demonstration program, and must have the capability to collect, evaluate, and process technical data, such as maintenance and operating cost records.

Each candidate demonstration site must also provide the potential for good public exposure under a variety of transit conditions. Route structures should include long, short, congested, open, hilly, and flat runs.

The environment of the demonstration site should contain variations in altitude, terrain, road surfaces, ambient temperatures, wind velocities, precipitation, and barometric pressure.

Finally, each candidate operating property must commit to implementation of the demonstration within the financial constraints of the allocated program budget. The program is intended to create no substantial financial impact on the demonstration city, however, and additional expenses incurred by the operating property as a result of this program will be reimbursed through the operating property's grant contract. Additional expenses may include driver/mechanic wages during the training period, costs of special demonstrations/displays, and the costs of data collection. The details of the grant contract will be negotiated between each demonstration site and UMTA.

The five coaches repowered with gas turbine engines will be operated for a period of one year in the demonstration city selected for Phase I. The in-city tests will be conducted in accordance with the demonstration plan which will include detailed procedures and instructions for the transit operator.

4.2.3 Proving Grounds Tests

One gas turbine powered coach and one unmodified diesel powered coach will be operated for comparison in endurance tests. The diesel powered coach will run for 25,000 miles to establish a data base regarding availability, maintainability, and operating costs, in the same condition as the gas turbine coach.

The proving grounds gas turbine tests will be conducted in accordance with the developed test plans and specifications, to include such tests as noise and emissions, performance, and durability over the transit operating duty cycle. Engine instrumentation will also be utilized to assist in the testing and data collection process. Data will be processed and evaluated in accordance with the data collection and evaluation plans developed for the proving grounds. The initial gas turbine coach test will also identify installation errors and improvements required for coaches in Phases II and III.

4.3 PHASE I PERFORMANCE REVIEW

A performance review is scheduled during the Phase I proving grounds testing and the in-city demonstration. At this review, the overall Phase I performance and the acceptability of the coaches repowered with gas turbine engines will be assessed. Service procedures and mechanic training programs as well as early operational data will be evaluated. Any special support required for transit fleets with gas turbine engines will be identified. In addition, preliminary operational and cost data collected on gas turbine performance versus diesel performance will be evaluated.

DDAD's status with regard to selling small production lots of preproduction gas turbine engines to other programs will also be evaluated. Such a sales program would impact this program by lowering the cost of the engines for Phase III to about $120K per unit.

It will then be decided whether to modify the program or to continue with Phase II as planned. Modification of the program may involve different numbers and combinations of engines, transit buses, and cities. If the program continues as planned, then improvements in the engineering plan scheduled for Phase II will be reviewed and additional changes to optimize the coaches being repowered with turbine engines may be directed.

4.4 PHASE II

Phase II will involve the acquisition and integration of preproduction gas turbine engines and Transbus coaches, two in-city revenue demonstrations, and the proving grounds tests. The program will follow the guidelines determined for Phase I, and any modifications identified in the Phase I performance review.

4.5 PHASE II PERFORMANCE REVIEW

Another performance review is scheduled to occur near the conclusion of Phase II before Phase III is conducted. Actual versus anticipated engine performance during Phase II will be assessed in detail, based on the parameters identified in the data collection and evaluation plans, as well as whether gas turbine application in transit coaches is meeting program expectations.

DDAD's final decision in 1981 of whether or not to proceed to commercialization with a production engine will also be evaluated. It will then be decided whether to continue this program as planned.

4.6 PHASE III

Phase III will involve the acquisition and integration of production model gas turbine engines and Transbus coaches, two in-city revenue demonstrations, and the proving grounds tests. The program will follow the guidelines determined for Phases I and II, with program modifications, as necessary, determined in the previous performance reviews. It may be possible, however, to demonstrate operation on a synthetic fuel in one or more of the coaches.

4.7 CONCLUSION OF PHASE III

Data reduction will continue toward preparation of the final reports in early 1985. Engine data will be evaluated as to the engine's stage of development, demonstrated reliability, fuel consumption compared to a diesel engine, and mass-production and life-cycle cost. Transit service data will be evaluated. Passenger, driver, and general public reactions will be measured, and in-city operational and cost data correlated with the mileage data obtained from proving grounds tests.

Finally, the designs for installation of gas turbine engines and all data generated by this program will be made available to transit coach manufacturers, who may offer the engine as a power train option in future coach procurements after review and qualification for support under the UMTA Capital Grants Program.

5.0 ORGANIZATION

5.0 ORGANIZATION

5.1 GENERAL

The "Gas Turbine Transit Bus Demonstration Program" is a cooperative effort by the Divison of Transportation Energy Conservation (TEC) of the U.S. Department of Energy (DOE) and the Urban Mass Transportation Administration (UMTA) of the U.S. Department of Transportation (DOT) to test and evaluate the use of gas turbine engines in transit coaches.

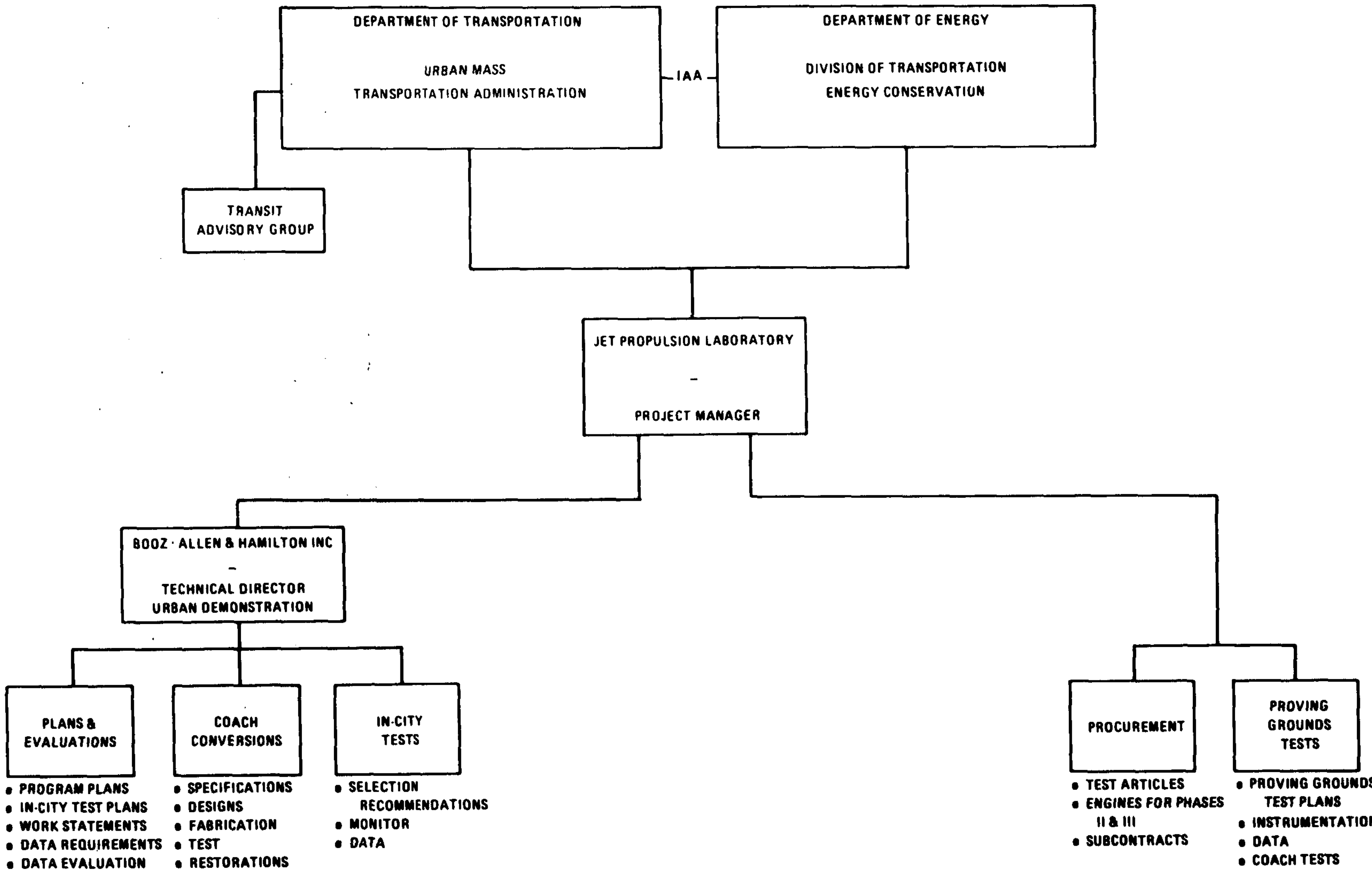
5.2 PARTICIPANTS AND RESPONSIBILITIES

The program participants are shown in Figure 5-1. In addition to DOE and DOT, they will include:

- Jet Propulsion Laboratory (JPL)
- Booz, Allen & Hamilton, Transportation Consulting Division
- Detroit Diesel Allison Division (DDAD) of General Motors Corporation
- Transit coach manufacturers
- Proving grounds
- Transit coach operating properties
- Transit advisory group(s).

DOE is responsible for the overall program direction. They will provide overall program strategy and controls consistent with meeting joint DOE and DOT goals and objectives. They will also supply funds for the planning and implementation, as well as issue reports on program results, including monthly progress reports and demonstration test reports, through the Project Manager. Because of the program's time constraints, they will directly procure the gas turbine engines for Phase I.

FIGURE 5-1
Program Organization



DOE will also interface directly with various government agencies and continually assess technical output for transfusion into the advanced automotive heat engine developments.

DOT is responsible for the overall technical direction of the in-city demonstrations. They will provide guidance for and coordinate the site selection activities for the demonstration cities and make formal announcements of demonstration cities. They will coordinate use of coaches and grants for the transit operating properties of the cities selected as demonstration sites. They will provide engineering and management support as required, and assist in special presentations and demonstrations as required. They will also provide coordination, liaison, and principal interface with other parts of DOT and the transit industry.

JPL is the Project Manager and is responsible for the procurement and monitoring of services required for program implementation. JPL is the single point of contact with regard to programmatic elements involving its contractors. They are responsible for the quality, timeliness, reasonableness of cost, and performance of these services. They will provide for schedule control, management reporting, and monitoring of technical results through the use of a reporting structure which ensures that technical, cost, manpower, and schedule data are compatible and can be analyzed on an integrated basis. They will procure test articles and engines for Phases II and III, and will subcontract for necessary program support. They will also provide endurance track operating instrumentation, data collection and evaluation, and coach testing at the proving grounds.

Booz, Allen & Hamilton is the Technical Director of the in-city demonstration project and is responsible for planning and implementing this project. They will develop detailed plans, procedures, specifications, and the data systems to be used in the testing program. They will subcontract the coach/engine conversion and integration activities as well as the restoration activities at the end of each phase and provide the technical direction and guidance for conversions. They will monitor the subcontractor work and provide support as required. They will conduct acceptance tests on the coaches before delivery for further program testing. They will provide for the collection and evaluation of the in-city test data.

DDAD will be responsible for provision of the gas turbine engines and the tranmissions that will be installed in the transit coaches for proving grounds and in-city testing. They will be under contract to provide six all-metal prototype engines for Phase I, 11 all-metal preproduction engines for Phase II, and 11 production engines with available ceramic components for Phase III. The phasing of the engine orders under this contract coincide with DDAD's projected engine development toward commercialization in 1983. They will provide engine bucks for each model and engineering support to the conversion shop for integration of the coaches/engines and for a heating system design. They will also provide engineering support, as necessary, during the proving grounds tests and the in-city demonstrations. Prior to the testing and demonstrations, they will provide training for the gas turbine powered coach drivers and mechanics. They will also provide technical assistance as requested to identify or correct any early engine installation or operating problems.

The transit coach manufacturers will supply coaches and spare parts procured for proving grounds tests. They will also provide manpower, facilities, equipment, and materials for the conversion activities. They will be subcontracted by Booz, Allen and under Booz, Allen's technical direction, they will develop the engine installation design and engineering drawings as well as develop a new heating system for use in the gas turbine powered test coaches. A prototype of the heating system will be built, tested, and any necessary modifications incorporated before the system is integrated into the test coaches. They will perform the actual coach conversions at the beginning of each phase and the restorations, as required, at the close of each phase.

A proving grounds will be contracted to provide manpower, facilities, and certain instrumentation for testing. They will conduct the engineering and shakedown testing of the first retrofitted coach in each phase and the acceptance testing of all converted coaches. They will conduct the durability testing on all proving grounds test coaches. They will perform routine service and maintenance on the proving grounds coaches as well as repairs when the coaches are down. They will keep accurate daily records of all proving grounds activities and submit reports as required.

The selected operating properties will be responsible for providing Advanced Design production coaches as required for conversion to gas turbine engine power and for acceptance testing before being returned for the in-city demonstrations. They will supply drivers, and mechanics for maintenance and repair for revenue service demonstrations. These employees will attend training by DDAD in the proper care, maintenance and techniques for operating the gas turbine coaches. The operating properties will be responsible for conducting the one-year demonstration testing in accordance with the demonstration plans provided by Booz, Allen. They will provide for routine coach maintenance and repair, for schedule adherence, for special demonstrations/displays, and for technical data collection and evaluation.

Transit advisory group(s) will provide technical liaison and will advise the program as requested. They will also provide for dissemination of program progress and test results within the transit industry.

6.0 SCHEDULE AND MILESTONES

6.0 SCHEDULE AND MILESTONES

Figure 6-1 shows the overall schedule for the three phases of the "Gas Turbine Transit Bus Demonstration Program." Each phase has an approximate duration of three years, including the time required for engine and coach procurements. The events shown under each phase are divided into three task areas:

- Conversion engineering and engine installation
- Proving grounds testing
- In-city demonstration testing.

While the two test programs are conducted essentially in parallel, extensive lead times are necessary for the coach and engine fabrication prior to the coach conversions. Approximately one year has been estimated for the test coach delivery, and nine months for the engine deliveries, from the issue of the purchase order or subcontract. During that time, conversion engineering work, included engine and engine compartment mock-ups, and heating system design and prototype development, will be accomplished.

The required lead times for hardware procurement make it necessary to schedule the phases to coincide with projected engine production schedules, with some phase overlap. As a result, the entire demonstration program has a planned duration of eight years, with Phase I commencing in early 1978, Phase II scheduled to start in mid-1980, and Phase III to begin in mid-1982.

For Phase I, engine deliveries are scheduled to occur one per month, with in-city coach conversions requiring one month each. In subsequent phases, the conversions should require less time per unit, based on the experience gained in Phase I.

Figure 6-2 shows the detailed milestone plot for Phase I. Planned completion dates for all tasks required to conduct the first phase of the program are shown, and earliest and latest possible completion dates are also depicted for those tasks not on the critical path. The plot shows the allowable time slippage for noncritical tasks before the overall phase schedule is affected. Those tasks without an earliest or latest possible completion date cannot be

FIGURE 6-1
Overall Program Schedule
Sheet 1 of 4

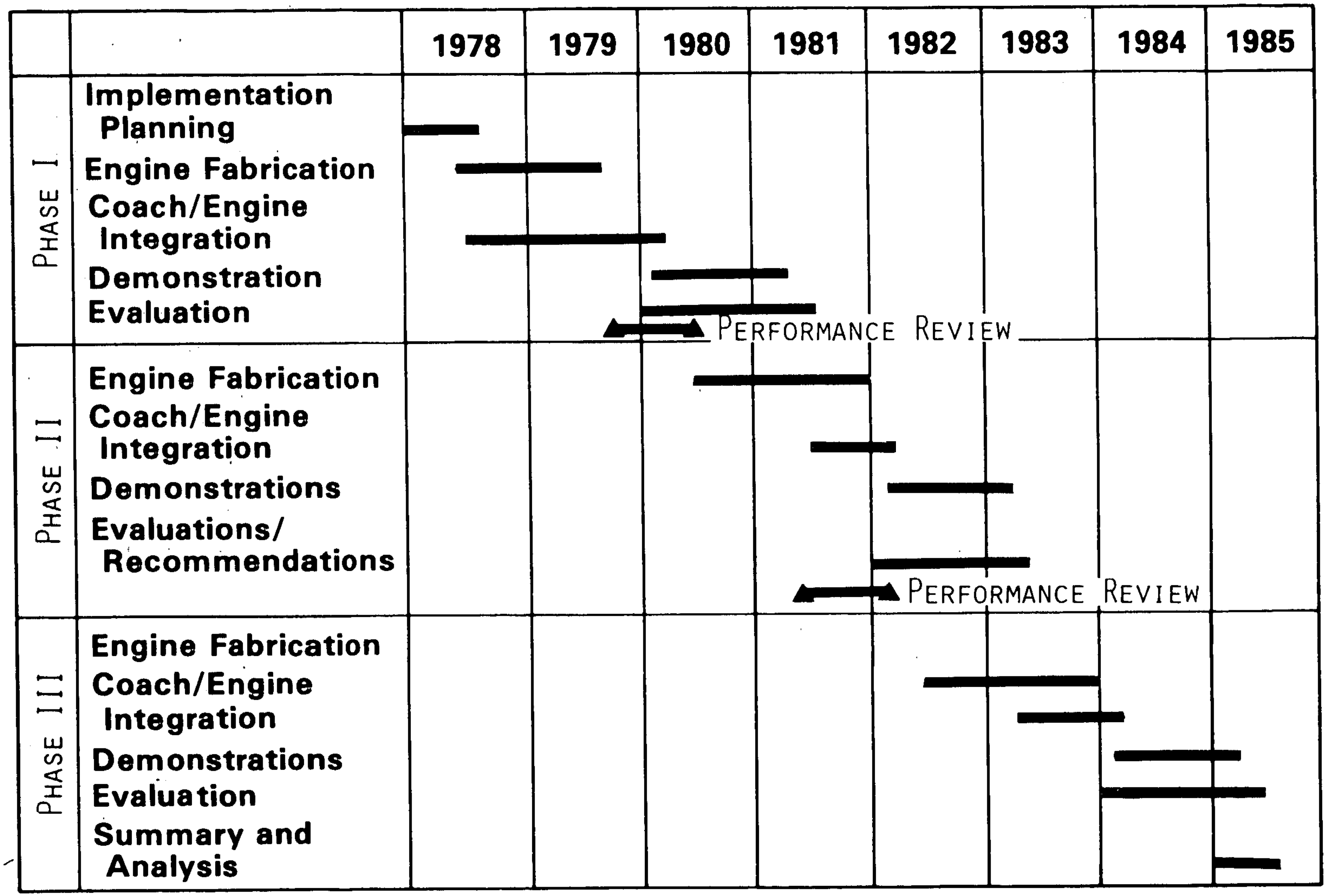


FIGURE 6-1
Overall Program Schedule
Sheet 2 of 4

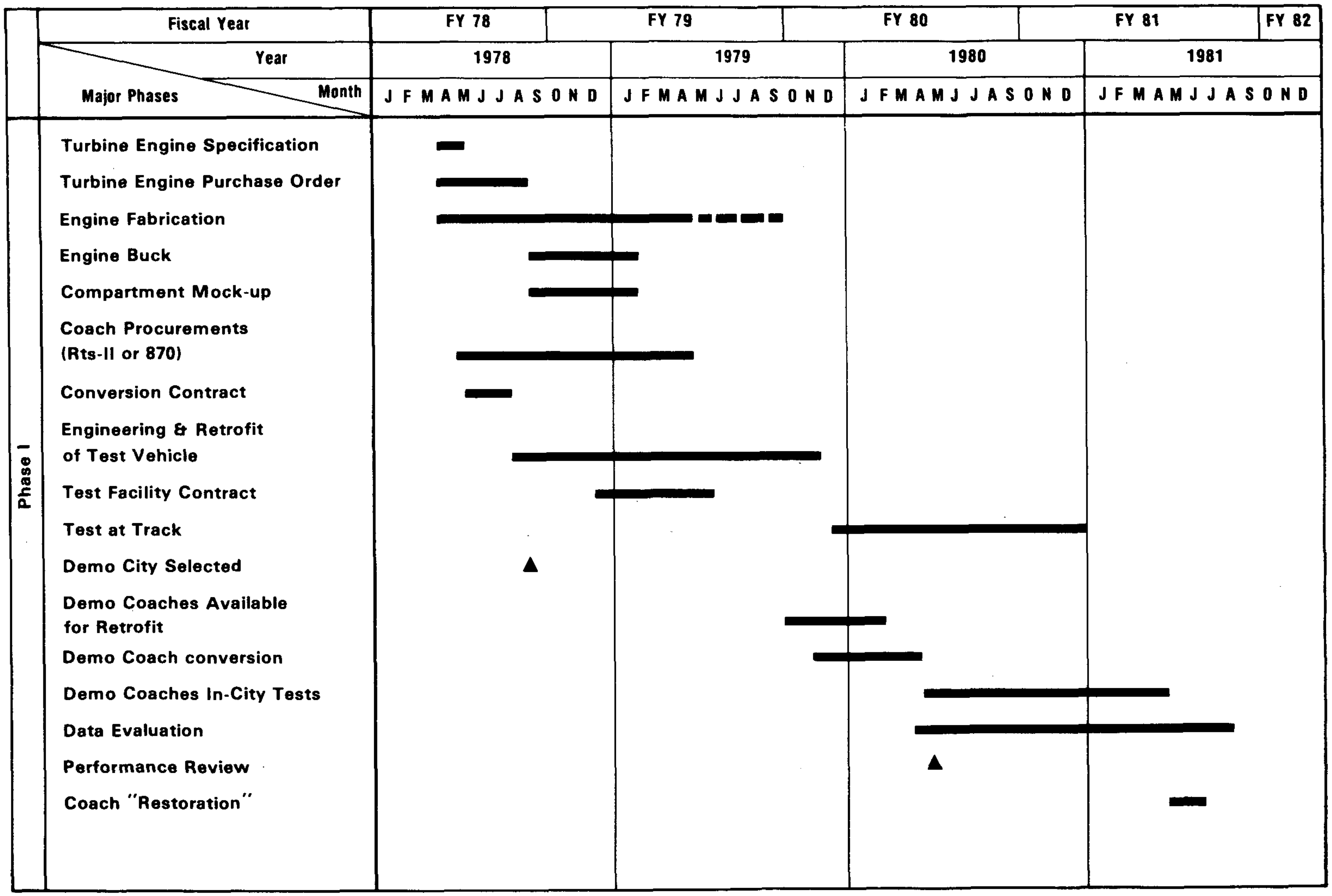


FIGURE 6-1
Overall Program Schedule
Sheet 3 of 4

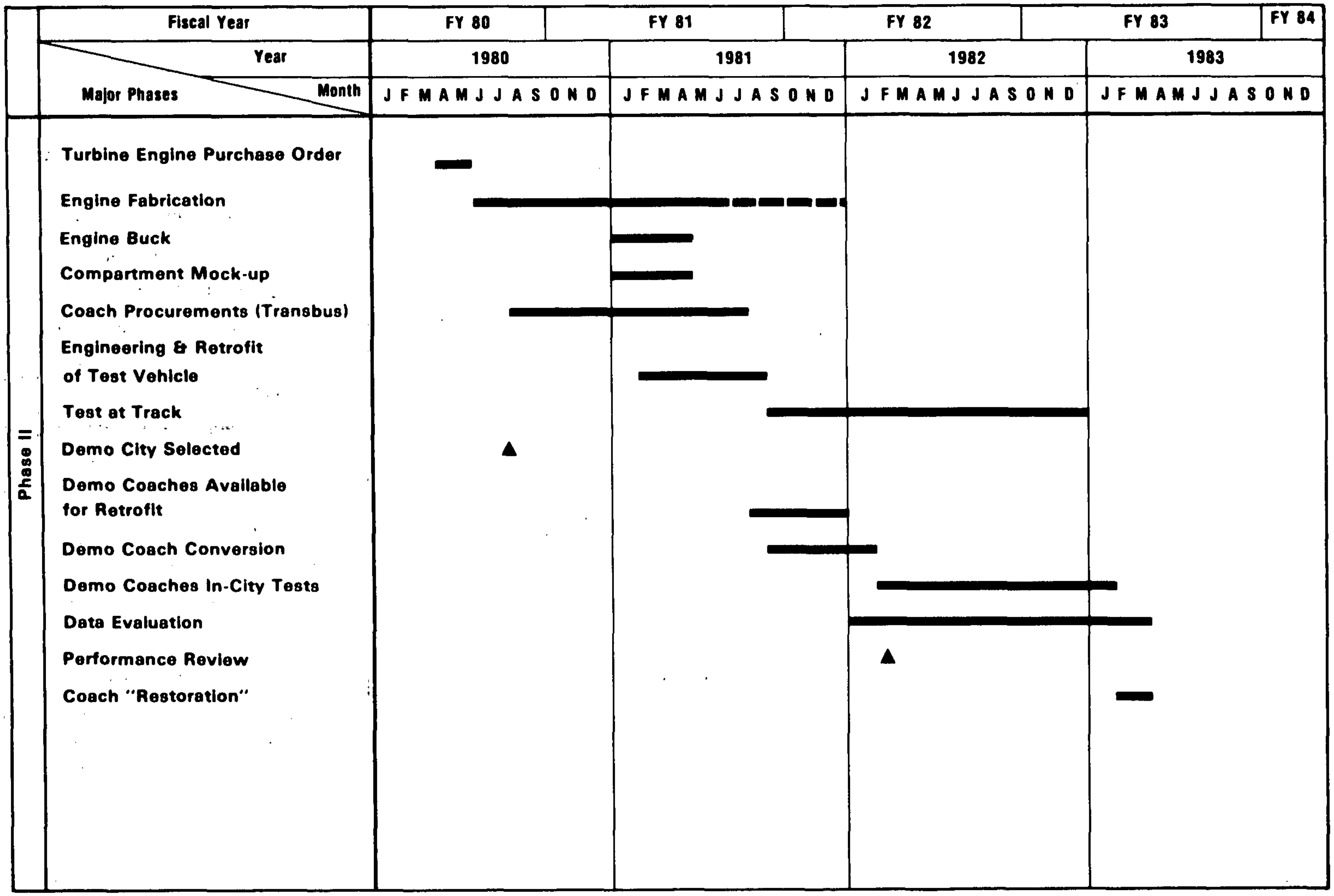
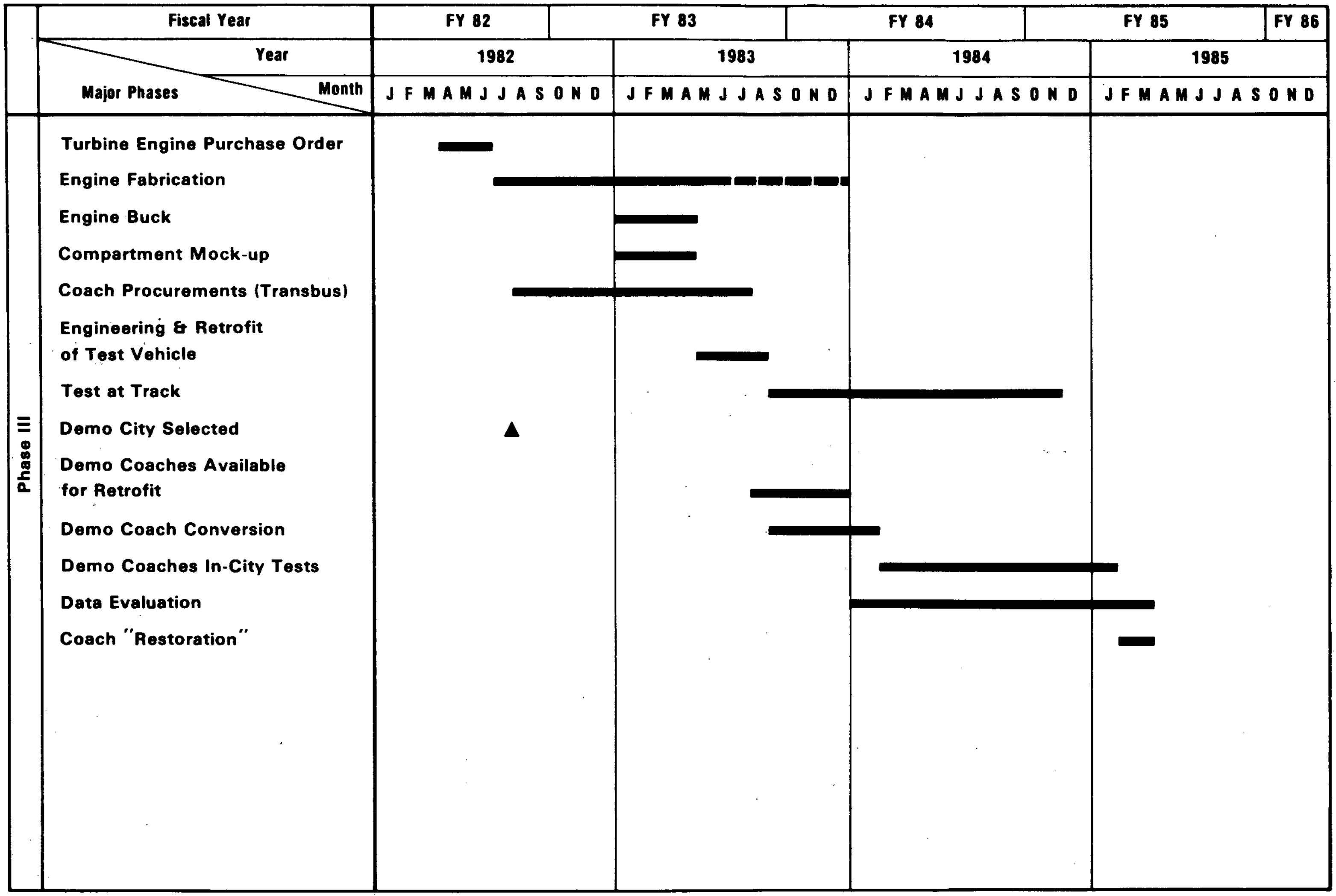


FIGURE 6-1
Overall Program Schedule
Sheet 4 of 4



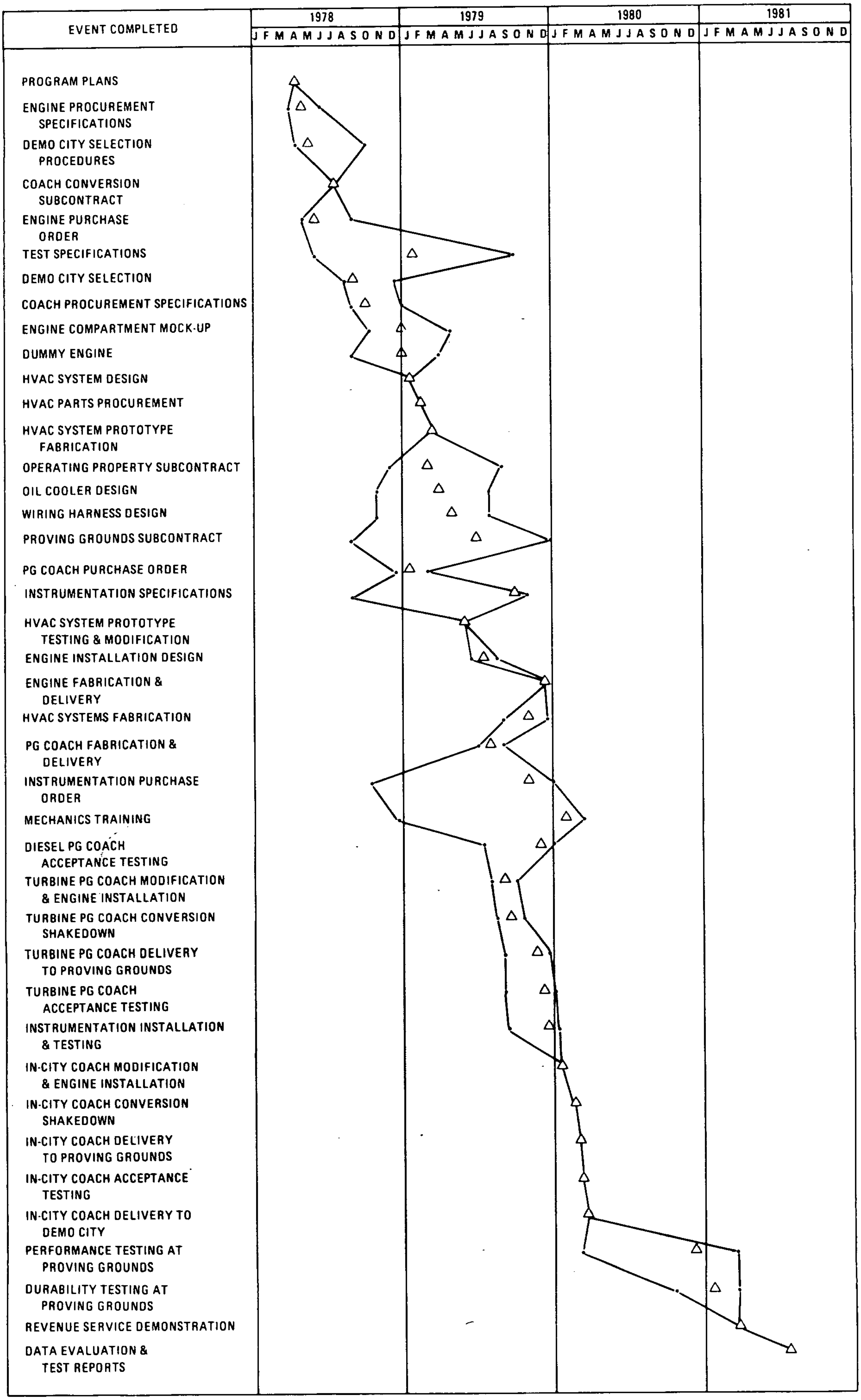


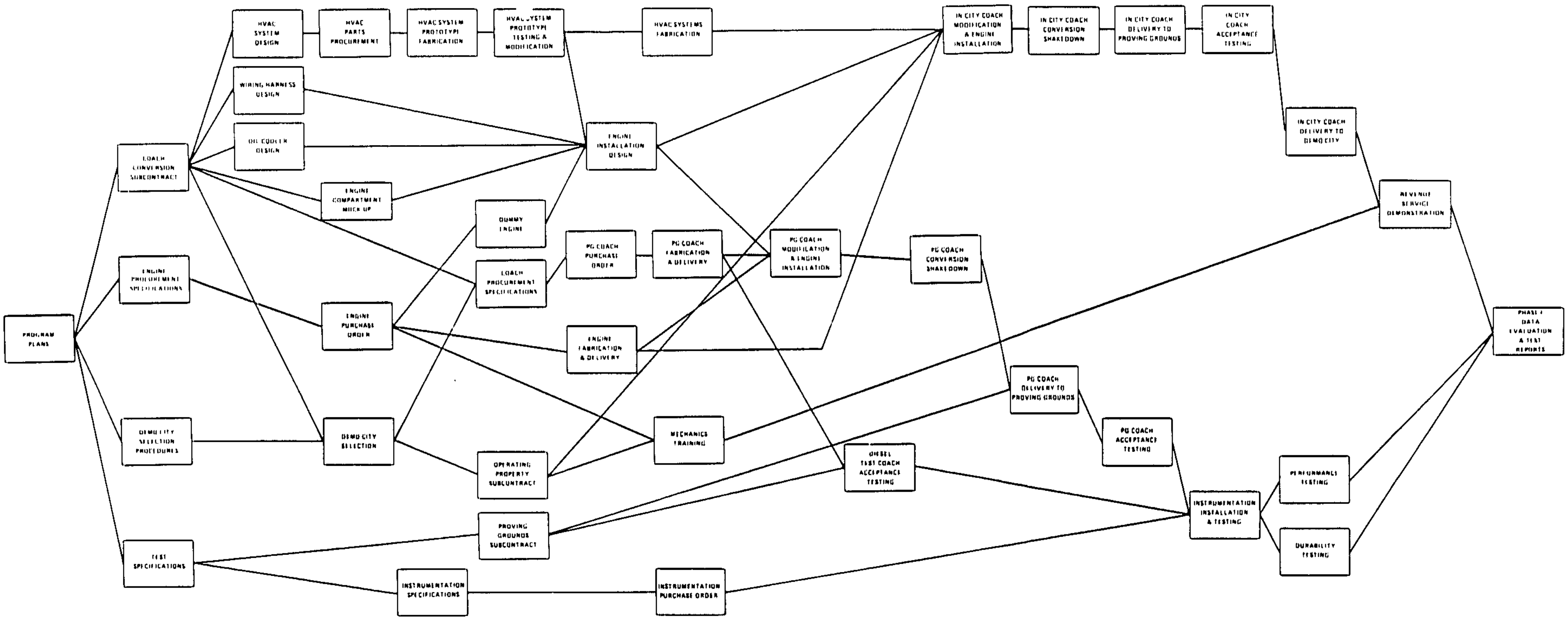
FIGURE 6-2
Phase I Milestone Plot

slipped without affecting the entire phase schedule. Tasks included on the critical path are the heating system design, prototype development and testing, heating system fabrication, the in-city coach modifications and engine installations, conversion shakedown and acceptance testing, and the revenue service demonstration and testing.

The logic diagram shown in Figure 6-3, indicates the sequencing of all tasks, and the critical path for completion of Phase I. While the milestone plot shows the completion dates for all tasks, the logic diagram displays the relationship among tasks, or precisely which tasks have to be completed before another task can be accomplished.

Similar milestone plots and logic diagrams will be prepared for Phase II and Phase III as detailed planning for those phases occurs.

FIGURE 6-3
Logic Diagram of Program



7.0 FINANCIAL

7.0 FINANCIAL

This section describes the financial plan for the "Gas Turbine Transit Bus Demonstration Program." Figure 7-1 shows a summary breakdown of estimated program costs. The first column lists the program phases and major task elements under each phase. Estimated costs for each line item are shown by fiscal year, with phase totals shown also by fiscal year. The bottom of the figure shows costs for each fiscal year. The ninth column of the figure shows the program costs for each phase and for each major task element in each phase, with the total program cost shown at the bottom of this column.

The major task elements listed in the figure correspond to the contract work breakdown structure. Estimated costs given for each major element represent the sum of cost estimates for all tasks under each element, as identified in the work breakdown structure.

FIGURE 7-1
Estimated Program Cost By Fiscal Year

	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	TOTAL
<u>PHASE I</u>									
1.0 Coach Conversions	226,000	1,446,000	823,000	75,000					2,570,000
2.0 Proving Grounds Testing		177,000	646,000	340,000					1,163,000
3.0 In-City Demonstration			121,000	152,000					273,000
4.0 Planning & Management	214,000	230,000	210,000	112,000					766,000
TOTAL PHASE I	444,000	1,853,000	1,800,000	679,000					4,772,000
<u>PHASE II</u>									
1.0 Coach Conversions				1,388,000	1,092,000	180,000			2,660,000
2.0 Proving Grounds Testing					945,000	373,000			1,318,000
3.0 In-City Demonstration					292,000	266,000			558,000
4.0 Planning & Management			29,000	140,000	239,000	126,000			534,000
TOTAL PHASE II			29,000	1,528,000	2,568,000	945,000			5,070,000
<u>PHASE III</u>									
1.0 Coach Conversions						794,000	474,000	190,000	1,458,000
2.0 Proving Grounds Testing						6,000	867,000	348,000	1,221,000
3.0 In-City Demonstration							279,000	209,000	488,000
4.0 Planning & Management					36,000	148,000	252,000	92,000	528,000
TOTAL PHASE III					36,000	948,000	1,872,000	839,000	3,695,000
TOTAL PROGRAM	440,000	1,853,000	1,829,000	2,207,000	2,604,000	1,893,000	1,872,000	839,000	13,537,000

8.0 PROGRAM CONTROL

8.0 PROGRAM CONTROL

The following section summarizes the control methods which will be used to manage the "Gas Turbine Transit Bus Demonstration Program."

8.1 SPECIFICATIONS

Specifications for the procurement of turbine engines, and transit coaches will be used as part of the control for the "Gas Turbine Transit Bus Demonstration Program." In addition to the procurement specifications, engineering drawings will be made to facilitate the coach modification, heating system fabrication and installation, and engine installation. The drawings are to be made based on the first coach that is modified, and will then be used for each subsequent coach retrofit in the same procurement.

Specifications and engineering drawings will be used for each phase of the program. It will also be necessary to coordinate the development of the bus procurement specifications with the transit operating properties participating in the program.

8.2 ACCEPTANCE TESTS

Acceptance test procedures will be used in testing to verify the quality and performance of the coaches procured, and to verify the quality of the coach conversion work. The testing is to be performed before shipping to the proving grounds and to the demonstration cities.

8.3 PLANS AND PROCEDURES

Proving grounds test specifications will be used for evaluating the test coaches. These specifications include high mileage durability testing, and engineering testing such as noise and performance tests. In-city demonstration plans will provide the guidelines and procedures for operating properties participating in the demonstration. Route selection, driver and mechanic training requirements, participant response procedures, and data collection requirements and formats will be described in the detailed demonstration plan. A data evaluation plan for the evaluation of data and determination of the viability of the turbine powered coaches will be prepared. This plan will delineate the format for processing and presenting all data used to evaluate the demonstration program.

Quality assurance plans will be used to verify the quality of coaches procured for the tests and to verify the quality of coach repowering work. These plans include detailed acceptance procedures to test and inspect each repowered coach before shipment to the proving grounds or demonstration city. A monitoring plan will be used to supervise each major subcontractor's progress by specifying reviews and technical audits of the work performed. This plan will also be used to verify the quality of the documentation received as part of the program, similar to the use of acceptance test procedures for the hardware procurement.

8.4 REPORTING

Participants contracted for tasks in the program will be required to provide interim progress reports and cost reports as inputs for progress reports to DOE/DOT.

Monthly progress reports will be submitted to DOE/DOT, by JPL, to include:

- Key activities and accomplishments in the reporting period
- Planned activities for the next reporting period
- Summary of cost report, planned versus actual expenditures.

8.5 TECHNICAL AUDITS

JPL will conduct reviews and technical audits of contractor performance in accordance with the monitoring plan.

The technical audits will be completed both on a periodic and random, spot basis to assure that the quality of work meets the plans and specifications. The periodic reviews also enable JPL to monitor project progress by auditing the work being performed.

8.6 PERFORMANCE REVIEWS

Phase completion reports will be prepared by JPL at the end of both Phase I and Phase II. These reports will document the performance reviews conducted near the end of each phase, and the actions taken as a result of those reviews.

At the completion of Phase III a final report will be prepared by JPL evaluating the overall performance of the program.

8.7 CONTRACT WORK BREAKDOWN STRUCTURE

The contract work breakdown structure is shown in Figure 8-1. The program tasks are detailed in four functional areas: coach conversions, proving grounds testing, in-city demonstration testing, and planning and management.

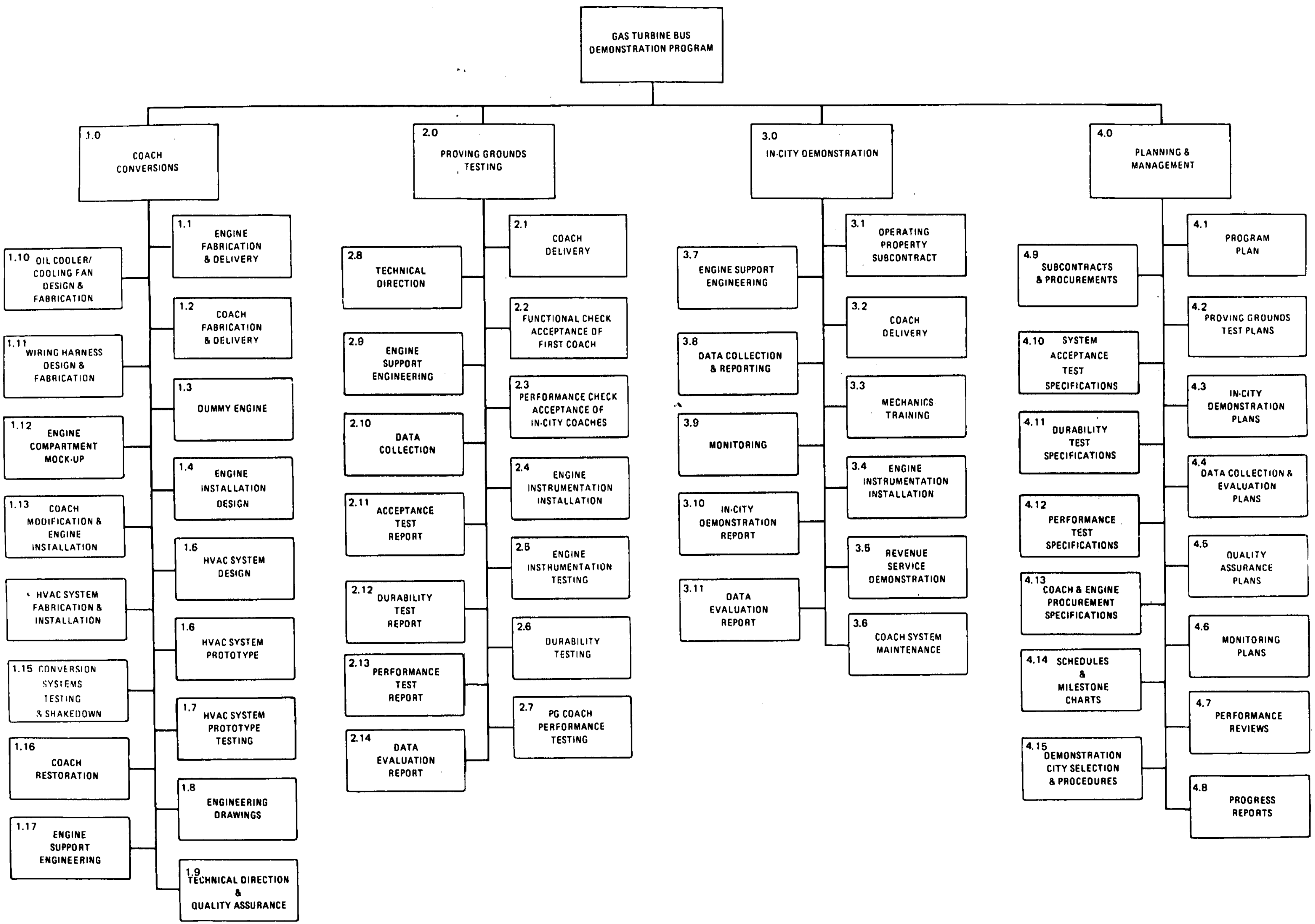
Coach conversions include all conversion engineering and installation design necessary to retrofit the transit coaches with turbine engines, and the actual engine installations and systems shakedown.

Proving grounds testing consists of acceptance testing of all coaches and durability and performance testing of the diesel baseline and the turbine test coaches. It also includes the necessary instrumentation and data collection to evaluate the turbine engine against a number of performance parameters, such as noise, emissions, fuel consumption, oil consumption, and reliability.

In-city demonstration testing includes the revenue service testing by an operating property, and related tasks for the proper evaluation of the turbine engines in actual transit applications.

Planning and management includes all of the detailed plans, procedures, and test specifications for the conduct of the three major functional tasks previously identified, subcontracts and procurements, performance reviews, and progress reports to assess program progress on a regular basis.

FIGURE 8-1
Contract Work Breakdown Structure



Using this work breakdown, task statements will be prepared to define work packages consisting of a task or group of tasks and assignments.

Work statements will be issued to the supporting group performing that particular assignment. This documentation will be used internally to assess the performance of participants on their assigned tasks.

8.8 SCHEDULE CONTROL

Section 6.0 discusses the schedule and milestones developed for the management of this demonstration program. These will be used as basic tools for monitoring and displaying project progress throughout the demonstration.

In particular, the detailed milestone plots developed for each phase will be used to track program progress, as completed tasks can be shown against planned completion dates on the same plot.

Schedule control is the responsibility of JPL. Through the use of these easily referenced milestone charts and schedules, monitoring of all critical tasks in the program will be accomplished.

8.9 COST CONTROL

Demonstration program expenditures will be monitored against the planned program budget using a resources trend chart similar to the one shown in Figure 8-2. Actual expenditures are taken from a computerized cost reporting system and plotted on the chart against the planned levels of effort. JPL will identify the causes for any deviations, and develop alternatives to correct them.

FIGURE 8-2
Resources Trend Chart

PROJECT NO & TITLE	DATE ISSUED
JOB OR SUB CONTRACT NO.	TASK NO & TITLE
MANAGEMENT RESPONSIBILITY	

PLANNED VS ACTUAL EXPENDITURE

COST

LEGEND:

INCREMENTAL FUNDING
PLANNED EXPENDITURE
ACTUAL EXPENDITURE
75% EXPENDITURE POINT

MONTH/YR													
BUDGET-MO													
BUDGET-CUM													
ACTUAL-MO													
ACTUAL-CUM													

PREPARED BY													
REVIEWED BY													