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DUAL-POWERED GAS TURBINE/ELECTRIC (GT/E) COMMUTER RAIL CARS

Final Report and Economic Evaluation

September 1980

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16. Abstract

Dual powered gas turbine/electric (GT/E) multiple-unit trains function as electric-powered multiple-unit (EMU) trains on railroad lines where wayside electric power is provided, and as high performance turbine-powered trains over trackage which is not electrified. This type of train can provide direct, high-speed service between outlying lines having no electrification and downtown terminals such as those in New York where access via tunnels requires use of electric propulsion.

The Metropolitan Transportation Authority has purchased eight prototype GT/E cars, four from the General Electric Co. (GE) and four from The Garrett Corp. All eight cars were operated in revenue service on the Long Island Rail Road (LIRR).

This report describes the design considerations that lead to the configuration of the GT/E cars and contains a description of the cars as built by GE and Garrett. The last portion of the report compares the costs of using GT/E trains to provide direct service to New York from select non-electrified lines with costs of extending electrification over those lines and operating conventional MU trains. Three rail lines are examined: the LIRR Port Jefferson and Oyster Bay branches, and Conrail's Upper Hudson to Poughkeepsie.

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General Electric GT/E train during test operations on Long Island Rail Road, October, 1975.

PREFACE

As ridership on commuter rail systems increases, the method of propulsion used to extend existing electric MU car service must be considered. One alternative proposed to simply extending third rail electrification has been the dual-mode Gas Turbine/Electric car.

The GT/E demonstration project described herein explored the engineering and economic feasibility of extending high performance MU car service past electrified territory with the use of a car that would operate on third rail power and then continue past the end of electrification using onboard turbine-generators. The cars also were equipped to handle both high level and low level passenger loading automatically. The reliability, performance and economic aspects of their operation were investigated and evaluated.

The GT/E cars were built by the Garrett Corporation and by the General Electric Company under contract with the New York State Metropolitan Transportation Authority (MTA).

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The success of the test program which is reported herein was dependent on the skills, integrity and dedication of the people listed below. The project sponsors owe a great debt of gratitude to these engineers, technicians and operating personnel.

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INTRODUCTION

The dual-powered Gas Turbine/Electric (GT/E) cars were electric multiple-unit (EMU) cars which could draw electric power from third rail electrification or from gas turbine-powered generators carried on-board the cars. A changeover from one electrical power source to the other could be made while moving, so that a train of GT/E cars could operate on wayside power in center city, and smoothly transition without stopping to on-board turbine power at the end of the third rail electrification. Prototype dual-powered Gas Turbine/Electric rail cars were developed by the Metropolitan Transportation Authority with funding provided by the Urban Mass Transportation Administration of the United States Department of Transportation and the New York State Department of Transportation.

Part 1 of this report reviews the rationale for developing GT/E type cars, relates the history of the development and test program, and describes the prototype GT/E cars built by the Garrett Corporation and the General Electric Company. The program demonstrated that the high performance of EMU cars operating on third rail electrification can be matched by the GT/E car operating on turbine-generated power.

Part 2 of the report develops economic comparisons between the use of GT/E cars and the extension of third rail electrification as alternative means of providing direct, high-performance commuter service to the ends of three MTA commuter lines which are not completely electrified. The results are presented in 1977 dollars and do not include the effects of recent inflation.

SUMMARY

The results of the economic analysis show that for each of the three routes, the initial capital investment would be lower for the GT/E-car alternative, and that the annual operating costs of the GT/E cars would be significantly higher than third rail electrifications and M-1 operation because of fuel costs and turbine maintenance costs. Extension of third rail electrification and operation of M-1 trains appeared to be the more attractive alternative for improving service to Port Jefferson and to Oyster Bay, two of the routes analyzed. For service to Poughkeepsie, the third route, the GT/E alternative appeared more economical overall than third rail extension with M-1 service for the frequency of service provided on the upper Hudson line in 1977.

Of the two models of GT/E equipment studied, it appeared that the cars equipped with industrial-type turbines, the Garrett cars, would consume slightly more fuel in each of the three cases examined, but that the cars equipped with the aircraft-derivative turbines, the GE cars, would be more costly to maintain. Overall, cars with industrial-type turbines appeared more economical to operate.

PART 1. DESIGN OF THE GT/E CARS

1.1 GT/E CAR CONCEPT

The principal aim of the Gas Turbine/Electric Car Program was the development of rail vehicles capable of providing direct, high-performance service into city center on lines not completely electrified. A closer look at what is meant by "high performance" in the context of high-train-density commuter rail service leads to an understanding of the need for a GT/E-type car.

High-performance trains have high-braking rates and high-acceleration rates which are limited only by wheel-rail adhesion and by passenger comfort. The high-braking and acceleration rates enable high-performance trains to stop and start more quickly than low-performance trains at stations and at wayside signals. The benefits of operating high-performance trains are threefold: trip times are reduced; line capacities are increased; and congestion can be cleared and operation restored more quickly after delays.

Commuter rail services are usually characterized by a relatively high number of station stops. In order to achieve more reasonable trip times the commuter trains must be designed for high-braking and acceleration rates to minimize the time required to stop and start at each station. This need does not exist for mainline intercity trains where the emphasis is on high speeds sustained for long periods of time between a few widely spaced stations.

A point often not fully appreciated is the role of high braking rates in commuter services. The length of a wayside signal block is determined by the speeds and braking rates of the trains. If the wayside signal system is designed for high-performance trains and low-performance trains are operated on it, the speed of the low-performance trains must be restricted so they are certain to stop within the wayside signal blocks. With a high density of trains, the high-performance trains will be slowed by the slower, low-performance trains. The results are longer trip times and lower line capacities than if only high-performance trains are operated on the line.

When the wayside signal system is designed for low-performance trains the signal blocks are longer than they need be for high-performance trains. Because of the longer block lengths the trains are spaced further apart resulting in lower line capacities and longer trip times.

The value of high performance is most dramatically demonstrated when there is unusual congestion caused by a delay. At such a time the ability of the trains to move quickly and relatively closer together without sacrificing safe train separation helps clear the congestion quickly.

Multiple-unit (MU) trains inherently out-perform locomotive-hauled trains in both acceleration and braking because uniform tractive forces are applied at all wheels on the train. The tractive forces are limited by wheel-rail adhesion and passenger comfort (too much acceleration will cause passengers to fall). All the weight of an MU train is born by powered wheels permitting the accelerating force to be directly proportional to the weight of the train.

With a locomotive-hauled train where only the wheels on the locomotive are powered, the accelerating force is proportional to the weight of the locomotive (and limited by wheel-rail-adhesion), but it must accelerate the mass of the whole train which can be much greater than the mass of the locomotive. As a result MU trains can always accelerate faster than a locomotive-hauled train.

All wheels of a locomotive-hauled train are braked, but again the weight of the locomotive prevents braking performance equal to an MU train. In practice a locomotive does not dissipate all of its own great kinetic energy and some of the energy must be dissipated by the trailing coaches. In effect the coaches must stop a mass greater than their own, requiring more time and distance. As a result MU trains can brake faster than locomotive hauled trains.

This discussion leads to the conclusion that high-train-density commuter operations are best served by high-performance MU trains to provide maximum system capacity, minimum trip times, and maximum operating flexibility.

Before the development of the GT/E cars, all high-performance MU cars were powered from wayside electrification systems, either overhead catenary (usually high-voltage ac) or third rail (usually high-voltage dc). The state-of-the-art of such equipment is well advanced and the capital and operating costs are well known. It was the purpose of the GT/E car development program to explore an alternative to the large capital investment required for wayside electrification and to determine under what conditions that alternative would be economically attractive.

The history of New York City requires that trains be capable of operating on wayside electrification. The most immediate reason for this criterion is a public ordinance, dating from 1904, which proscribes combustion engines in tunnels and, in essence, requires electric traction for all trains entering the center of New York City. It should be noted that there may be increasing pressure to electrify in central-city areas as the sale of air rights over railroads for offices, residences and schools becomes more prevalent.

Therefore, the alternative MU car design must have full electric propulsion capability along with some additional source of motive power for times when the car is not on wayside-electrified trackage. For this second power source, the choice of gas turbine instead of diesel engine was made on the basis of the turbine's superior power-to-volume and power-to-weight ratios. The compactness of the turbine made it possible to incorporate two 500 horsepower power plants into each car with no infringement on railroad clearances and with little or no loss of passenger space.

The use of gas turbines rather than diesels in this application had the advantage that turbines are well matched to the power requirements of the dc traction motors. Both the turbines and the motors have the capability to tolerate short-term overloads. This capability allows both turbines and motors to exceed their continuous ratings during car accelerations without causing premature failure.

Since the cars must have a full electric propulsion system and a majority of the car miles would be in the wayside power mode, it would not be logical to incorporate a separate direct-mechanical drive system between the turbines and the wheels. Instead, the gas turbine was applied as an on-board electric power plant to supply energy to the wheels through the same electric motors and controls that were used when the car was on wayside electric power.

Thus the Gas Turbine/Electric cars were basically high-performance EMU cars with alternative sources of electric power: 650-V dc third rail electricity when the cars were on electrified trackage and 650-V dc on-board, gas-turbine-generated electricity when on non-electrified trackage.

1.2 HISTORY OF THE GT/E CARS

The GT/E cars described in this report represent the fourth stage in a systematic development program begun in the mid-1960's with the development by the Budd Company of a single test car. The first car was denoted the GT-1 and incorporated a turbomechanical drive. The purpose of the GT-1 test was to determine if a turbine (a Garrett 831) could withstand the rigors of propulsion service requirements for a commuter railcar. The car was not configured to carry passengers so it was tested in simulated service in 1966-67. The principal conclusions drawn from this testing were (Reference 1.):

TURBINE

Could achieve the required acceleration rates and top speed.

Could withstand the frequent start-stop cycles.

Would not cause unfavorable vibration, noise or exhaust gas problems.

FUEL

Use of jet fuel was not practical on a railroad.

Fuel consumption appeared tolerable at mid-60's fuel costs.

The particular mechanical drive system on the GT-1 car was found to have been inadequate, but this was of only passing interest, since the ultimate objective of the overall program was to develop an electric drive system compatible with the third rail electrification.

In 1968 the test car was re-configured by Budd and Garrett (AiResearch Manufacturing Co. of California, a division of The Garrett Corporation) to incorporate a dual-powered electric drive and was renamed the GT-2. The objective of this stage of development was to test the basic feasibility of a dual-powered electric drive, including changeovers between turbine and third rail power, and to determine if the Garrett turbine could operate on railroad diesel fuel.

The testing of the GT-2 car took place in 1970 and was marred by a very low reliability of the electric propulsion system (which had been assembled from 1000-V dc components used earlier in the original Bay Area Rapid Transit system research program). Nevertheless, the testing did establish (Reference 2):

TURBINE

No increase in smoke resulted from the use of diesel fuel.

DUAL-POWER DRIVE

Changeover between power sources could be achieved smoothly while moving.

The GT-2 testing brought the use of the "patched together" test bed to its limits. Any further track testing, it was concluded, would have to be performed with production prototypes.

A design trade-off study was performed by the General Electric Company (GE) (Reference 3) in preparation for the detailed design of prototypes referred to as "GT-3" cars. The study established propulsion power requirements for the new cars by assuming performance comparable to M-1 cars operating on third rail and simulating the use of the cars in a variety of service applications. The study considered several commercially-available turbines applied to the cars. The GT-2 test work and the GT-3 study were both completed early in 1971.

1.3 GT/E DEMONSTRATION PROGRAM

During the GT-1 and GT-2 test programs and the GT-3 study, Garrett Corporation and GE acquired a working knowledge of many of the factors relevant to the design and construction of GT/E cars.

It was decided that both manufacturers should be encouraged to develop GT/E car designs and to construct prototype vehicles suitable for full revenue operation. Parallel efforts by competing design and construction teams were felt to be consistent with a prudent, programmed development of the GT/E car concept.

An estimate of the car design and construction costs led to the determination that each manufacturer should supply four GT/E cars. The minimum operating group for each car design was to be two-car married pairs. The purchase of four cars from each manufacturer took advantage of the fact that the cost of the second pair was in each case approximately 50% less than the first.

On this basis, a $14.8 million project was envisioned, with approximately $6.5 million going to each manufacturer for four cars and $0.5 million going to each manufacturer for spare parts. Funding in equal shares was obtained in 1971 from the United States Department of Transportation's Urban Mass Transportation Administration and from the State of New York.

The cars were built and tested to verify compliance with the car specification requirements, and then operated in revenue service during 1976-1977 on the Long Island Rail Road over routes requiring operation in both the third rail and the turbine modes. Fuel consumption, poor reliability, and the rapidly rising cost of fuel caused their removal from service.

Figure 1.4-1 M-1 Car Exterior

1.4 GENERAL CHARACTERISTICS OF GT/E CAR DESIGN

This section of the report explains a number of the basic requirements which affected the design of the GT/E cars, and describes design features that are common to both sets of GT/E cars. The following two sections describe design details as developed by the two manufacturers in response to the GT/E Car Specification.

Although the GT/E Car Specification was essentially an addendum to the M-1 specification and was similar to other performance-type specifications, the unusual nature of a four-car prototype order resulted in two departures from normal rail car procurement practices.

First, in accord with the general aim of encouraging new design and construction techniques, and in view of the opportunities for innovation at reduced risk in a small quantity prototype program, the role of the Engineer was reduced to some degree. The engineering consultant (in this case Louis T. Klauder and Associates) retained strong authority on matters relating to safety and to operational requirements while a greater-than-normal degree of leeway was allowed on design or construction details which were not fundamentally related to safety or to operations.

Second, since (as will be explained below) the two GT/E car designs have much in common with the dc electric Metropolitan (M-1) cars in service on the Long Island Rail Road and on the Harlem and Hudson Lines of Conrail, many of the subsystems and components were specified to be their equivalents on the M-1. This particular aspect benefited the purchaser in reducing spare parts inventory and maintenance personnel retraining. The carbuilder benefited, as well, by not having to repeat the performance of certain qualification tests.

Figure 1.4-2 Garrett GT/E Exterior

Figure 1.4-3 General Electric GT/E Exterior

1.4.1 Compatibility with M-1 Cars

A basic feature of the GT/E cars was the ability to operate in trains with M-1 cars. This provided the operational flexibility of coupling GT/E cars to the head end of several M-1 cars. For example, for a trip from Penn Station in Manhattan to Port Jefferson on Eastern Long Island (see Figure 2.1-1) the entire train would operate as an ordinary electric MU train until the end of the third rail electrification at Huntington. At Huntington, the GT/E cars would be uncoupled from the M-1s and would continue, under turbine-generated electric power, to Port Jefferson, while the M-1 cars would return to New York or be routed over other third rail electrified trackage.

This combined-operation capability led to three basic requirements in the design of the GT/E car.

First, the GT/E cars were constructed to resemble the M-1 cars as closely as possible (Figure 1.4-1, -2 and -3). The carbody dimensions, interior configuration and seating, operating cab layout and exterior appearance were designed to duplicate the M-1 configuration, with only the minimum of deviation which was required to include the turbine-generator-related equipment.

Second, the propulsion and braking performance of the GT/E cars in the third rail mode had to equal the M-1 cars, and as can be seen in Table 1.4-1, a high level of performance was carried through to the turbine mode, as well.

Third, the propulsion, braking, communication, door control and other trainlines were designed to allow the operation of these GT/E car systems from a control station in an M-1 car or vice versa. Of course, operation of the uniquely GT/E systems, such as low-level passenger loading or turbine starting, were to be initiated only from a GT/E car control station. However, for these trainlined functions which are listed in Table 1.4-2, the four General Electric cars and the four Garrett cars were to be completely compatible with each other.

1.4.2 Carbody Configuration

The M-1 and GT/E cars were designed and built to operate in two-car, married pair units to allow the

TABLE 1.4-1

GT/E CAR PERFORMANCE SPECIFICATIONS

Acceleration

Time required to travel given distance from standing start, seconds

Distance Miles	GT/E Car Turbine Mode	GT/E Car Third Rail Mode	M-1 Car
1	87	84	70
2	138	133	115
4	228	220	195

Maximum Speed

GT/E Car Turbine Mode	GT/E Car Third Rail Mode	M-1 Car
93.5 mph	94 mph	100 mph

Braking

Full service application of blended dynamic and friction brake:

Car Speed Range	Braking Rate M-1 and Both GT/E Modes
Maximum to 50 mph	Continuously increasing from 1.9 to 3.0 mphps
50 mph to Stop	Constant 3.0 mphps

Emergency application of friction brake only:

Car Speed Range	Braking Rate M-1 and Both GT/E Modes
Maximum to Stop	3.0 mphps

sharing of certain equipment between the two cars. Thus, in general, one of the cars (denoted the "A" car) carried the motor-alternator and batteries, while the mated car (the "B" car) carried the air compressor, main air reservoir, the cab signal and communications equipment, and the toilet room.

Each individual car contained an operating cab and a complete propulsion and braking system. The cars of a pair were semi-permanently coupled together at the non-cab ends with electrical connection being made through jumper cables. At the cab ends the electrical connections, along with the mechanical and pneumatic connections, were made with fully-automatic couplers. Up to six pairs could be coupled together to form 12-car trains.

The Garrett GT/E car underfloor equipment arrangement differed from the M-1 car because of the dc chopper propulsion system, forced air ventilated traction motors and the turbine fuel storage requirements. The Garrett propulsion is described in Reference 4. The underfloor layouts of the M-1, Garrett GT/E Cars, and the GE GT/E cars are shown in Figure 1.4-4, -5, and -6. The GE GT/E car underfloor arrangement differed from the M-1 car only by the addition of the fuel system.

1.4.3 Turbine Compartment

Safety dictated that the turbine-generator units be enclosed in compartments external to the car body. In the Garrett cars, the carbody roof passed beneath the turbine modules and in the GE cars, the carbody sidewall passed on the passenger side of the turbine modules. In both cases the turbines and associated components were on the outside of the car, from the passenger's point of view, thus ensuring the existence of a fire and noise barrier between the passengers and the turbines.

TABLE 1.4-2

GT/E CAR TRAINLINE WIRE ASSIGNMENTS FOR GT/E CAR CONTROL FUNCTIONS

Trainline Wire No.	Identification	Function
PMH	High Platform Mode	Energized for high-platform mode door operation
PML	Low Platform Mode	Energized for low-platform mode door operation
SM	Third Rail Mode	Energized for third rail mode operation
TM	Turbine Mode	Energized for turbine mode operation
SR	Shoe Raise	Energized to raise third rail shoes
TS	Turbine Start	Energized to initiate the trainline turbine start sequence
TC	Turbine Cranking Light	Energized when the trainline turbine cranking sequence is in progress
TF	Turbine Fault	Energized when one or more turbines in the train have shutdown
F	Turbine Fire	Energized when a fire has been detected in a turbine pod and the fire extinguisher has been activated

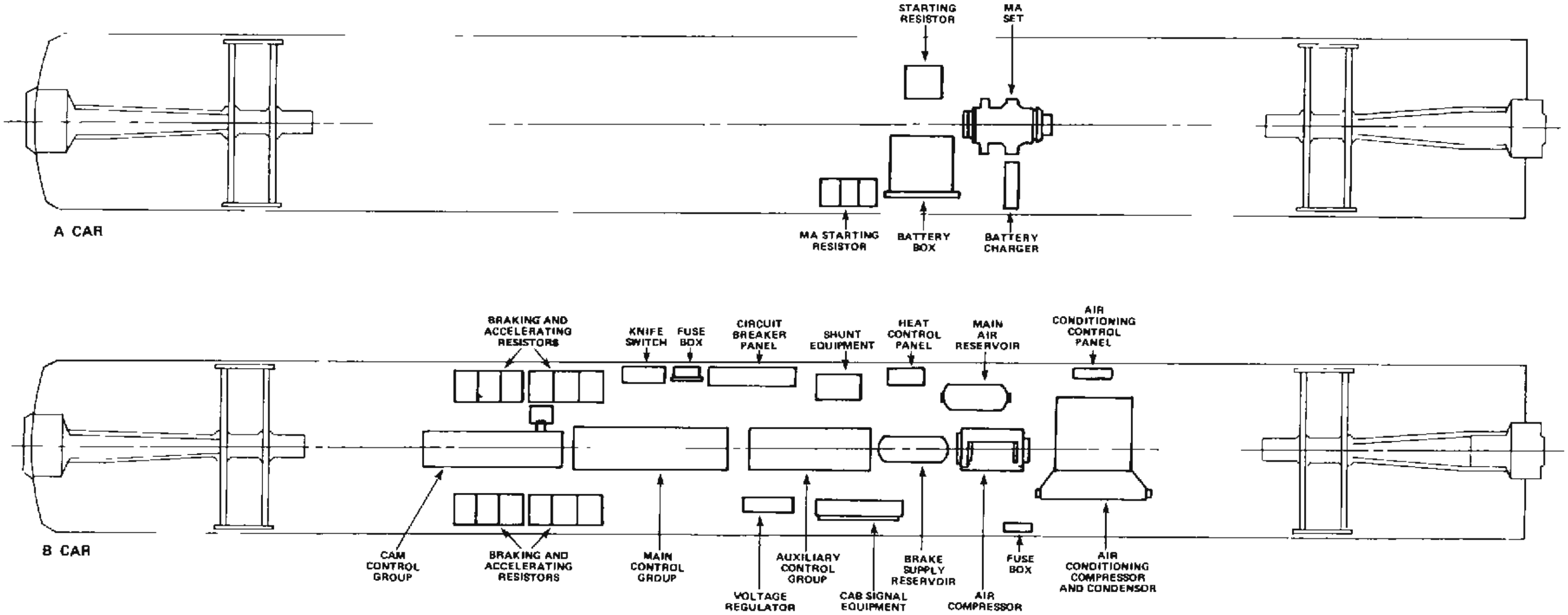


Figure 1.4-4 M-1 Underfloor Equipment Arrangement

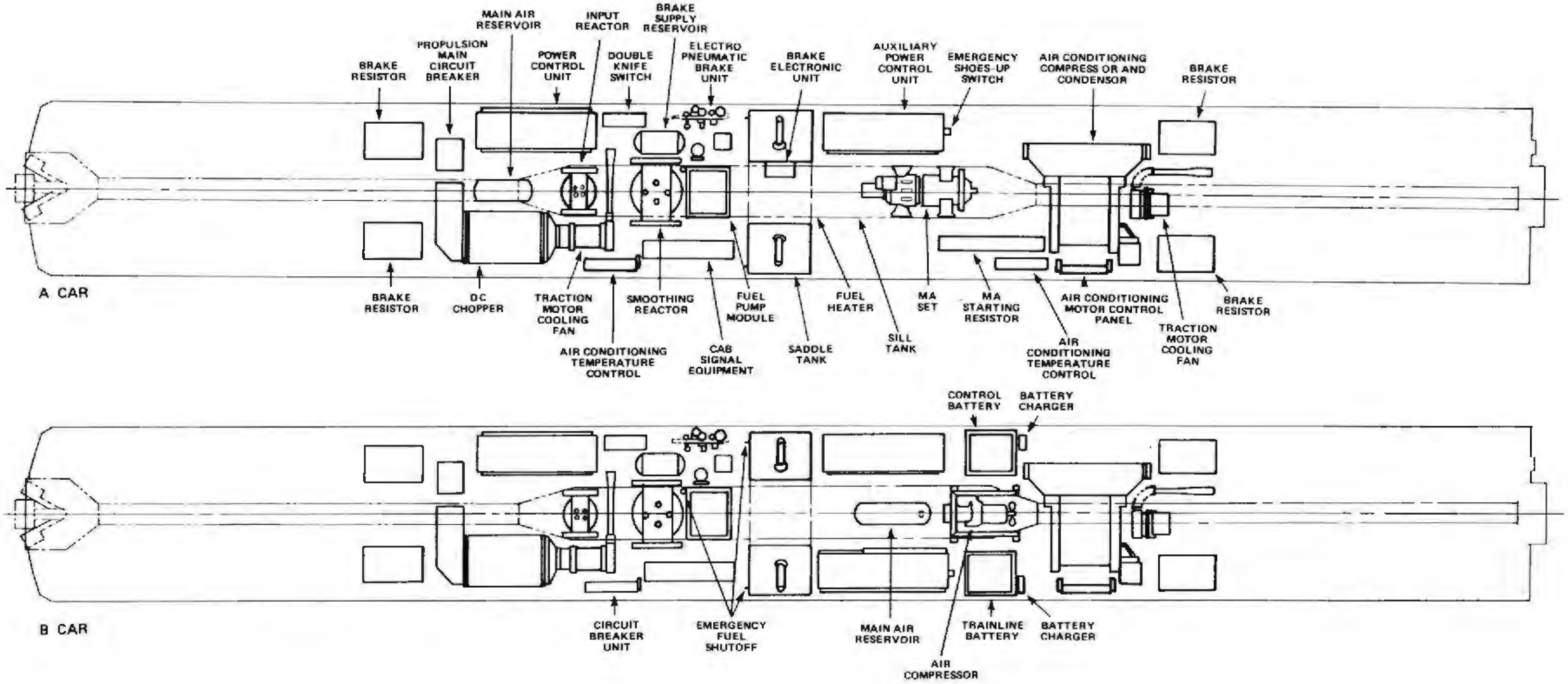


Figure 1.4-5 Garrett GT/E Underfloor Equipment Arrangement

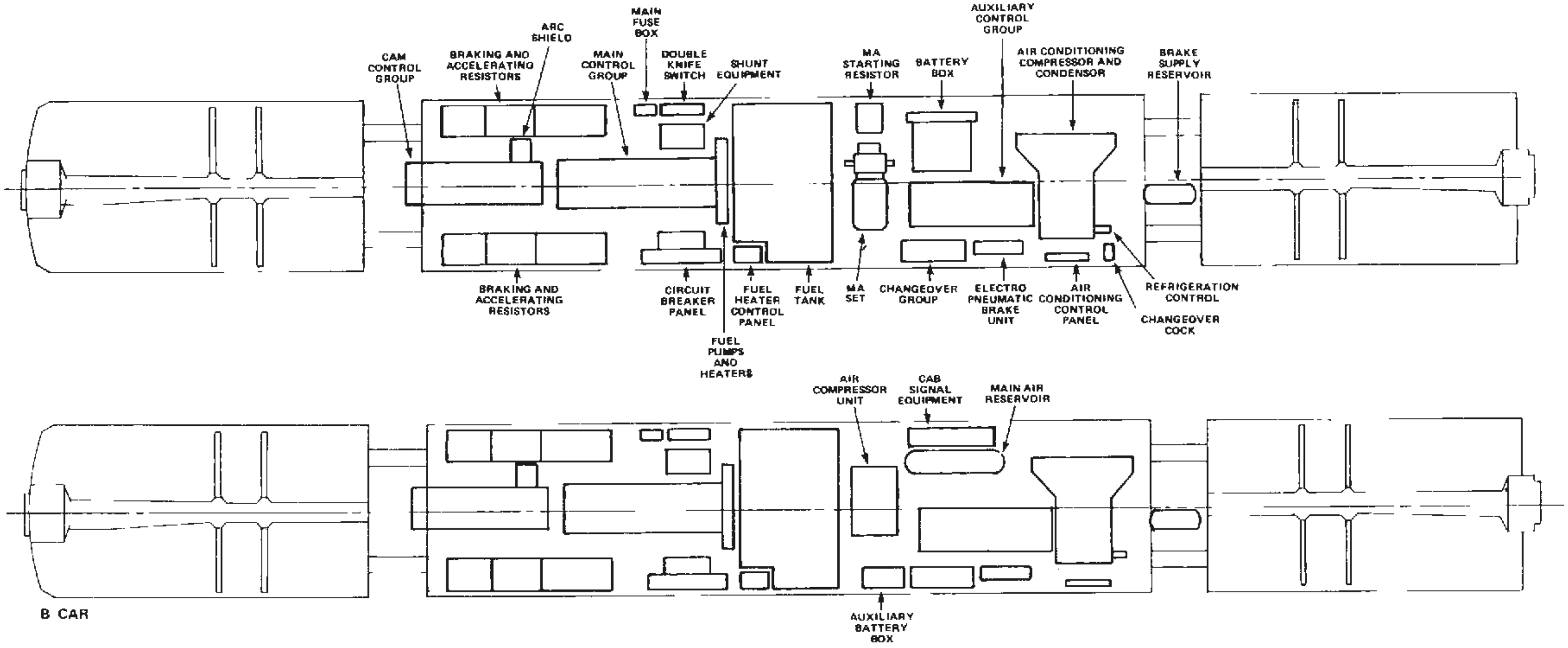


Figure 1.4-6 General Electric GT/E Underfloor Equipment Arrangement

An additional constraint in the design of the turbine installation was the necessity of keeping the turbine exhaust-gas temperatures low enough to not damage the overhead structures and catenary wires. The criterion for this requirement was established by measuring the exhaust temperature of an Erie Lackawanna Railroad push-pull diesel locomotive (General Electric Model U34CH) at full power at the minimum wire height of 15 feet, 9 inches. The temperature was determined to be approximately 350 °F. Air was added to the turbine exhaust gas to reduce the temperature to that level at full power.

1.4.4 Turbine Rotor Containment

Safety also dictated that additional protection be provided against turbine rotor and rotor-blade failures. At the MTA's insistence steel rings were added to the turbine engines at the rotor locations to provide the protection. The precaution proved its value during service when all blades of one wheel disintegrated and only a single blade fragment entered the turbine compartment.

1.4.5 Turbine Fire-Protection System

Each turbine compartment contained a fire protection system consisting of a fire detector, an extinguisher and controls. In the event of a turbine module fire, both turbines on the car were automatically shut down, the system was deenergized, and the extinguishment released into the module. A trainlined signal energized the "Fire" indicator and audible fire alarm in the operating cab, and the exterior turbine fault lamps were lit for the faulted turbine. A turbine shutdown for fire could not be restarted until the module was inspected and repaired, and the fire extinguishment was replaced. The second turbine on the car could be operated after the fire-shutdown turbine was bypassed.

The fire detector was a length of stainless steel tube, containing an inert gas and a gas-filled core material, mounted along the walls of the turbine compartment. The detector operated a pneumatic switch to initiate shutdown and subsequent extinguisher operation. An increase in the average temperature of the sensor would cause the inert gas pressure to rise and operate the switch, or a local hot spot in the detector would liberate the gas from the gas-filled core, raising the pressure and operating the switch. An average temperature of 250° to 300 °F or a one-foot hot spot temperature of 800° to 900 °F would activate the system.

Once activated and following a suitable time delay to allow turbine shutdown, the fire protection system would release the contents of the fire extinguisher into the engine compartment. The fire extinguisher was a welded, hermetically sealed, stainless steel sphere filled with eight pounds of Halon 1301 which produced an internal pressure of 200 psig at 70 °F. The agent was released into the compartment by firing an electrical detonator to rupture a sealed metal diaphragm holding back the Halon. The resulting surge of gas would flood the compartment with a flame extinguishing concentration which would prevent combination until the compartment was ventilated.

1.4.6 Turbine/Third Rail Operating Controls

In view of the small number of GT/E cars, relative to the 950 cars in the M-1 fleet, every effort was made to simplify the controls on the GT/E cars required for the additional functions. The goal was to minimize the amount of training required to qualify an engineman for GT/E service, once he had learned to operate an M-1.

The special GT/E controls and indicators were provided on a panel located on the engineman's main console, at the base of the windshield. The Engineman's turbine control panel on both the Garrett and GE cars were similar. An outline of the GE panel is shown in Figure 1.4-7. The Garrett panel was similar with the "Fire" and "Turbine Fault" light positions interchanged.

For a trip starting in third rail territory, the engineman would operate his train identically as he would an M-1 train. Approximately two minutes before leaving the third rail, he would push the turbine start switch to the "Start" position for about five seconds. (All of the switches on this panel spring back to the center position when they were not being held.) This initiated a sequential startup of the turbines in each GT/E car pairs in the train, whereby each of the four turbines in that pair started in turn. Sequential, rather than parallel, starting in the married pair allowed a reduction in battery capacity for cranking. The crank light remained lit until the turbine starting sequence was completed. If any turbine did not succeed in starting (or if one shut-down at a later time enroute), the turbine fault light would go on. The engineman could find out which turbines were shut down by either looking back at local fault lights along the outside of the train or by asking a trainman to check the local turbine control panels throughout the train.

Changeover from third rail to turbine power was performed by moving the turbine/third rail switch to "Turbine" to set up the trainline circuits and transfer the cars to turbine alternator power just prior to leaving the third rail. The turbine-mode light was lit, and

Figure 1.4-7 Engineman's Turbine Control Panel

the propulsion of the train continued unaffected, under normal circumstances.

When the entire train had proceeded beyond the third rail, the shoe switch was pushed to "Shoes Up", activating the trainline circuits which raised the third rail shoes. No further special actions were required of the engineman for operation of the GT/E car under turbine power.

Operation of the train from non-electrified to third rail territory was performed in exactly the reverse manner, with switch actuation proceeding for right to left on the engineman's panel (i.e., "Shoes Down", then "3rd Rail", then "Turbine Stop").

If one of the sensors of the fire detection and suppression system in a turbine compartment detected an excessive temperature, the turbine in that compartment would shut down and the compartment fire extinguisher would be automatically actuated. The engineman was made aware of this occurrence by an alarm (which could be silenced manually) and by a red warning light on the panel (which cannot be extinguished except by an action from within the affected turbine module).

In addition, the engineman was kept informed by indicator lights of the door-opening mode which was currently in effect. This enabled him to prevent the conductor from opening the doors if the conductor had not chosen the mode which was appropriate to that territory.

1.4.7 Turbine Fuel

One of the major conclusions of the GT-1 program was that the use of kerosene (or "jet" fuel) would be impractical on a railroad. This conclusion was based on the fact that all the fuel used for railroad locomotives is No. 2 Diesel and that the logistics of providing an additional type of fuel would be too complex to be followed on a routine basis. As a result of this experience, combined with the successful use of

No. 2 Diesel in the turbines of the GT-2 test car, the GT/E cars were designed to use No. 2 Diesel fuel.

Each GT/E car had a separate and self-contained fuel system consisting of a fuel tank(s), fuel heater, fuel pump module, and associated valves and plumbing. The functions of the fuel system were the storage, heating and pressurization of the diesel fuel for supply to the turbine modules.

Both GT/E car designs included a diesel fuel capacity of 800 gallons. As with the turbine compartment, the entire fuel system was external to the passenger compartment (i.e., below the floor or outside of structural members and sheathing).

In addition to a number of automatic cutoff valves, manual emergency fuel cut-off valve operators were located in the cab and below the floor, on each side of each car.

1.4.8 Power Distribution

The M-1 cars are equipped with a single-blade knife switch to allow shop personnel to disconnect the car from the third rail 650-V power source during maintenance operations. The M-1 knife switch has three operating positions and a fully-open position as shown in Figure 1.4-8.

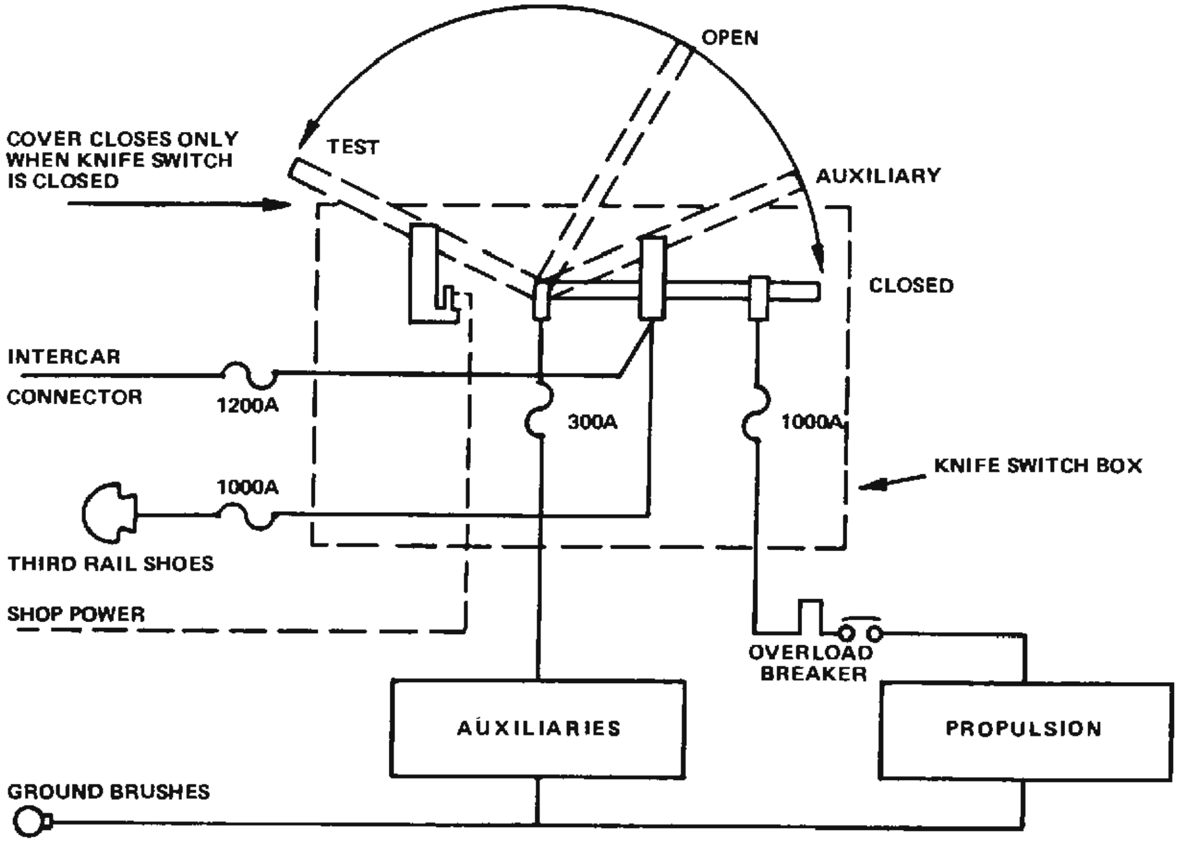
One position connects the car auxiliary circuits to the 600-V shop power through a cable plugged into the car inside the knife-switch box. In this position the third rail shoes were deenergized and the knife switch box cover could not be closed, both in the interest of shop safety.

In the second partially-closed position the auxiliaries are energized from the third rail shoes and the propulsion system is not energized. In the fully-closed position both the auxiliaries and the propulsion are energized from the third rail shoes and the knife switch box cover can be closed.

A concern for the safety of the maintenance personnel working on the GT/E cars led to the requirement that the GT/E knife switch function identically to that of the M-1. This standard was achieved only by the addition of a second blade to the knife switch (operating in parallel with the first blade) because of the capability of the on-board turbines to feed high-voltage electricity to these same circuits.

In order to avoid another possible safety hazard, the high-voltage circuits were arranged so the third rail shoes could not be energized by the turbine-generators.

Figure 1.4-8 M-1 Knife Switch and Power Distribution



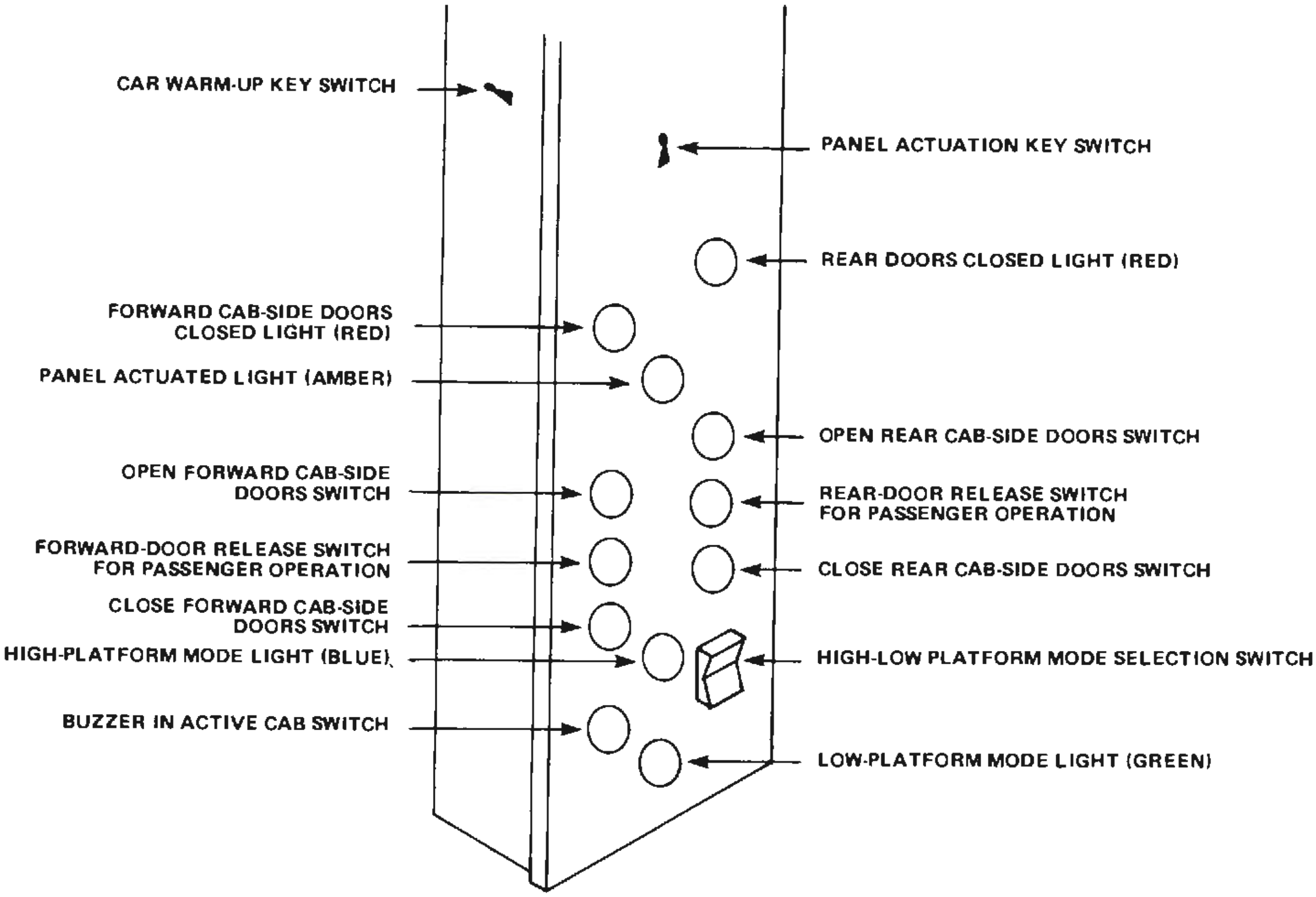


Figure 1.4-9 Garrett Door Control Panel

1.4.9 Third Rail Shoe Support and Retraction

In order to allow operation of the GT/E cars on the electrified portions of the LIRR (with over-running third rail) and Conrail's Harlem and Hudson Lines (with under-running third rail) the current collection "shoes" of the GT/E cars had to be capable of both types of collection. This capability is feasible because of a ¾-inch overlap between the lower face of the Conrail third rail and the upper face of the LIRR third rail. The combination of this overlap dimension plus the shoe thickness enables spring pressure to be applied in both the up and down directions.

In the normal current collection position the third rail shoes violate the car clearance lines in the non-electrified territories. To keep the wayside expenditures at a minimum, the shoes were required to be retractable in order to eliminate the violation. Thus, after the train had left third rail territory, the engineman actuated a toggle switch on the Engineman's Turbine Control Panel (Figure 1.4-7) to retract all the shoes on the train. In the retracted position the entire shoe mechanism was within the normal railroad clearance lines and no additional clearance was required on the wayside. The process was reversed in the other direction, with the shoes going into position throughout the train before entering third rail territory. In order to guard against the Engineman's inadvertently neglecting to retract shoes after leaving or to extend shoes before entering the third rail territory, "Shoes Up" and "Shoes Down" signs were provided at the appropriate locations on the wayside.

The carbuilders were not required to provide an extension/retraction mechanism which would function while the cars were alongside a third rail. If the shoes were extended while a third rail was present they were broken off the car.

Both the capabilities of retraction and of over and under running had been achieved on New Haven Railroad locomotives operating into Grand Central Terminal and Penn Station, New York since 1917. The GT/E cars were the first MU cars to require such capabilities, however.

One additional detail of the third rail shoe arrangement, which compounded the design complexity, resulted from the particular truck chosen by both carbuilders. The truck (GSI G-70) had inboard journals which created a comparatively long distance between the third rail and the equalizer bars

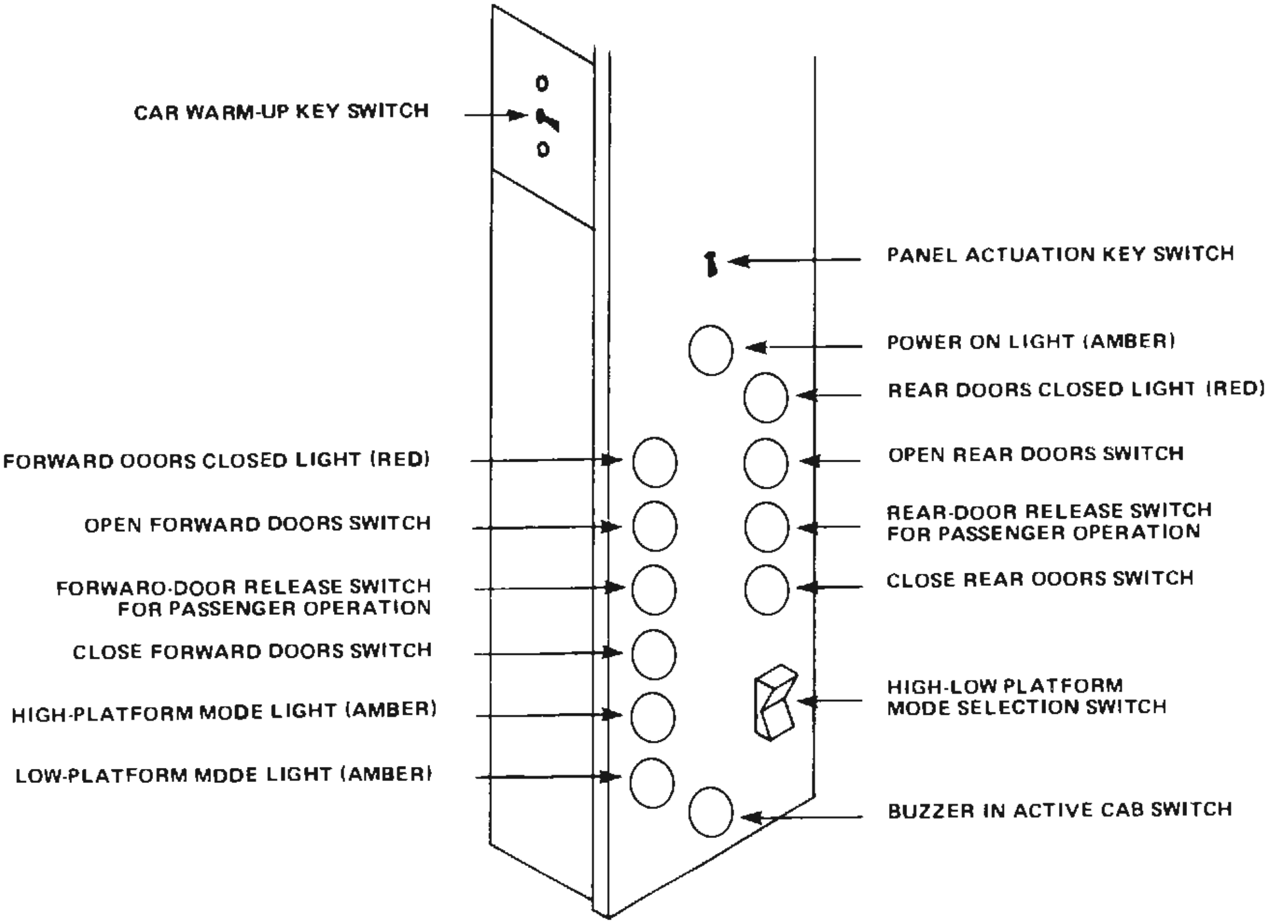


Figure 1.4-10 General Electric Door Control Panel

(which are the only non-rotating parts of the truck of constant height with respect to the third rail). A direct mounting of the shoe mechanism on the equalizer bars would have placed a twisting load on the equalizer bars. Therefore, it was necessary for the car designers to provide a mounting platform for the shoe mechanism that was stable in space, with respect to the third rail.

1.4.10 Doors and Bilevel Steps

One of the most successful design features of the M-1 cars in improving operating efficiency has been the use of wide, floor-level, passenger doorways located at the ¼ and ¾ points along the length of the 85-ft. cars. The wide doors combined with high-level station platforms (i.e., at the car-floor height of 50 inches above the rail) optimized the flow of passengers in and out of the cars and dramatically reduced station dwell times.

One of the goals of the GT/E program was to retain the quarter-point, wide-door concept without investing an enormous amount of capital to build high-level platforms at the multitude of stations to be served by the eight-car "fleet" of GT/E cars. The two carbuilders approached this goal in very different manners, as will be discussed in detail later in this report. Both, however, provided a means for the train conductor to select, on a train-wide basis, between the high-level mode (which allowed entrance and exit at car-floor level) and the low-level mode (which provided steps at the same doorways to a station platform only slightly above the top of the rails).

In a typical run on the LIRR or the Harlem and Hudson Lines, the cars were started from an outlying terminal with platform and the door controls set up for low-level passenger loading, and when the Conductor operated one of the "Door Open" pushbuttons (Figure 1.4-9 and -10), the doors on that side of the train were opened with low-level steps exposed. When the train entered a region with high-level platforms (coincident in this case with the start of electrification), the Conductor actuated the "High Mode" switch from any one of the door control panels in the train and all subsequent door openings were at the car-floor level.

1.5 GARRETT CORPORATION GT/E CAR

1.5.1 Turbine Compartment

The turbine-alternator assemblies in the Garrett GT/E car were located in modules set in depressions in the car roof as shown in Figure 1.5-1. The turbine modules were mounted externally to the roof of the car and were not a structural element of the car body. The roof of the car passed under the turbine module, preventing any leakage of water, fuel or oil into the passenger compartment. The control and power cables entered the turbine module from the end of the car, preventing any fluid leakage around cables and connectors. The headroom in the interior of the car was comparable to that existing if the baggage rack had been extended inward to the aisle. Thus, no seated headroom was lost. The roof depression was notched upward at the conductor's operating station window to allow adequate headroom for the standing conductor.

The Association of American Railroads/Federal Railroad Administration's 800,000 pound carbody compression test was performed with ballast installed in the roof depressions in place of the 3,875 pound turbine modules. The weight of the ballast simulated mounted turbine module loads during the test.

Efforts to prevent entry of turbine and drive train noise into the passenger compartment were threefold, as illustrated in Figure 1.5-2. The turbine, gearbox and alternator assembly were mounted to the turbine module enclosure on rubber isolating mounts. The turbine module wall construction consisted of two sheets of stainless steel with a layer of polyurethane foam insulation between them for noise suppression. The module was then mounted to the carbody structure on vibration isolators. Due to these measures, turbine noise was barely percep-

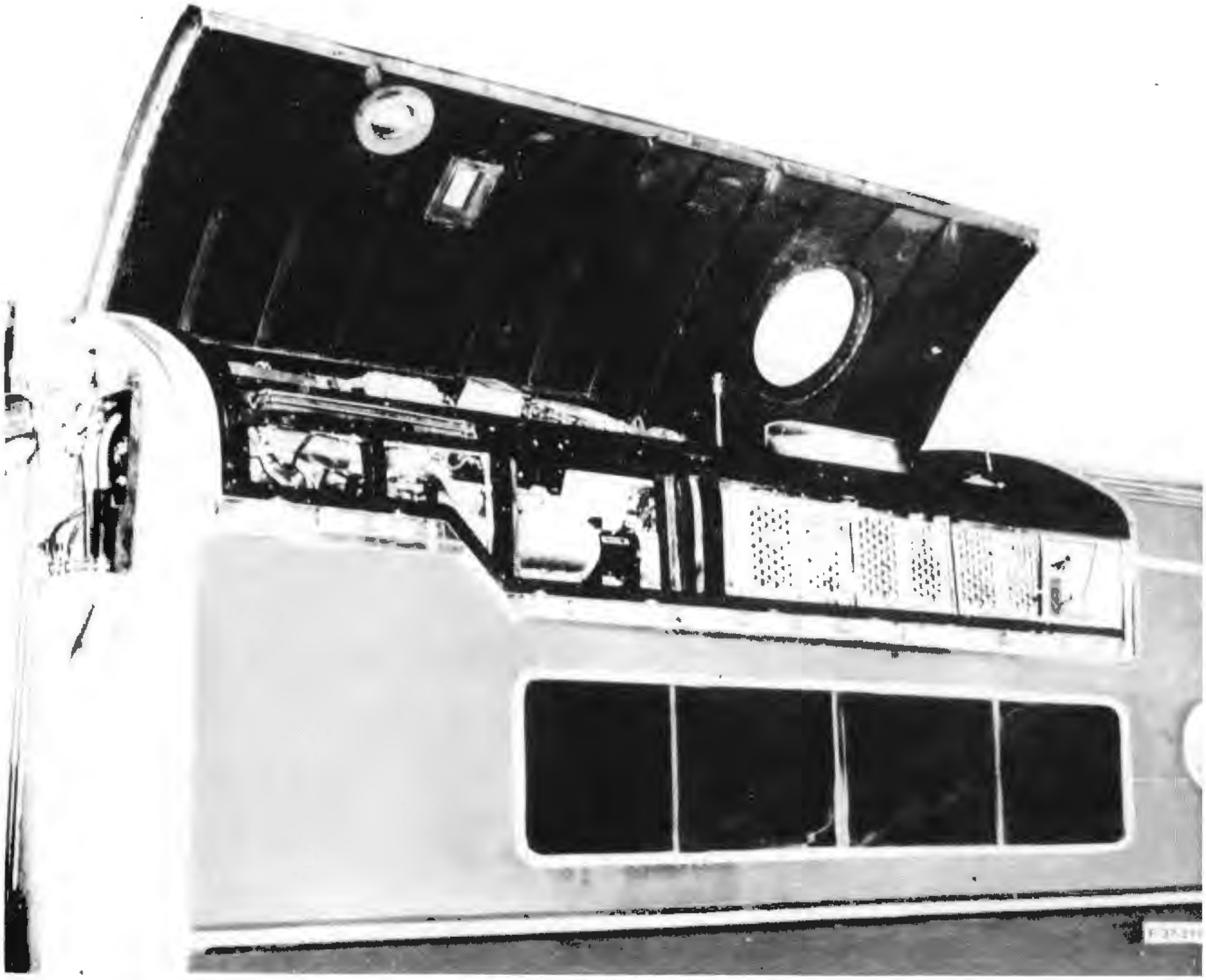


Figure 1.5-1 Garrett Turbine Module Installed in Car

tible inside a moving car. The module cover was hinged on the top side, and supported by a hydraulic cylinder that was operated by a hand pump for raising and lowering the cover. The cover was secured with captive bolts when closed and was held with a safety rod when open. The module-cover construction included an inside skin of 1010 perforated stainless steel sheet which allowed sound to enter the 2-inch thick polyurethane foam insulation and be absorbed.

Figure 1.5-3 is a photograph of the inside of a Garrett turbine-generator module showing the arrangement of the apparatus in the module. The module was divided into an electrical compartment and a turbine compartment by a firewall. The electrical compartment contained the gearbox, alternator, rectifier, electronic controls and the fire extinguisher, while the turbine compartment contained the turbine, inlet air filter, oil cooler and blower, and turbine exhaust-gas cooler. The turbine, gearbox, and alternator shafts were linearly arranged in the module to achieve the long narrow profile required for the overhead installation.

The gas turbine engine was an AiResearch Model GTP 831-500 modified somewhat for the railcar application. The turbine was rated 500 hp for continuous operation, 550 hp for intermittent operation and 580 maximum performance rated at sea level. The nominal engine rotor speed was 41,730 rpm. No. 2 diesel fuel consumption varied from 30 gph at no load to 55 gph at full load.

The gear box assembly reduced the shaft speed to 9,090 rpm and drove the alternator. The gear box was oil spray lubricated with gravity oil drainage.

The ac generator was built by Westinghouse Electric Corporation and operated at 9,090 rpm with pressure lubricated bearings. The generator output rating was matched to the turbine rating and was 450 kVA continuous, 500 KVA intermittent. The generator operated at 277/480 V ac, 454.5 Hz, and was three-phase, 4-wire connected. The output voltage was regulated by controlling the exciter field current with a solid state voltage regulator.

The output of the generator went through a three-phase, full-wave rectifier and then to the car power distribution system. The output of the rectifier was 650 V dc with a momentary overload rating of 200%. The rectifier was forced air cooled, requiring 600 cfm of air at 122 °F or less.

The fuel delivered to the turbine pod by the undercar fuel system was pumped through a filter, metering valve, solenoid shutoff valve, heater, and atomi-

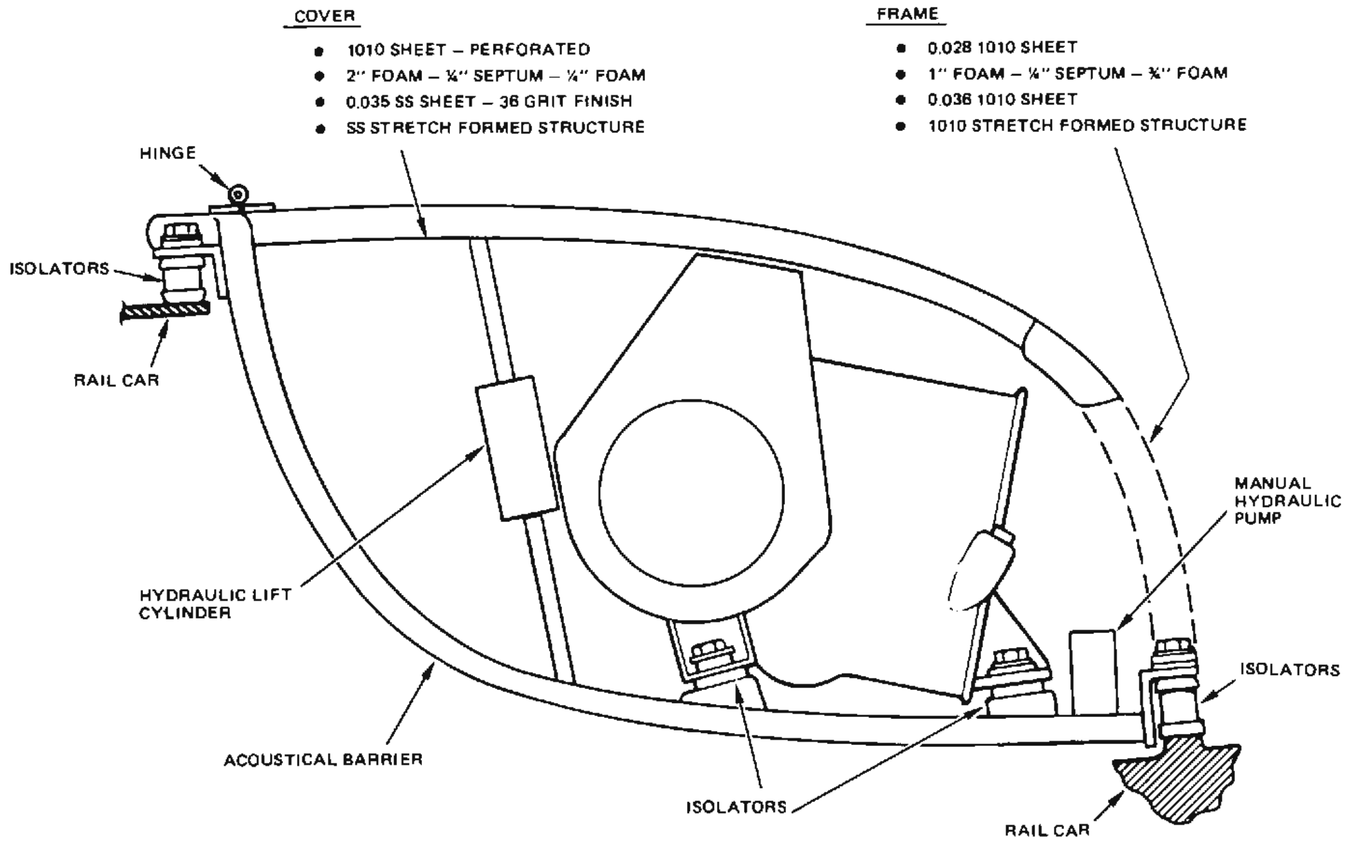


Figure 1.5-2 Garrett Turbine Isolation

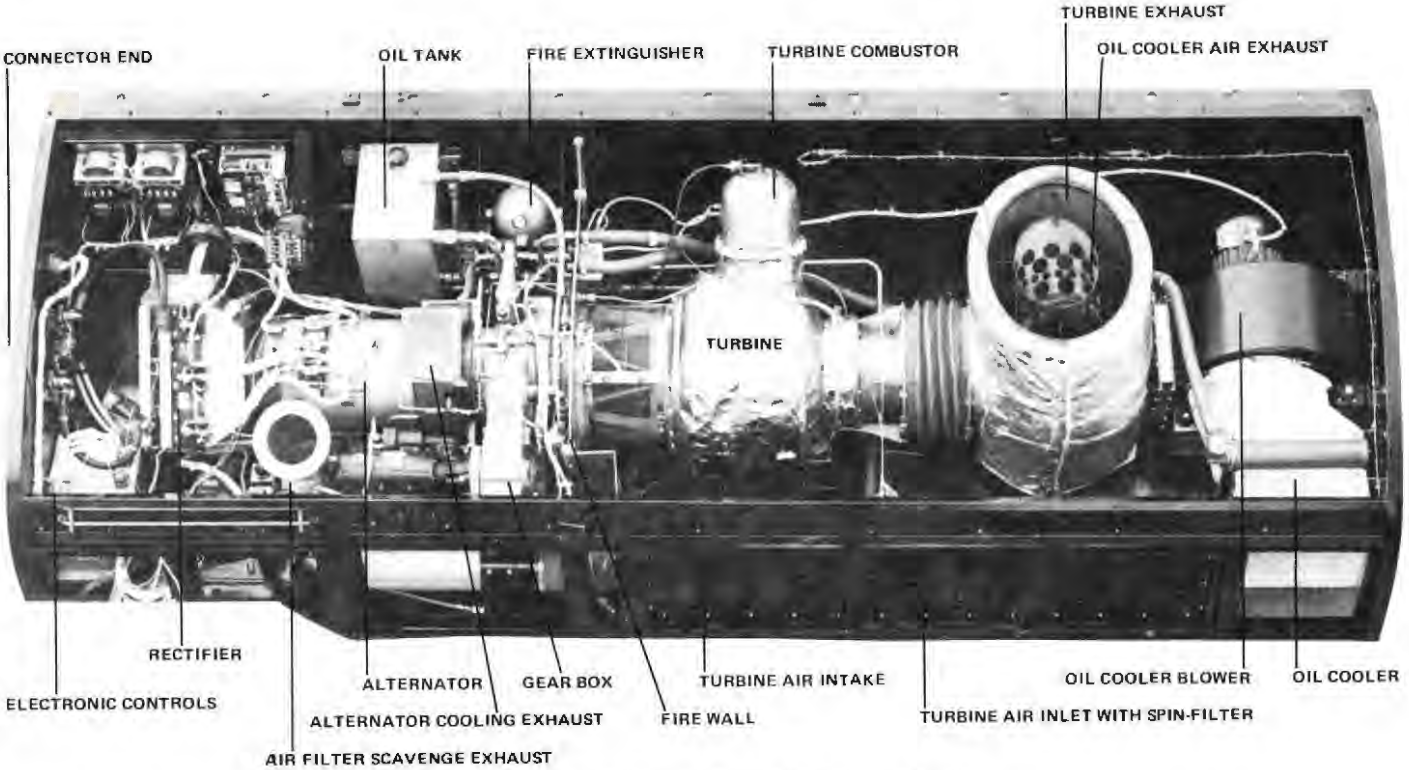


Figure 1.5-3 Interior of Garrett Turbine Module

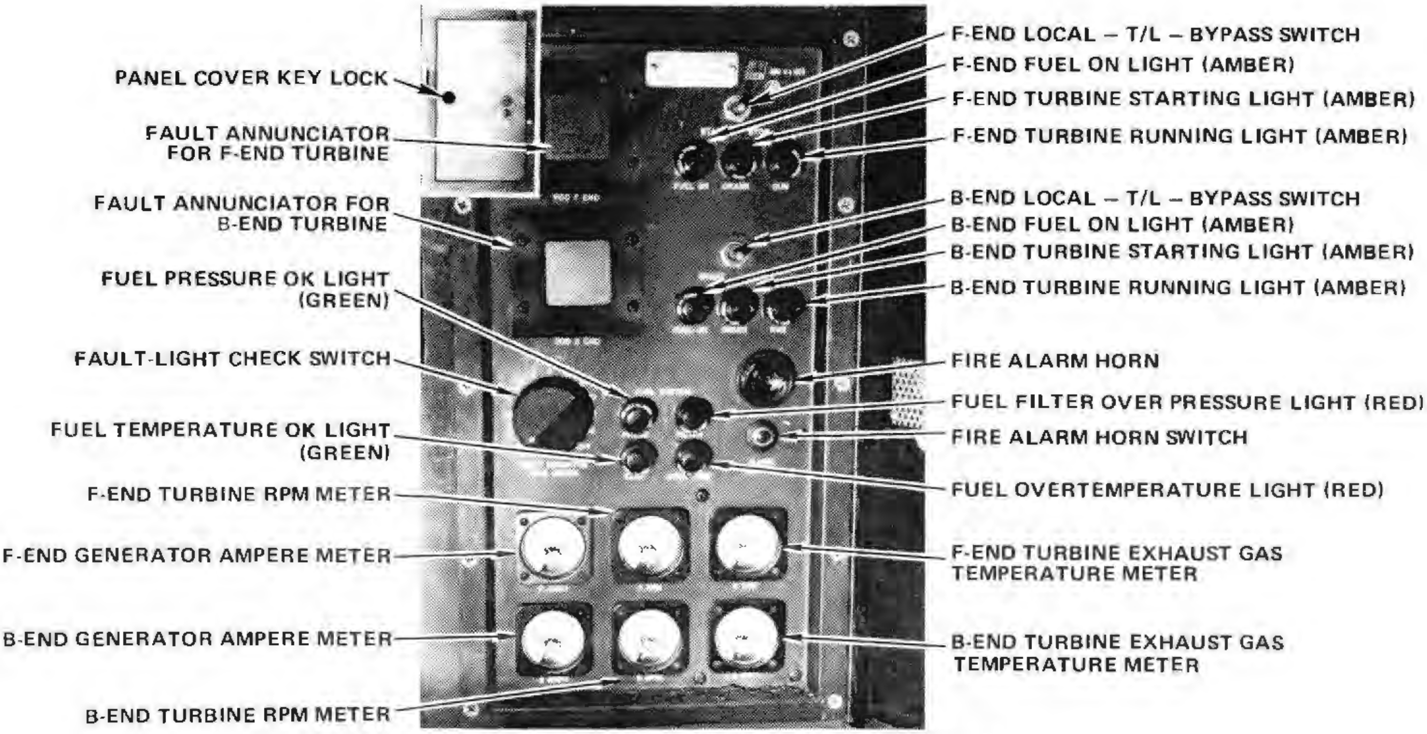


Figure 1.5-4 Garrett Local Turbine Control Panel

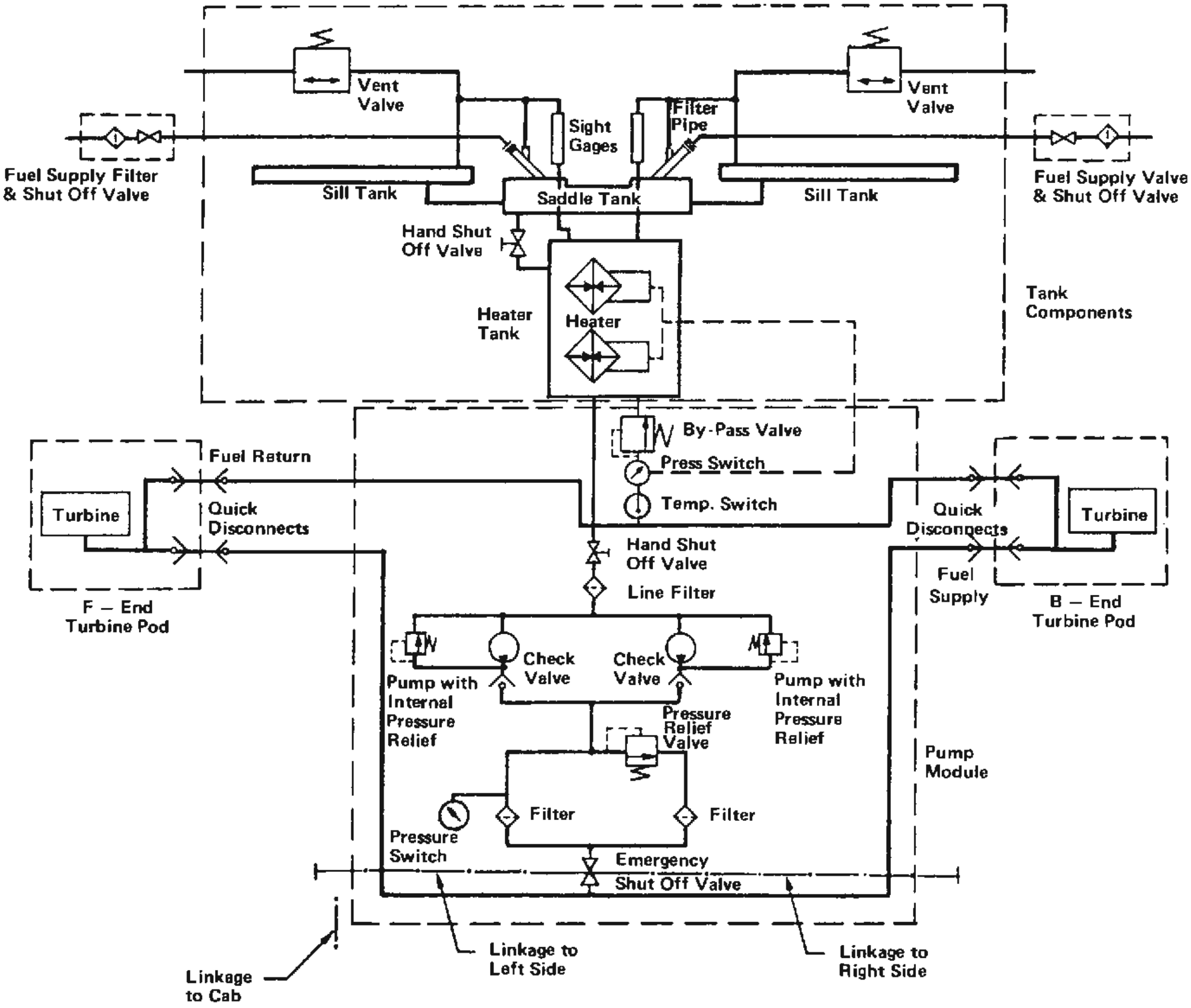


Figure 1.5-5 Garrett Fuel System Schematic Diagram 20

zer into the turbine combustor. Fuel flow to the combustor was regulated by draining off the unneeded fuel output of the dc-powered high-pressure gear pump.

The dc starter motor was mounted on the gearbox and accelerated the turbine to ignition speed under the control of the electronic control unit. The electronic control unit monitored all pertinent turbine generator parameters and would not start the turbine and would shut the turbine down when the parameters were not within the prescribed limits.

1.5.2 Turbine Controls and Indications

On the Garrett GT/E cars the fuel system indications and individual turbine controls and indications were provided on a local turbine control panel located in the outside corner structure of the operators cab, facing the length of the car. It was covered by a locked door to limit access to authorized service personnel. The panel is shown in Figure 1.5-4.

Individual controls and indications, for both of the turbine modules on a car, were provided on the local turbine control panel. A local/trainline/bypass switch permitted the turbines to be started and controlled locally or remotely by trainline, and to be made inoperative. For each turbine there was an amber "Fuel On" light that was lit when the fuel supply pressure was satisfactory; an amber "Crank" light that was lit while the starter was engaged and a green "Run" light that was lit when the turbine was ready for an electric load. Meters indicated turbine speed, turbine exhaust gas temperature and generator output current.

An annunciator gave visual indication as to the type of failure in a turbine generator pod.

A trainlined horn sounded on the local turbine control panel in the control cab for a turbine fire anywhere on the train. The operator could temporarily silence the fire horn by operating the alarm switch through a hole in the panel cover.

1.5.3 Fuel System

The Garrett GT/E car fuel system consisted of three fuel tanks, a fuel heater, a fuel pump module and associated valves and pumping, as indicated in Figure 1.5-5. Each GT/E car had an identical fuel system to heat, pressurize and filter the No. 2 diesel fuel used by the turbines on the car.

Fuel was stored in three tanks on each car. Two, longitudinal 175-gallon tanks were installed within the center sill of the car body, and one, transverse 450-gallon tank was carried below the center sill at the longitudinal center of the car.

Each fuel tank contained a rubber bladder filled with open-cell foam. The 175-gallon bladders were retained by the center sill and the 450-gallon tank was mounted within a 0.19-inch thick, low-alloy, high-tensile steel saddle tank. The rubber bladders were used to maintain fuel tank integrity in the event of collision and the foam interior retarded the release of fuel if both the structure and the bladder were ruptured. The bladders were installed through holes in the tank structures that were sealed with a flanged assembly containing the connecting piping.

The fuel tanks were inter-connected to permit filling all three tanks from either of the fuel fill nozzles located one on each side of the car body at the midpoint. As the sill tanks were above the saddle tank, the saddle tank filled first, venting through the sill tanks. Total fuel quantity was indicated on a fuel level sight gauge. The tank connections are shown in Figure 1.5-6.

A 230-V ac, three-phase, 18-kW fuel heater was installed in a 50-gallon tank and heated the fuel as it was pumped from the tanks and circulated to the turbines. The fuel heater was thermostatically regulated to maintain the fuel temperature in the tank between 70 and 85 °F. A temperature controlled bypass valve permitted recirculation of fuel, from the turbine supply and return lines when the return line temperature dropped below 60-63 °F. The bypass valve was closed when the return line temperature was above 65-68 °F. Additional fuel heaters were located in the turbine modules to ensure proper fuel temperature at the engine combustor nozzles. A fuel system temperature light on the auxiliary control panel was lit green when the fuel temperature was above 72 °F. A fuel system over-temperature light was lit red when fuel temperature exceeded 85 °F.

The fuel pump module incorporated two pumps, three filters, a pressure relief valve, a bypass valve, two pressure switches, two check valves, and an emergency shut-off valve. The fuel pumps consisted of a hydraulic pump with an internal pressure relief valve, driven by a 32-V dc motor. The fuel system control relays operated the pumps alternately. Fuel was constantly circulated to the turbines, back the return lines and through the filters with burned fuel made up from the heater tank. A fuel system pressure light was lit green on the auxiliary control panel when fuel supply pressure was above 20 psi.

The three filters were arranged so fuel flowed through two of them in series at all times. A pump inlet filter prevented pump damage while outlet filters prevent turbine contamination. The two outlet

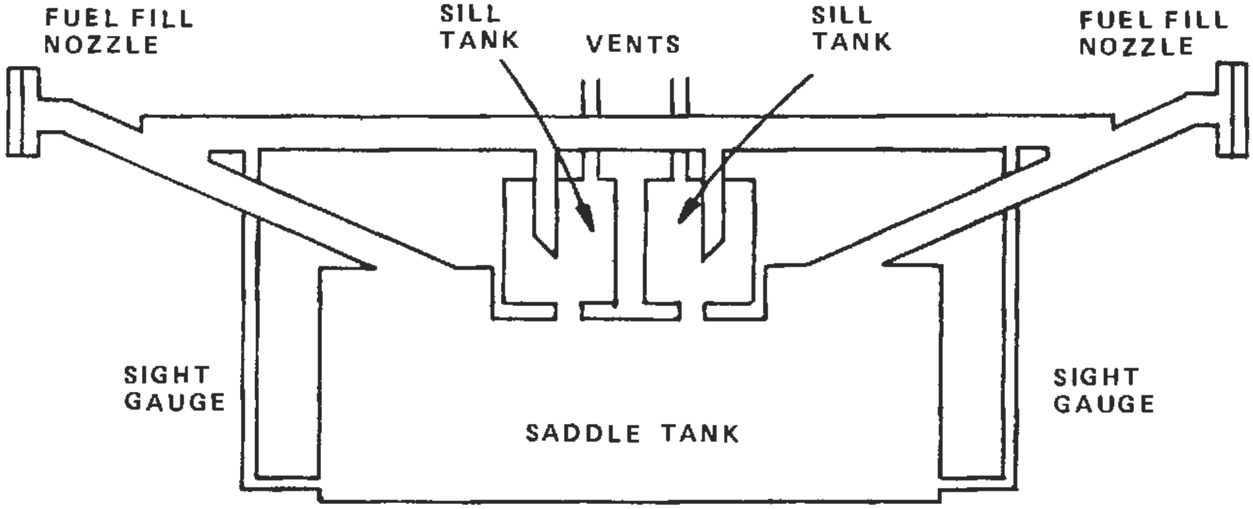


Figure 1.5-6 Garrett Fuel Tank Connections

filters were connected in parallel with a pressure switch across one and a pressure relief valve across the other. When contaminations cause the pressure across the primary filter to rise to 45 psig the pressure switch opened the relief valve and fuel flowed through the parallel filter. The dirty filter condition was indicated on the auxiliary control panel by a red light.

A manual emergency shutoff valve was located in the supply line at the filter outlet. The emergency fuel shut-off valve was operated by a linkage from each side of the railcar and the engineer's cab.

1.5.4 Power Distribution

The supply of dc power to the GT/E car subsystems was provided either directly from the 650-V dc third rail (over-running or under-running) or from the output of the pair of on-board, gas-turbine-driven three-phase alternators. The dc distribution connections were such that the turbine-alternator power supplies functioned as a substitute for the dc third rail power supply in non-electrified territory. The power distribution system is shown schematically in Figure 1.5-7.

The knife switch box contained a two-pole knife switch, a 1200-A main fuse, a 1200-A intercar bus line fuse, and a 150-A heater fuse. In addition, the A-car knife switch box also contained a 400-A motor-alternator fuse and a 2-A dead battery MA start fuse. The two-pole knife switch was designed to; 1) isolate all car systems from the third rail power and turbine-generator power when in the open position; 2) provide power to the car auxiliary systems for test purposes from a shop power supply in the test position; and 3) provide auxiliary power to the car from the third rail or turbine generators in the half-closed position. In these three positions the traction power connection was isolated.

Either the line switch or turbine contactor closed to connect the car systems to the third rail or to the turbine-generator. The line switch and turbine contactor operated in response to the mode trainline which was energized by the engineer's mode switch on the cab console. The opening and closing of the line switch and turbine connector were normally made under no-load conditions and were interlocked to prevent simultaneous operation.

The inductance and capacitance (LC) filter con-

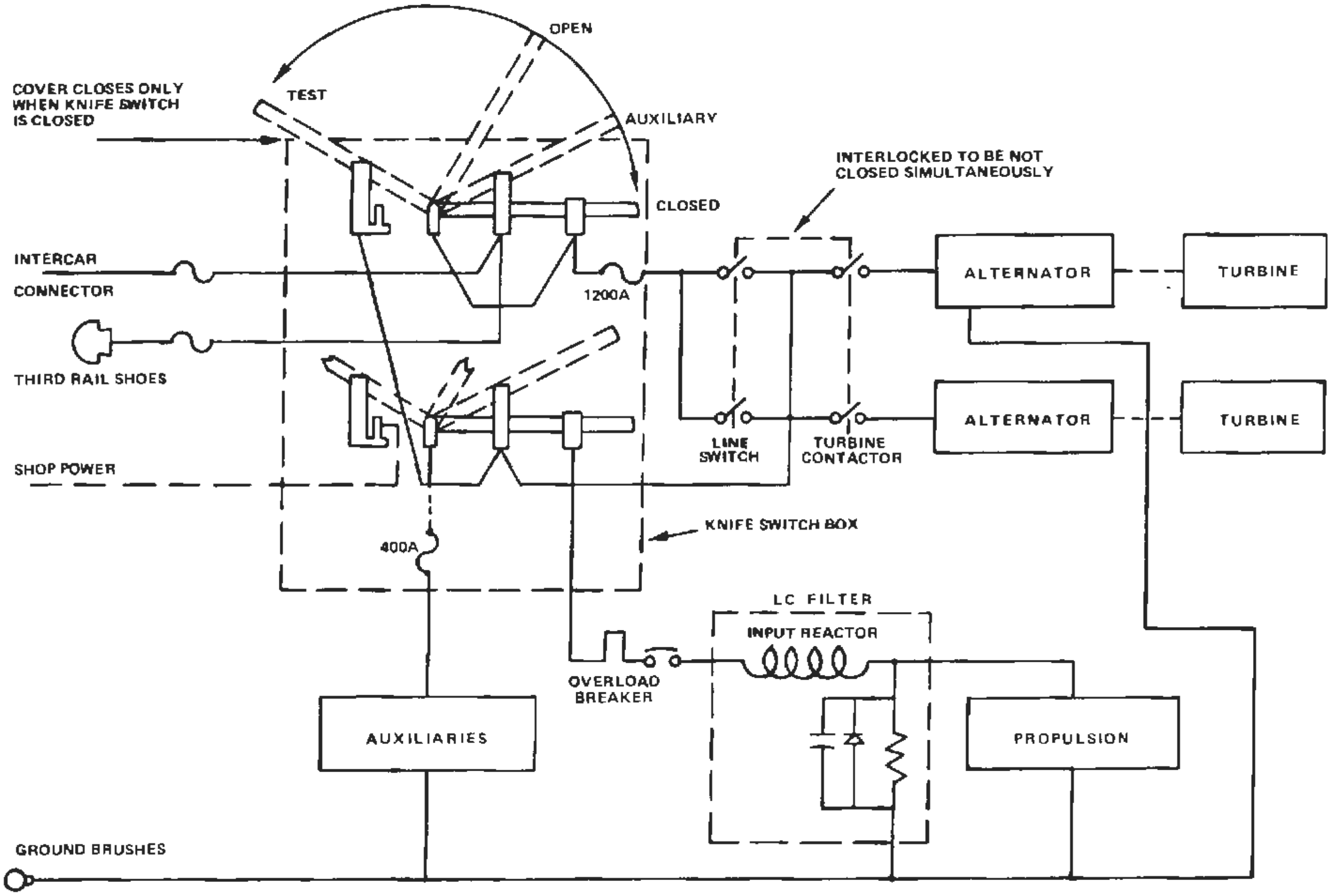


Figure 1.5-7 Garrett Power Distribution System

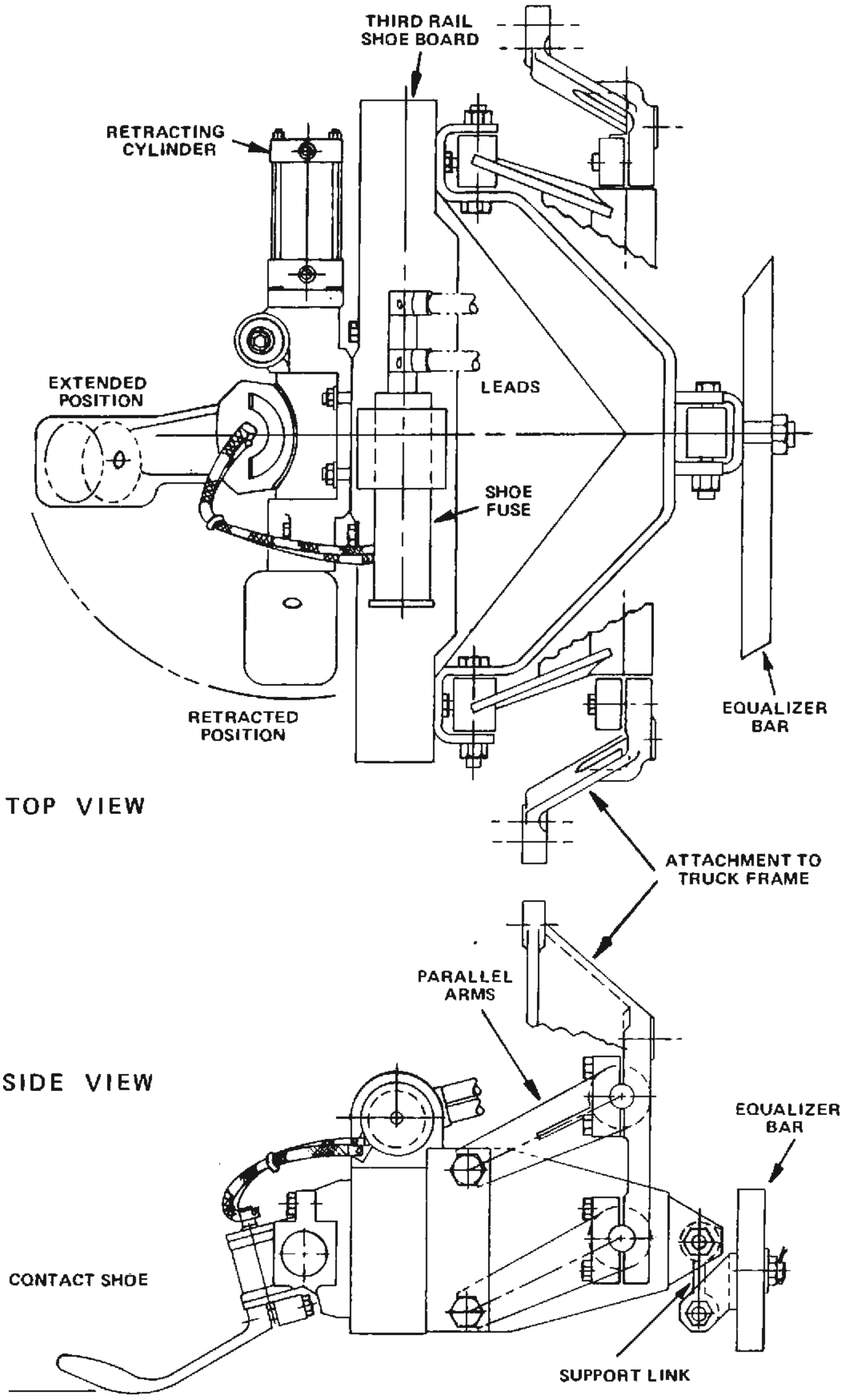


Figure 1.5-8 Garrett Third Rail Shoe Support and Retraction

sisted of a high-current, strip-wound, air-core inductor rated at .3 ± .015 millihenry and 1230 amperes rms, and a bank of 55 capacitors rated at 6000 microfarad with a −10%, +50% tolerance. The LC filter was connected between the third rail or turbine generator and the dc chopper to limit voltage and current transients into the chopper power control system.

An overload breaker was connected between the knife switch and the dc chopper to isolate the propulsion system from the third rail and turbine-generator supply during the dynamic braking mode, to interrupt the supply during a fault, and to remove propulsion power upon an emergency brake application.

1.5.5 Third Rail Shoe Support and Retraction

The Garrett Corporation cars utilized parallel linkages attached to the truck frame and a double pinned connection to the equalizer to maintain the third rail shoes in a position of nearly constant height above the top of the rails. The linkage is illustrated in Figure 1.5-8. The parallel linkage provided the moment required to support the weight of the third rail shoe mechanism at a distance from the equalizer while transmitting the weight of the mechanism directly to the equalizer.

The parallel linkage and the link at the equalizer allowed the truck frame and equalizer to move relative to each other without adverse effects on the third rail shoe position.

A wooden shoe beam was attached to the support mechanism and in turn had the third rail shoe assembly attached to it. An air cylinder rotated the third rail shoe one-quarter turn in a horizontal plane and thus extended or retracted the third rail shoe.

1.5.6 Doors and Bilevel Steps

The Garrett GT/E cars achieved high- and low-platform capability by using a fixed stairway and a section of horizontally-moving floor to cover the stairs for high-platform use and to expose the stairs for low-platform use. The arrangement is shown in Figure 1.5-9.

The sliding-floor section moved longitudinally a distance of 30 inches while one door leaf opened fully and the other door leaf opened only five inches. The low-platform stair width was thus 30 inches. During operation the sliding-floor section was moved first and when near fully opened (closed) the doors began to open (close).

A handrail was mounted on the end of the sliding-floor section to prevent passengers from stepping off the two- and three-step side of the stairwell. The sliding-floor section had a sensitive-edge control on the exposed edge to prevent capturing passengers in the sliding-floor section. A sensitive edge was also located on the wall at the closing point of the sliding-floor section. A mechanical release was provided to permit manual operation of the sliding floor section.

Figure 1.5-9
Garrett Doors and Bilevel Steps

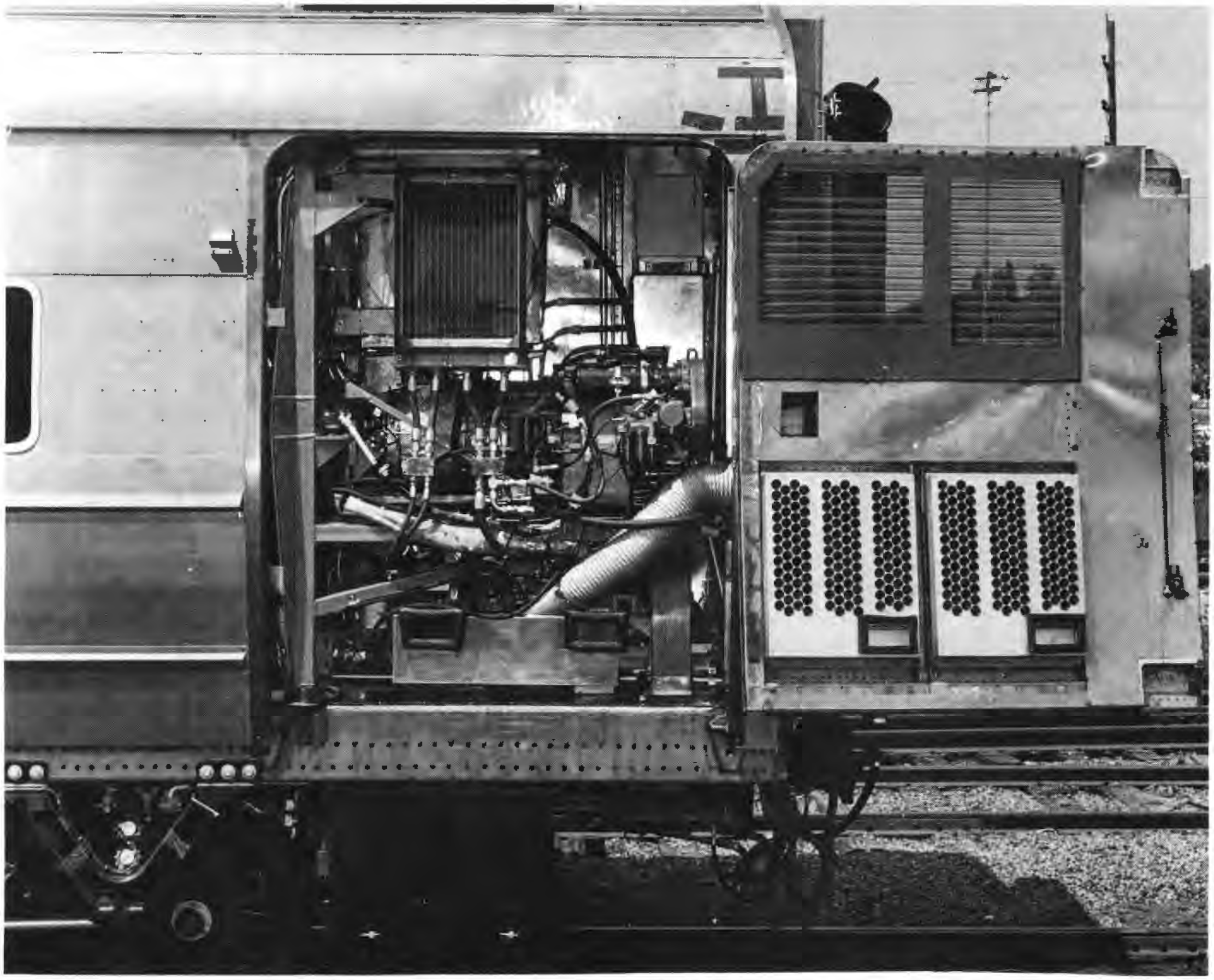


Figure 1.6-1 General Electric Turbine Compartment

1.6 GENERAL ELECTRIC CO. GT/E CAR

1.6.1 Turbine Compartment

The turbine-generator units on the General Electric Company cars were located diagonally opposite each other at the ends of the cars. The compartments were floor-to-ceiling intrusions into the carbody structure, as illustrated in Figure 1.6-1, and reduced the seating capacity of the cars by eight seats.

The turbine-generator space measured approximately three by five feet, and extended the height of the car from the floor to the roof. The space was functionally external to the passenger space and separated by inner walls of continuous steel construction, sealed against heat, sound and fumes from the contained machinery.

The turbine compartment was originally designed for a Ford regenerative automotive turbine and was larger than required for the Pratt and Whitney turbine described below. The Ford Motor Company suddenly dropped its automotive turbine program, forcing General Electric to switch to a Pratt and Whitney turbine.

Access to the compartment was gained through a door hinged at one side which formed the car's outer profile. All air for the turbine, turbine space ventilation and oil and propulsion equipment cooling was drawn through screens in the doors and inertial filters mounted behind the door.

The ceiling above the roof rail contained the turbine exhaust duct and the roof exhaust port which included louvers to direct the exhaust towards the center of the car and to protect the turbine engine while the car was shut down during inclement weather.

The turbine, drive gear and generator formed an integral assembly. The turbine in its own support cradle was bolted to the drive gear case and drove the input pinion through a conventional flexible gear coupling and an overtorque slip clutch contained in the flywheel. The flywheel and clutch served to screen the engine from short circuit torque loads caused by high-voltage circuit faults.

The drive gear box was a three-shaft, spur gear train which provided speed matching between the turbine (6000 rpm) and the generator (8000 rpm) as well as accomplishing the offset necessary for an over and under arrangement of the turbine and generator. The intermediate idler gear shaft provided the oil pump drive (3000 rpm).

The generator provided variable voltage, 400-Hz, three-phase power which was rectified and transmitted to the electric power distribution system.

The ST6K turbines used were industrial models of the PT6 family of two shaft aircraft turbines built by Pratt and Whitney Aircraft of Canada, Ltd., and were rated at 550 output shaft horsepower at standard conditions burning standard No. 2 diesel fuel.

The generators were also an industrial version of machines originally configured for aircraft use. They were of relatively lightweight construction, fitted with continuously lubricated and scavenged ball bearings, and were rated 500 kVA, 0.95 P.F. at 277 volts, 8000 rpm nominal.

A two-element oil cooler, forced ventilated with external air, cooled both the engine oil and the gear oil. An auxiliary gearbox, driven from the turbine accessory drive, mounted the electric starter and fuel pump and controls.

A double-ended, dc motor driven blower was mounted below the turbine. One end delivered air to cool the generator, rectifiers, motor-alternator set, and the traction motors. The other end scavenged contaminated air from the clean-air system centrifugal filters and exhausted it through the compartment floor.

The turbine was packaged in a separate, quick-change module. The suspension of the turbine was designed to be prealigned with the locating face of its saddle frame, and installation was made by inserting and bolting the quick-change module into the main gearbox input drive pad. The generator mounted in the same manner. The turbine, gearbox and generator constituted an assembly that was independently suspended in the installation assembly frame on three rubber vibration isolation mounts. The alternator was additionally supported by a steel coil spring.

Separately supported above and contacting the turbine through flexible seals, were the turbine exhaust and inlet air handling components. The exhaust components included the exhaust-air mixer assembly where cool air was mixed with the exhaust to reduce its temperature. Part of the cooling air was supplied through the oil cooler and the rest was drawn from the turbine compartment to ventilate it. The cooling-air fans were driven by two high-pressure hydraulic motors supplied by a drive gearbox-mounted oil pump. The oil passing through the second motor also flowed through the drive gearbox bearings and the alternator bearings. The alternator scavange tank was drained by a scavange pump mounted on the drive gearbox opposite the main oil pump.

All three sections, the exhaust and inlet air ducting, turbine-gear-generator assembly, and the double-ended blower assembly, were mounted on a cradle frame that was pivoted to swing out of the opened compartment to provide all-around access for inspection and maintenance. Figure 1.6-1 shows the module swung out of the compartment. The turbine-generator could be operated in the swung-out position for inspection and maintenance.

1.6.2 Turbine Controls and Indications

There was a separate local control panel for each turbine module on the General Electric GT/E car. The panel was located in the passenger area of the car near the turbine module. The General Electric local turbine control panel is illustrated in Figure 1.6-2.

Dial indications were provided on the panel for five essential turbine parameters. A gas generator speed gauge indicated the gas generator shaft speed as a percent of maximum. The shaft speed varied with load and was 38,100 rpm (100%) at full load. The turbine output shaft speed gauge indicated the speed into the gear unit in percent with 6,000 rpm being 100%.

The turbine temperature gauge indicated the temperature in the combustion chamber, not exhaust gas temperature. The normal combustion temperature ranged from 1,000 to 1,700F. The turbine was shut down if combustion temperature exceeded 1,400F while starting or exceeded 1,866°F while in operation.

The turbine oil pressure gauge indicated the lubrication system oil pressure. Normal oil pressure was 70 to 100 psi, with turbine shut down if the oil pressure dropped below 50 psi. The turbine lubricating oil temperature was normally about 160F and the turbine was shut down if oil temperature exceeded 220F. The turbine operating time gauge indicated hours and tenths of hours of turbine operation in the module.

In addition to indicating turbine status and alarms the local turbine control panel permitted local operation of the turbine for inspection and maintenance. The turbine control power breakers (CB 1 and 2) shut the turbine down but did not cause any fault lights to be lit. The alternator power breaker shut off the alternator excitation power resulting in no alternator output. The manual crank pushbutton was used to turn the turbine over for lubrication and check out but did not initiate the start sequence. The local turbine start/stop switch permitted normal trainline starting and stopping of the turbine in the normal position, shut the turbine down in the off/cutout position and initiated a local turbine starting sequence when held in the "Start" position for about five seconds.

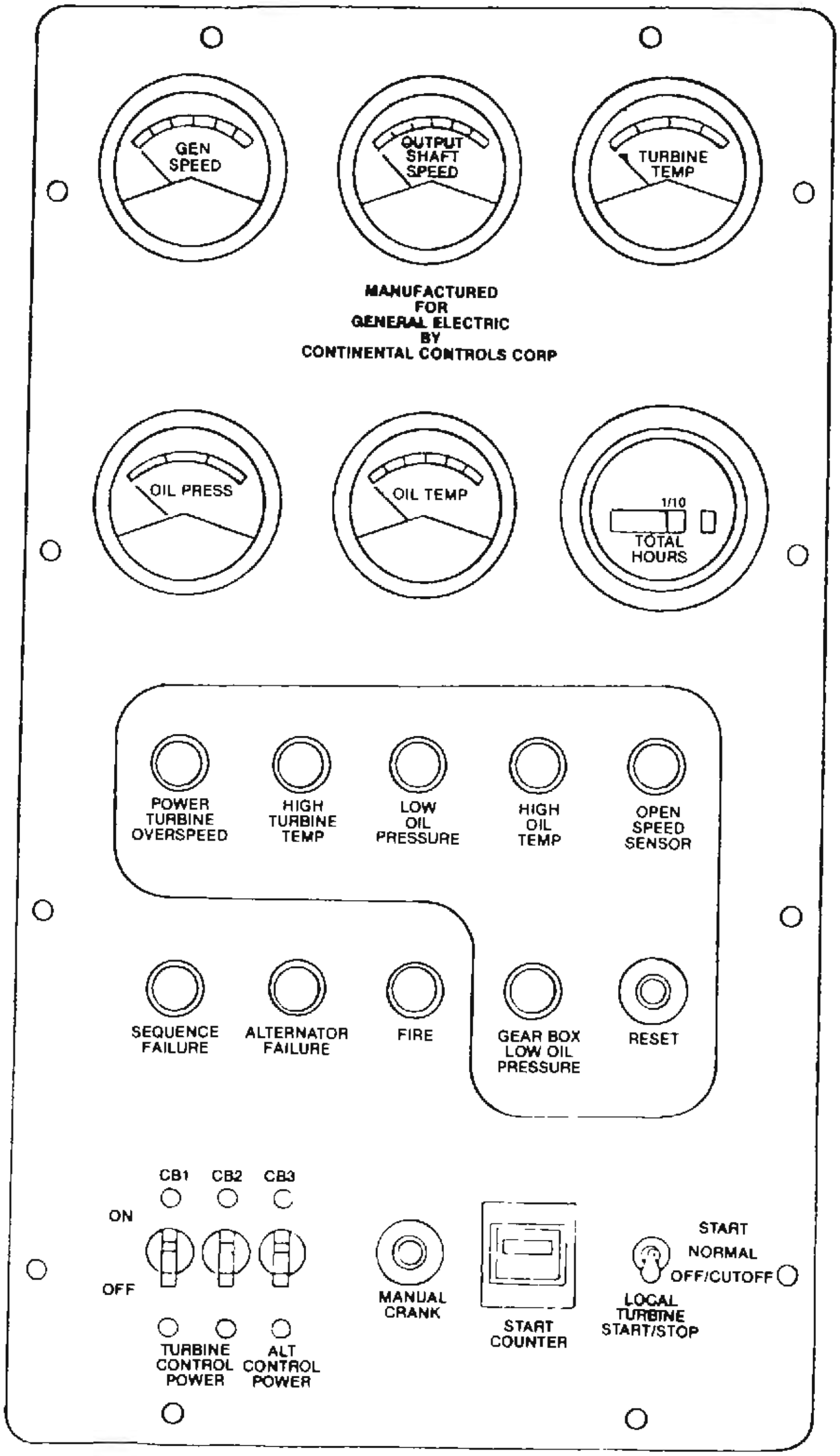


Figure 1.6-2 General Electric Local Turbine Control Panel

1.6.3 Fuel System

The General Electric GT/E car fuel system is depicted in Figure 1.6-3. The fuel was stored in a single 800-gallon tank under the center of the car. The fuel was drawn through a shut-off valve, heater and filter, and was then pumped through a second filter to the turbines through thermally insulated tubing. Fuel not burned in the turbines was returned to the fuel tank either by fuel return bypasses around the turbines or by engine bleed lines through the turbines. Pressure was maintained in the fuel supply lines by pressure-relief valves.

The fuel tank was located under the middle of the car and incorporated a sight glass and a fuel-level gauge. The fuel-level gauge indicated 0 to 700 gallons. From 700 to 800 gallons the level of the fuel was observed in the sight glass. Filler adaptors with automatic shut-off, sight gauge, and fuel level gauge were provided on each side of the car.

The emergency fuel shut-off valve could be operated from the cab and each side of the car at the "F" end of the fuel tank by pulling a ring. The emergency fuel shut-off valve shut the fuel off at the tank outlet.

The fuel heaters were heating strips attached to the fuel lines. The internal construction of the fuel tank was such that fuel which bypassed the engines was directed back through the heaters and recirculated to the turbine. With this arrangement the fuel in the circulating lines was heated without heating the bulk of the fuel in the tank. The heaters were controlled to maintain a constant fuel temperature and were turned off in the event of low fuel line pressure, turbine compartment fire, and ambient temperatures above 45°F.

The fuel pump and the main solenoid shut-off valve were interlocked so that the shut-off valve was closed when the pump was off. The centrifugal fuel pump had a rating of 3.4 gpm at 10 to 12 psi. Whenever the turbine control circuits were energized, the pump was turned on and fuel was circulated through the system.

Fuel pressure was regulated by two pressure-relief valves and two fuel-pressure switches. A pressure-relief valve in the return line at the fuel tank was set at 10 psi requiring the fuel system to be pressurized to that pressure before any fuel recirculated to the tank. The second relief valve was located at the pump outlet. It was set for 15 psi and prevented the fuel system pressure from exceeding 15 psi. Pressure switches in the fuel lines were set to close at 5 psi and to open at 3 psi. Pressure below 3 psi would shut the turbines down.

There were two filters in the fuel system in addition to the fuel filters in the turbines. The filters were rated at 10 microns and insured clean fuel being delivered to the engines.

Compressed air was supplied to each turbine from the car pneumatic system to aid atomization of the fuel during cold weather engine starts.

1.6.4 Power Distribution

The supply of dc power to the GT/E car subsystems was provided either directly from the 650-V dc third

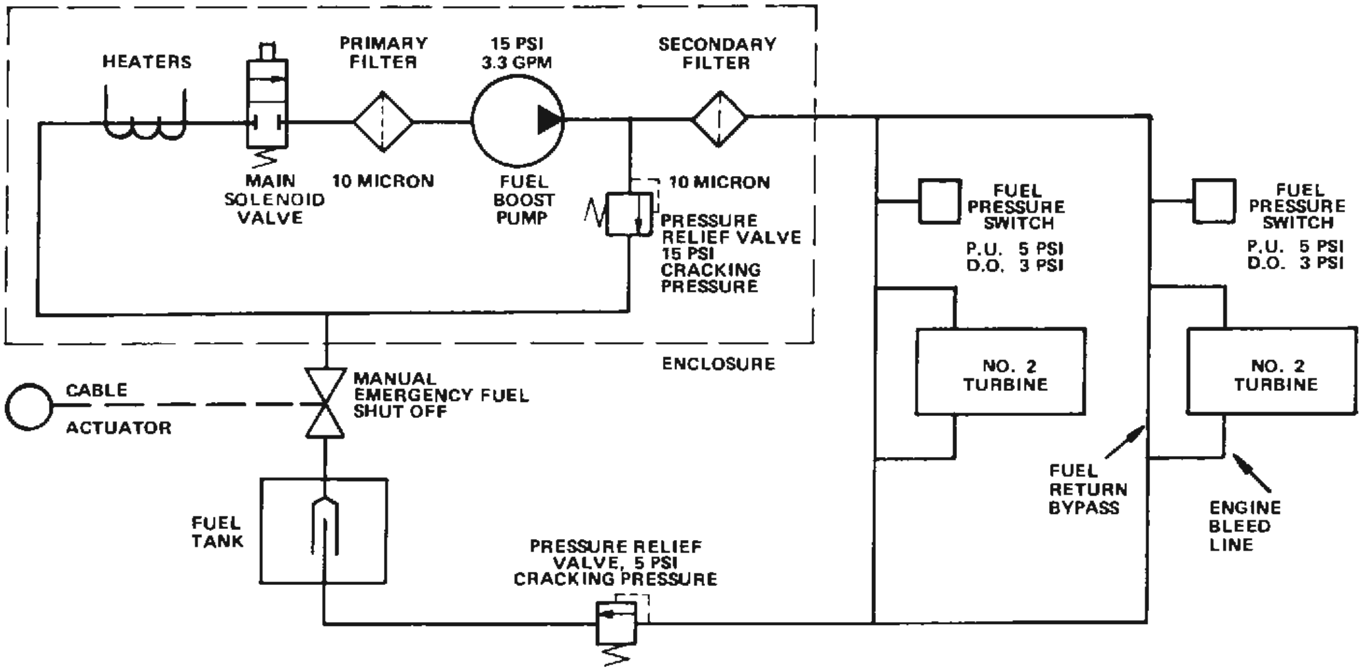


Figure 1.6-3 General Electric Fuel System Schematic Diagram

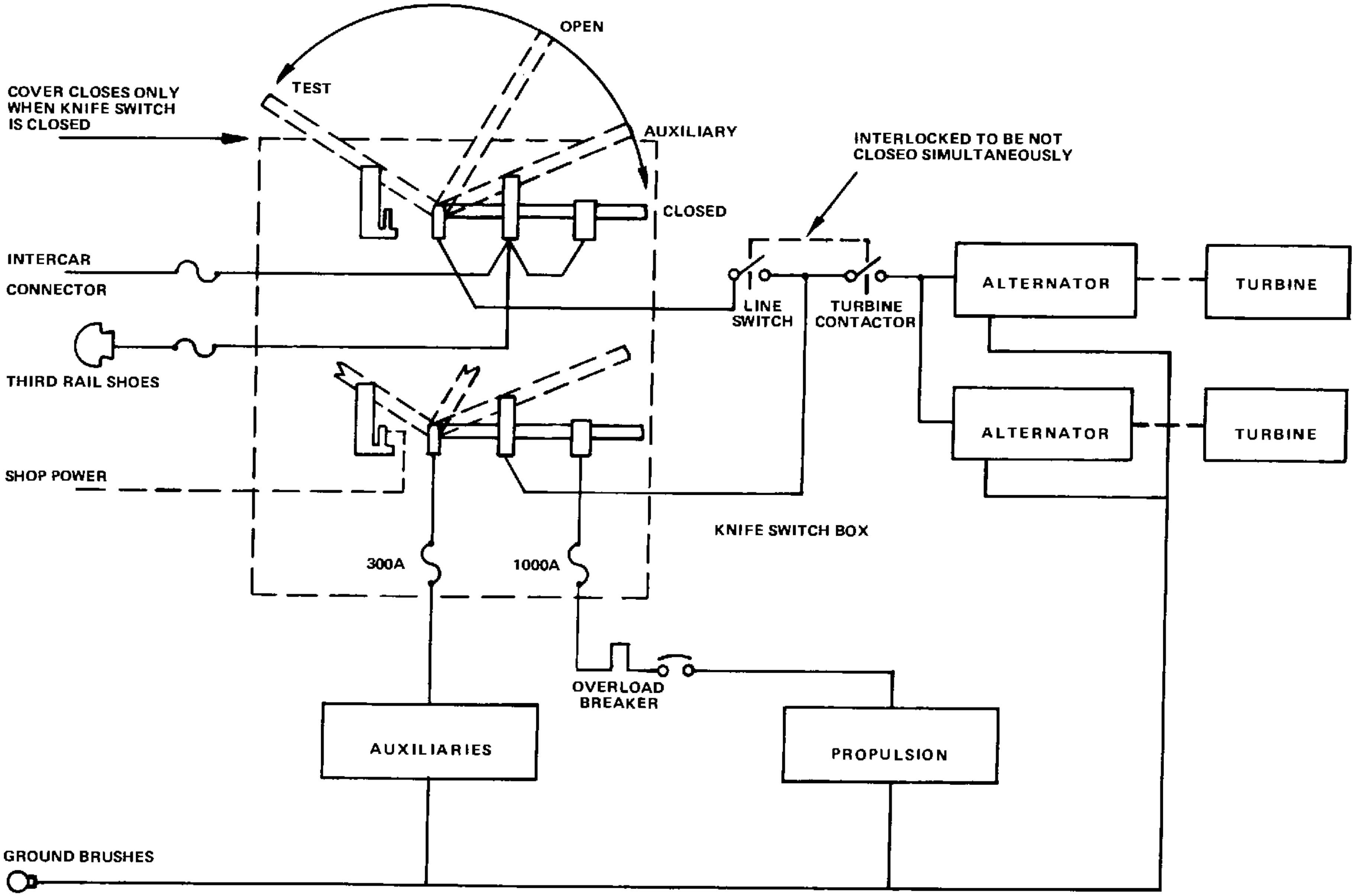


Figure 1.6-4 General Electric Power Distribution System

Figure 1.6-5 General Electric Third Rail Shoe Support and Retraction

rail (over-running or under-running) or from the output of the pair of on-board, gas turbine-driven three-phase alternators. The dc distribution connections were such that the turbine-alternator power supply functioned as a substitute for the dc third rail power supply in non-electrified territory. The power distribution system is shown schematically in Figure 1.6-4.

The dc distribution system included a two-pole knife switch, a 1200-A intercar bus line fuse, and a 1000-A propulsion fuse. In addition, the A-car knife switch box also contained a 300-A motor-alternator fuse. The two-pole knife switch was designed to; 1) isolate all car systems from the third rail power and turbine-generator power when in the open position; 2) provide power to the car auxiliary bus for test purposes from a shop power supply in the test position, and 3) provide auxiliary power to the car from the third rail or turbine generators in the half-closed position. In these three positions the traction power connection was isolated.

Either the line switch (SMC) or the turbine contactor (TMC) closed to connect the car systems to the third rail or to the turbine-generator. The line switch and turbine contactor operated in response to the mode trainline which was energized by the engineer's mode switch on the cab console. The opening and closing of the line switch and turbine connector were normally made under no-load conditions and were interlocked to prevent simultaneous operation.

1.6.5 Third Rail Shoe Support and Retraction

To prevent the third rail shoe from applying a twisting load to the equalizer, the General Electric Co. built a beam around the equalizers. The beam extended across the truck and had a third rail shoe mechanism attached at each end.

The third rail shoe on the GE car was retracted inside the car clearance by rotating the wooden beam on which it was mounted. The third rail shoe assembly was cantilevered out from the truck frame. The wood beam pivoted on the bottom and was activated by an air cylinder on the top as illustrated in Figure 1.6-5. The air cylinder was double-acting and extended to lower the third rail shoe for current collection, and retracted to raise the third rail shoe into the car clearance area.

The shoe-mode switch in the control cab caused air to be admitted to the cylinder from an 800-cubicinch reservoir through a two-stage, double solenoid valve. Pressure was maintained on the "up" or "down" side of the cylinder to hold the shoe in the up or down position.

The third rail shoe assembly was mounted on the third rail shoe beam. The assembly provided for vertical and horizontal adjustment of the contact shoe and spring loaded the shoe against the third rail.

1.6.6 Doors and Bilevel Steps

For high- and low-level platform loading, General Electric built a movable step assembly which in its raised position was the vestibule floor and in its lowered position provided three steps down as shown in Figure 1.6-6. The movable step assembly was activated by jack-screws driven by a dc motor. The drive assembly was equipped with a spring applied brake to hold the steps in their extreme positions.

Operation of the movable steps was sequenced as follows. The operator selected the low-level mode and signaled the doors to open. After the doors opened, the movable steps descended to the lower position and locked in place. When the "door close" signal was given the steps were raised, locked into position, and the doors closed.

The movable step mechanism is illustrated in Figure 1.6-6. The three steps were connected to the actuators with compensating linkages and moved up and down, guided by slots in the side panels of the assembly.

The side frame of the car is notched inward toward the centersill to provide the space for the movable step mechanism.

Figure 1.6-6 General Electric Doors and Bilevel Steps

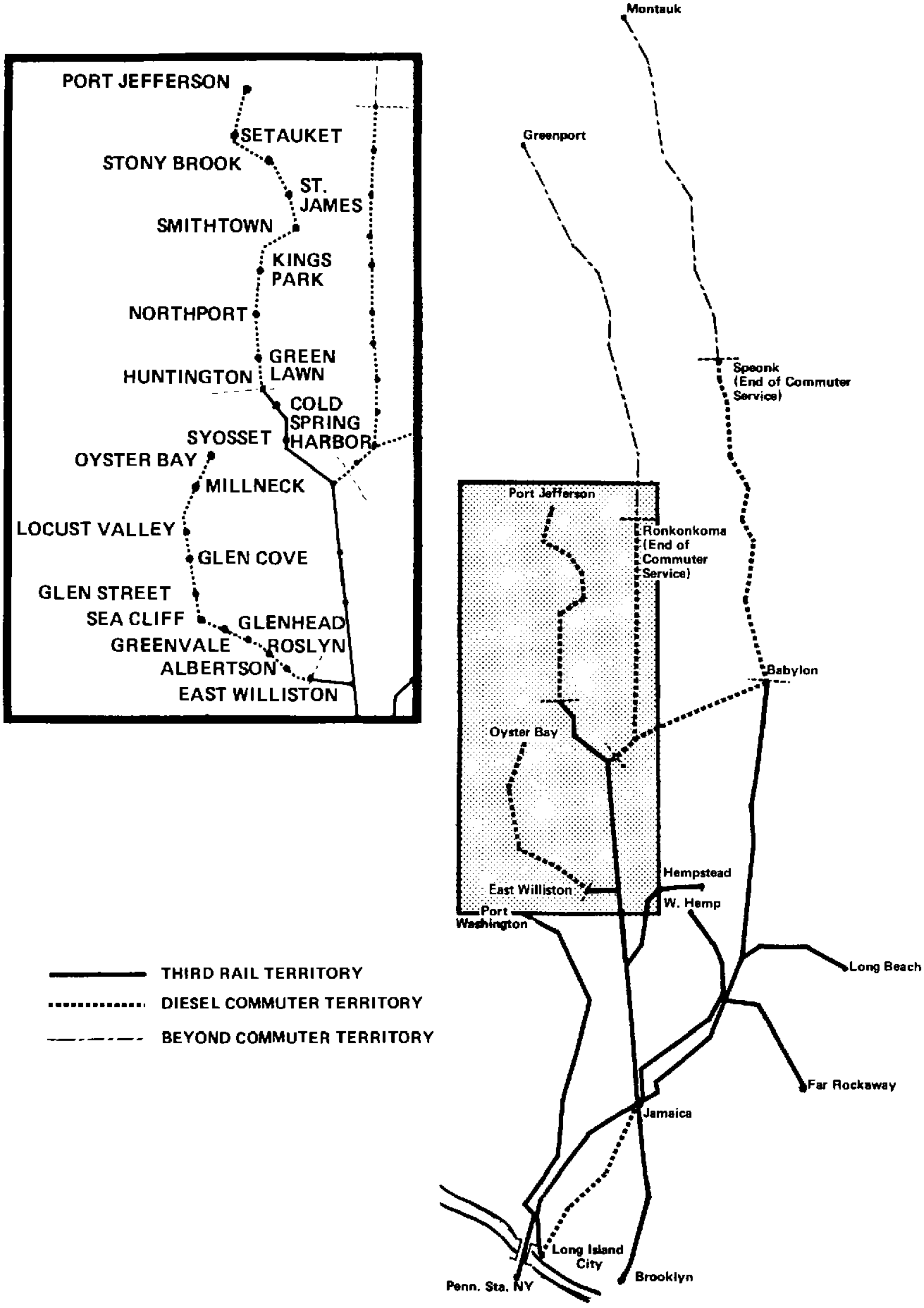


Figure 2.1-1 Long Island Rail Road Route Schematic

PART 2. COST COMPARISON OF GT/E CAR AND THIRD RAIL ELECTRIFICATION

2.1 SCOPE OF THE ECONOMIC ANALYSIS

As stated earlier, the GT/E car was conceived as a means to provide high-performance commuter service on partially electrified commuter routes. It would be a viable concept for that application only if it could provide the service at a lower overall cost than the service could be provided by electrifying the entire trackage.

A differential cost analysis was made to determine if the GT/E car could be used to extend high-performance MU train service into non-electrified portions of commuter routes at a cost less than for providing the same high-performance MU service by electrifying the entire trackage and operating M-1 cars. Relevant capital, maintenance and operating costs were estimated for dual-powered GT/E trains operating on the existing track and for the extension of third-rail electrification to the ends of the routes and operation of M-1 trains on the entire route.

Costs were estimated in 1977 dollars and do not reflect fuel price increases occuring since that time.

Estimates were prepared for three lines, the Port Jefferson and Oyster Bay services of the Long Island Rail Road and Conrail's Upper Hudson service to Poughkeepsie.

The majority of commuter rail service in the MTA region is provided over electrified trackage, with power transmitted either through third-rail or overhead catenary. The remaining, unelectrified portions are outlying areas and are served by diesel-powered equipment which cannot use tunnels and does not provide passengers from the outlying areas with direct access to the major, city-center New York terminals.

For example, the Long Island Rail Road operates diesel service to Speonk, Ronkonkoma, Port Jefferson, and Oyster Bay as illustrated in Figure 2.1-1. Passengers on these trains do not have direct access to the major, city-center terminals and must transfer to EMU trains at some intermediate point. During the rush hour, push-pull and conventional diesel trains operate over third rail territory through Jamaica to and from the terminals at Hunterspoint Avenue and Long Island City, where passengers transfer to or from the subway. During off-peak periods the push-pulls shuttle between Port Jefferson and Huntington, and between Oyster Bay and Jamaica where passengers transfer to EMU trains.

Conrail provides diesel service north of Croton-Harmon and North White Plains on the Hudson and Harlem Lines and on the Waterbury and Danbury branches of the New Haven line as illustrated in Figure 2.1-2. All trains from Brewster and rush hour trains from Poughkeepsie and Danbury are pulled by dual-powered, diesel-electric/third-rail-electric (FL9) locomotives and provide through service to Grand Central Terminal. All other non-electric service is provided by one and two rail diesel car (RDC) trains which shuttle to connect with EMU trains operating to Grand Central Terminal in New York. In the peak period some of the RDC's shuttle between Montrose or Peekskill and Croton-Harmon while others express between Peekskill and Croton-Harmon and then make all stops to Poughkeepsie.

Conrail's service on the former Erie Lackawanna Railway lines to Spring Valley and to Suffern and Port Jervis is provided by diesel locomotive-hauled push-pull trains as illustrated in Figure 2.1-3. Passengers travel to the Hoboken, N.J. terminal and transfer to PATH trains to Manhattan. A planned rail link between the Erie Lackawanna and Amtrak mainlines could provide a direct route to Penn Station, New York through the North River Tunnels. The use of the tunnels would require wayside electric powered trains.

Although dual-power capability meets a need which is more evident on the MTA commuter rail lines than anywhere else, the concept has potential on other systems where extension of electrification may not be feasible in the short run.

A dual-powered car, such as the GT/E car, would enable the New Jersey Department of Transportation to operate its Raritan Valley service directly into Penn Station, New York instead of requiring passengers to transfer at Newark. In fact, with a short extension of the third rail that already exists in the North River Tunnels, the eight existing prototype GT/E cars could operate this service.

When the Philadelphia center city commuter tunnel is completed (replacing Reading Terminal with an underground station), a high-performance, dual-mode car like the GT/E could provide direct service on the former Reading Lines that are currently served by diesel trains. Also, the two former Reading trains that now terminate at Newark, N.J. could be routed into Penn Station, New York.

So it can be seen that the GT/E cars and other similar dual-mode equipment may offer cities a means of providing high-performance rail service from non-electrified commuter areas to city-center terminal by way of underground trackage. The dual-powered car offers planners a range of alternatives affecting level-of-service and economy. The amount of electrification can be varied, and direct downtown service could still be provided from all points on the line.

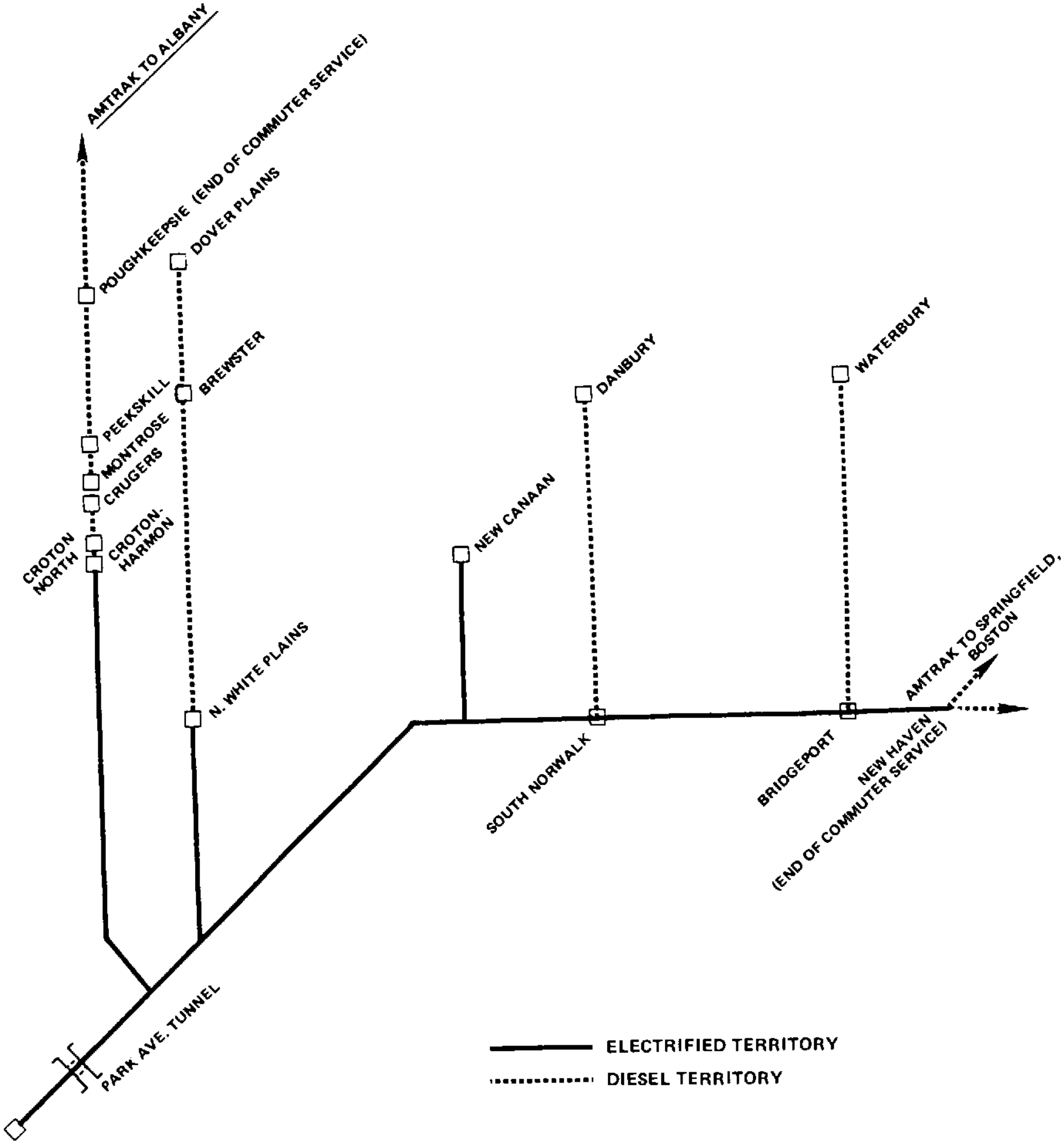


Figure 2.1-2 Conrail Metropolitan Region Route Schematic

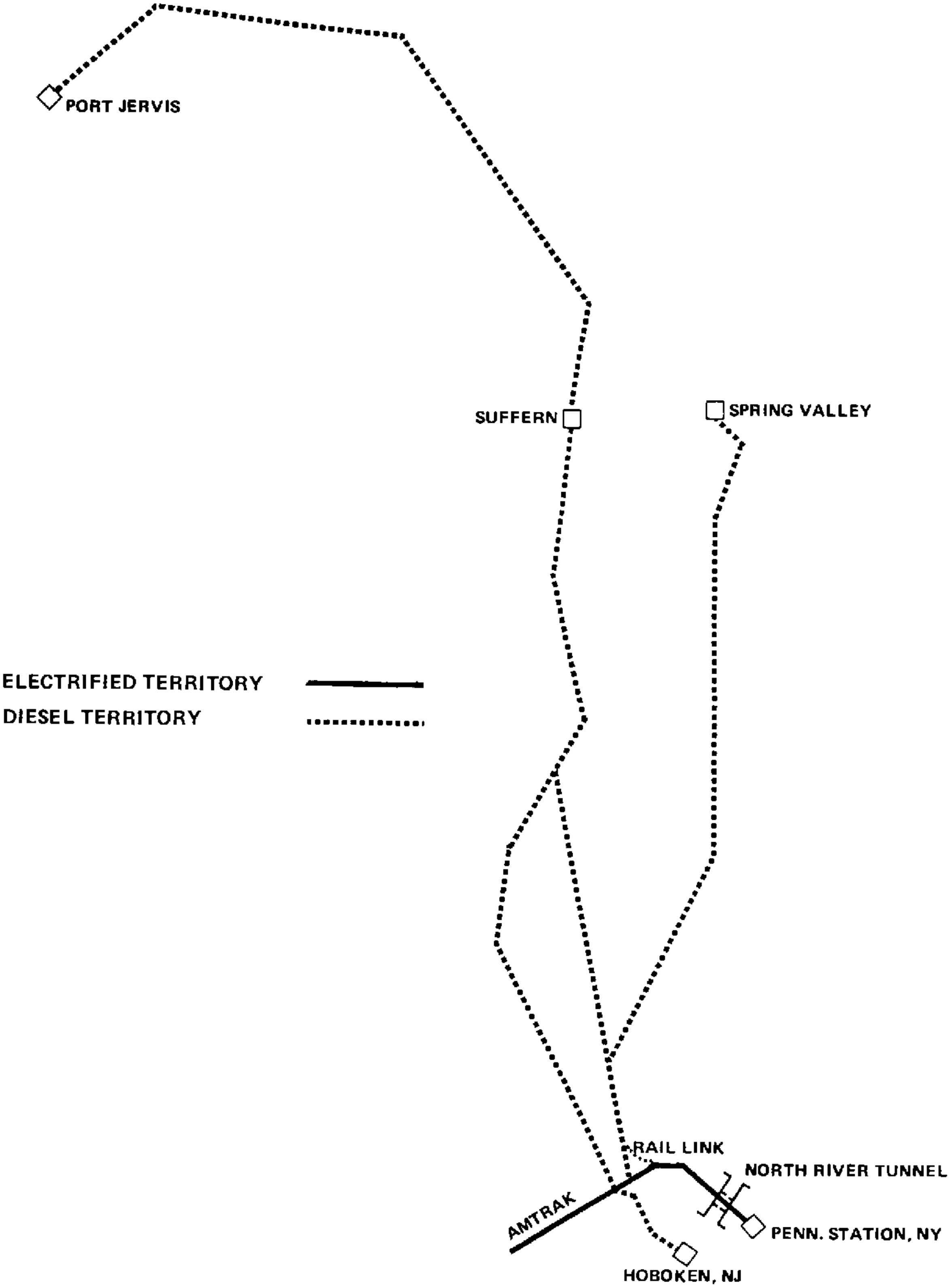


Figure 2.1-3 Erie Lackawanna Railway Route Schematic

2.2 ELEMENTS OF THE ECONOMIC ANALYSIS

To determine the economics of operating dual-powered GT/E trains, as a means of extending high-performance through service into diesel territory, the differences in capital, maintenance and operating costs between it and the extension of third rail electrification to provide the same service with EMU trains were estimated. Estimates were prepared for three routes into New York City; the Port Jefferson and Oyster Bay services on the LIRR and Conrail's Upper Hudson service to Poughkeepsie. For both types of equipment, through service to Penn Station was assumed for the LIRR branches and to Grand Central Terminal on the Conrail line. It was further assumed that no shuttles would be operated in either the peak or off-peak periods, and no transfers would be required. Schedules were established without regard to the operation of other lines and no consideration was given to the economics of a system-wide coordination of services.

For the third-rail-extension alternative, power would be taken from the third rail at all times. For the GT/E alternative the trains would operate on third-rail power whenever third rail existed, and the turbines would be operated where the third rail did not exist and when the turbines were being warmed up and shut down. The outlying terminal and yard trackage would be electrified to expedite yard moves and permit third rail operation of GT/E car auxiliary equipment during layup.

Only essential cost differences were examined. Improvements to track and signals would apply equally to both alternatives and were not examined, except that signal system modifications required for compatibility with electrification are reflected in the electrification costs. Track maintenance and train crew costs were assumed to be the same and were not examined.

To estimate the incremental cost of the GT/E cars it was assumed that the GT/E cars were identical to the M-1 cars in every respect except the turbine power package and related accessories, including all apparatus in the turbine modules, the fuel system, turbine and changeover controls and related trainlines. Separate estimates were prepared for the GE and the Garrett GT/E cars. Economic factors related to the Garrett car's solid-state traction control system were not considered. Because both the GT/E and new M-1 cars could provide high- and low-level platform service with movable steps and retractable contact shoes, the cost of building high-level platforms was not included.

The specific differential capital costs that are estimated included:

1. The extension of third-rail electrification for M-1 car operation, and yard electrification for the GT/E cars,
2. The turbine-power-related components of the GT/E cars, and
3. The wayside fueling facilities for the GT/E cars.

The specific differential annual operating costs that were estimated included:

1. Electric power and diesel fuel costs for operating the extended services,
2. Maintenance of the third rail electrification extensions,
3. Maintenance of turbine-power related components of the GT/E cars, and
4. Maintenance and operation of turbine fueling facilities.

The approach taken in the cost analysis was to estimate unit costs factors for application to all three routes, estimate the service and equipment required for each of the routes and apply the unit costs to determine the total differential cost for each route.

Unit costs for the GT/E cars were derived from the prototype operation of the Garrett and General Electric GT/E cars and other information provided by the manufacturers. Electrification and fueling unit costs were based on Long Island Rail Road data and other data available through the MTA.

The service and equipment required for each route were estimated by the method illustrated in Figure 2.2-1. First, information was collected on the existing route, service and equipment, and train performance was simulated over the route to determine run time and power consumption with the new equipment. A new timetable was then prepared for the M-1 and GT/E service, based on the simulated run times and the existing timetable. The new timetable was used to determine the car-miles and car-hours in each mode, the car-trips operated and the fleet size required.

The unit cost factors were then applied to the service and equipment requirements for each route. The costs calculated in this manner included fuel and electric power costs, turbine maintenance costs, equipment purchase costs, and fueling facility costs.

Electrification costs were developed from previous studies, route descriptions, and unit costs.

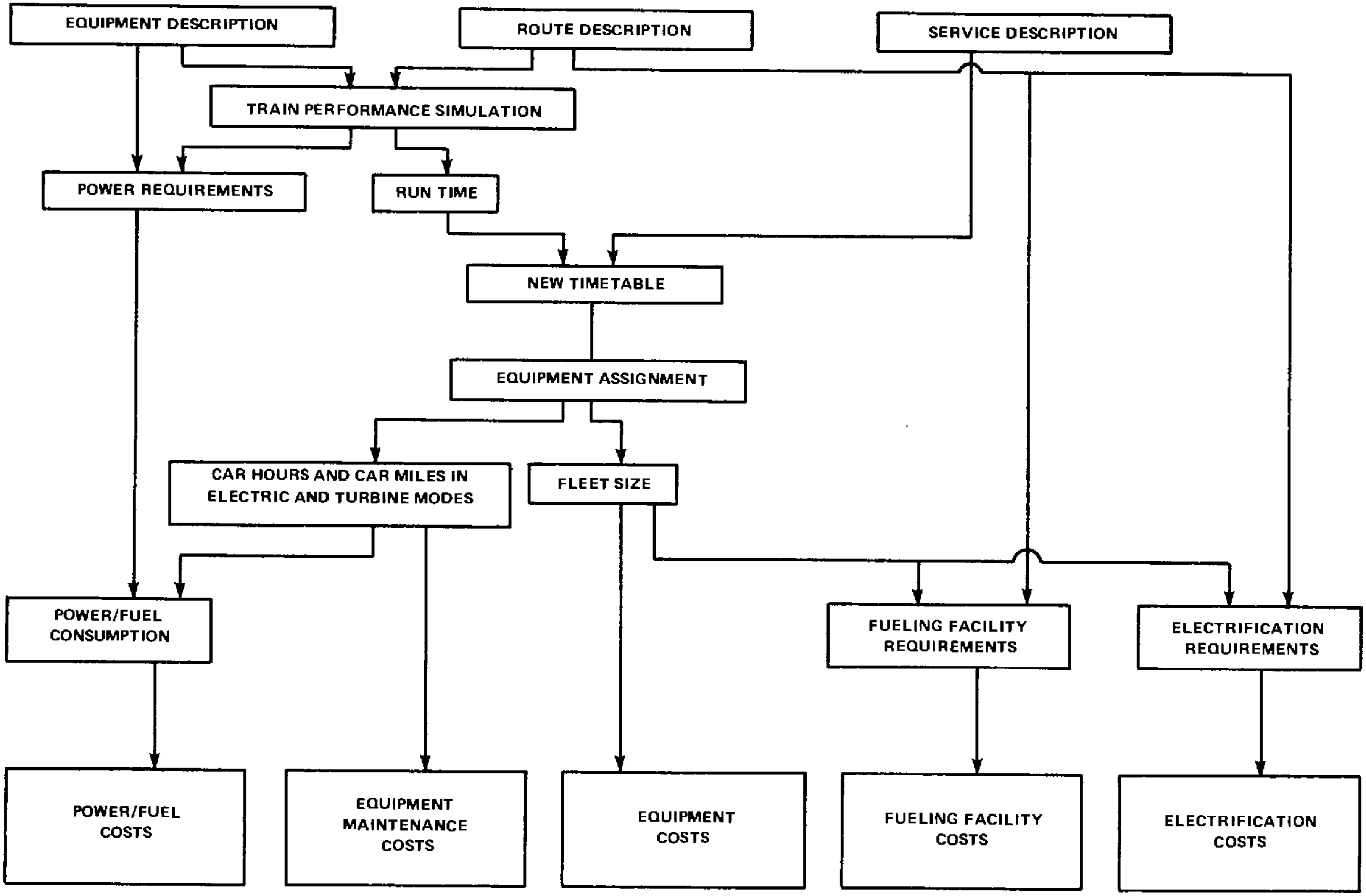


Figure 2.2-1 Method of Approach to Cost Comparison

2.3 ESTIMATES OF CAPITAL COSTS

The estimates of the capital costs are explained below. All costs were estimated in 1977 dollars.

2.3.1 Capital Cost of Electrification

For M-1 service to be provided the full length of each route, the third-rail electrification must be extended to the outlying terminus and installed on the layup trackage. For the GT/E alternative, only the electrification of the layup trackage would be installed.

Separate data were available for the extension of third-rail electrification on each of the three routes. The cost of extending electrification to Port Jefferson had been detailed by Gibbs & Hill in a November, 1975 report to the MTA. Another Gibbs & Hill report, dated December, 1976 included the costs of electrifying to Peekskill on the Hudson Line. Oyster Bay Branch electrification cost data had been prepared at the MTA's request by the LIRR Engineering Department in 1976.

The New York-Port Jefferson Branch is 59.3 miles long and is electrified west of Huntington for a distance of 36.6 miles. According to Gibbs & Hill, extension of the electrification over the 22.7 miles now serviced by diesel would require 134,000 feet of third rail and 16 substations.

The New York-Oyster Bay branch is 34.8 miles long and is electrified west of East Williston for a distance of 21.7 miles. According to the LIRR Engineering Department extension of the electrification over the remaining 13.1 miles would require 121,000 feet of third rail and nine substations.

The New York-Poughkeepsie branch is 73.6 miles long and is electrified for 34.6 miles to Croton North. To electrify the remaining 39.0 miles would require approximately 420,000 feet of third rail. Extrapolation of the six substations required between Croton-Harmon and Peekskill, as determined by Gibbs & Hill, indicate that 31 substations would be required to electrify to Poughkeepsie.

For the third-rail electrification alternative, the Port Jefferson and Oyster Bay costs were used as reported, while the Peekskill costs were extrapolated to cover the length of the route from Croton-Harmon to Poughkeepsie. To the Gibbs & Hill figures were added MTA-developed costs for associated third-rail items, work trains, flag protection, real estate for the substations, and an estimate of additional engineering costs. The LIRR Engineering Department figures were intended to reflect the full cost of electrification and already included these costs.

For the GT/E car alternative, costs were estimated for one substation at the outlying terminus. The substations were sized to power the auxiliary equipment of the stored cars. Only enough third rail costs were included in the estimate to allow the stored cars access to the third rail.

The estimated electrification capital costs are summarized in Table 2.3-1.

TABLE 2.3-1

CAPITAL COSTS OF ELECTRIFICATION

Route	Capital Costs: Third Rail Extension	Capital Costs: With GT/E Cars
NY-Port Jefferson	$40,061,000	$2,931,000
NY-Oyster Bay	$15,270,000	$1,556,000
NY-Poughkeepsie	$77,633,000	$1,921,000

2.3.2 Capital Cost of Turbine Power-Related Car Components

The estimates for the differential costs of the turbine power-related component of the cars were based, in part, on information supplied by the manufacturers of the cars. There was no significant difference in the capital costs of the Garrett twin industrial-type turbine power system and the GE twin aircraft-derivative turbine power system. The cost of the turbine power-related components of the GT/E car were estimated to cost $300,000. Non-GT/E car costs would be equal to both, and were not included in the analysis.

2.3.3 Capital Cost of Turbine Fueling Facility

A fueling station now exists at Port Jefferson that has adequate storage capacity but which would require an additional pump to handle the GT/E cars. Complete fueling facilities would be required at Oyster Bay and Poughkeepsie. A fueling facility does exist at Croton-Harmon on the Poughkeepsie route, but it would not be functional for the GT/E through service.

Cost estimates for fueling facilities were obtained from a Contractor who has installed similar facilities at Port Jefferson and at Ronkonkoma. The estimates assumed a fueling facility would consist of a 20,000 gallon tank with two pumps, each rated at 100 gallons per minute. The estimated cost of an additional pump was $10,000; for a completed fueling facility it was $30,000.

2.4 ESTIMATES OF UNIT AND ANNUAL COST FACTORS

The estimates of unit and annual costs factors are explained below. All costs were estimated in 1977 dollars.

2.4.1 Cost of Third-Rail Electric Power

Electric traction power consumption was estimated for the M-1 by train simulation, and then adjusted by a weight factor for the GT/E cars. Power consumption rate of the auxiliary equipment on M-1 car was supplied by the MTA and it was assumed the GT/E cars would be the same. Electric power consumption of the two GT/E-cars types were assumed to be equal.

The average cost of electric power was supplied by the MTA. The cost was determined from a 1977 bill for electric power from the Power Authority of the State of New York. No differentiation was made between the cost for peak and off-peak power. The estimated cost of third rail electric power was 3.7 cents per kilowatt-hour.

2.4.2 Cost of Turbine Fuel

Turbine fuel consumption at different power levels was measured on both a GE and a Garrett car by Scott Environmental Technology, Inc., as a subcontractor to LTK&A. Table 2.4-1 summarizes the results of their measurements. The table shows that fuel consumption for the two cars was comparable at high power levels. At free idle (no load), however, the constant speed Garrett industrial turbine consumed more fuel than the variable speed GE turbine. Thus the overall fuel consumption of the Garrett turbine in GT/E service could have been higher than the fuel consumption of the GE turbine.

A piece-wise linear relationship between power level and fuel consumption rate was developed using the Scott data. Total fuel consumed on a run was then estimated from simulated operation which calculated the time spent in each of eleven power ranges. The product of time and fuel consumption rate of each range was summed to give total fuel consumption. To this total was added the fuel consumed during turbine warm-up and cool-down cycles.

The 37 cent-per-gallon cost of diesel fuel used in the calculations was the mid-1977 price paid by the Long Island Rail Road.

2.4.3 Cost of Maintaining Third Rail Electrification

Total expenditures for maintaining third rail and substations for the year 1976 were obtained from the LIRR. A 67% overhead factor was added to the labor cost, which was estimated to be 40% of total cost. Unit costs per foot of third rail and per substation were estimated by dividing the total expenditures by the total length of existing third rail and the total number of substations. The estimated annual cost of maintaining the third rail was $1.23 per foot, of maintaining a substation was $20,370.

TABLE 2.4-1

MEASUREMENT OF FUEL CONSUMPTION BY SCOTT ENVIRONMENTAL TECHNOLOGY, INC.

GENERAL ELECTRIC			GARRETT		
% Power	Fuel Flow (lb/hr)	Fuel Flow (gal/hr)	% Power	Fuel Flow (lb/hr)	Fuel Flow (gal/hr)
Idle	123.3	17.6	Idle	180	25.7
*15	193.0	27.6	*10	189	27.0
63	255.0	36.5	62	250	35.7
64	270.9	38.7	62	253	36.1

*Station Idle

2.4.4 Hourly Cost of Maintaining Turbine-Power-Related Components

Both unscheduled and scheduled maintenance were considered in estimating the turbine maintenance costs. Repairs due to design deficiencies in the prototype cars were identified and omitted, as were repairs of manufacturing defects.

Unscheduled maintenance costs were based on the GT/E car activity logs maintained by the MTA's field representative for the GT/E car project. Maintenance activities on the turbines in the four Garrett cars and two active GE cars were analyzed for the nine-month period from May 3, 1977 to January 19, 1978. With the aid of MTA and LIRR personnel, an estimate was made of man hours and materials required for repairs. Total maintenance costs for the GE and the Garrett cars were determined and the total divided by the respective total car-miles operated during the period examined. These unit costs were then converted to a cost per turbine hour.

Scheduled maintenance costs were based on the manufacturers' recommended maintenance schedules and the LIRR's experience with the GT/E cars. With the assistance of the LIRR Equipment Performance Department, periodic inspection schedules were developed for the GT/E cars. While developing the maintenance schedules it was assumed that each turbine would operate 700-1000 hours per year as indicated by the service simulation. Labor and material costs were determined on either a per-year or a per-turbine hour basis, as appropriate. All costs were then converted to a per-turbine hour basis, assuming 850 hours of operation per turbine per year, and summed.

The combustion components of the GE turbines differed significantly from the combustion components of the Garrett turbine. The difference in these components, referred to as the hot section of the turbine, result in significantly different maintenance cost.

Hot-section repair and major overhaul costs for the GE cars were estimated by AirWork, Inc., which performed these services for the GE GT/E cars and the Amtrak Turbotrain engines. Hot section inspections and repairs were expected to be required every 1500-2000 hours of turbine operation, major overhauls after 4000 hours and replacement after 20,000 hours.

Based upon this turbine service life, the average hours operated per year, and an expected car life of 30 years, it was determined that a turbine replacement program would be required. The average replacement cost per turbine hour was determined by dividing the replacement cost per turbine by twice its service life, which was the number of hours of operation that would be possible with the original turbine and one replacement. The turbine replacement cost was estimated by GE.

Little information was available on overhaul and replacement intervals and costs for the turbines in the Garrett cars. Although the AiResearch turbine is in wide use, the GT/E application is the first to use diesel fuel; all other applications apparently used natural gas and operated in much cleaner environments. The different operating conditions affect the overhaul intervals and costs. Based on the LIRR experience and other information that was available, it was estimated that overhauls would be required every 5000 hours, and that turbine life would be of sufficient length that no replacement would be required over the life of the car. Major hot-section inspections and repairs would not be required on the Garrett turbine, but a more frequent, less costly inspection of the combustion chamber lining assembly would be required ever 500 hours.

The estimated turbine maintenance costs per car hour are summarized in Table 2.4-2 for 700-1000 hours of car operation per year.

TABLE 2.4-2

PER CAR-HOUR ESTIMATED TURBINE MAINTENANCE COSTS

Maintenance Item	GE Turbine	Garrett Turbine
Unscheduled maintenance	$ 1.36	$ 2.16
Hot-section inspection and overhaul	2.06	.37
Turbine overhauls	14.74	13.18
Turbine replacement	3.04	—
Scheduled maintenance	13.25	12.06
Total Hourly Maintenance Costs	$34.45	$27.77

2.4.5 Annual Cost of Maintaining and Operating Turbine Fueling Facility

The cost estimate of maintaining the turbine fueling facility was based on the cost of maintaining existing fueling facilities on the LIRR. The total cost of fueling facility maintenance reported in the 1976 Annual Report was divided by the number of LIRR fueling facilities to estimate the maintenance cost per fueling facility. The estimated annual cost of maintaining a turbine fueling facility is $1,000.

The cost of operating the fueling facilities was estimated by estimating the crew size and hours needed for the fueling operation and multiplying by an $8/hour wage rate with an additional 67% overhead factor. The estimated annual cost of operating a turbine fueling facility with a 3-man crew is $83,000, with a 4-man crew it is $111,000.

2.5 NEW YORK-PORT JEFFERSON THROUGH SERVICE COST COMPARISON

2.5.1 Operating Statistics for High-Performance Through Service

Computer simulated operation of M-1 trains between New York and Port Jefferson indicated a trip time of 78 minutes, based on an 80 mph maximum speed, the M-1 performance settings; and running express from Jamaica to Huntington. The GT/E trains would have had the same trip times since they would have had the same high performance. The computed trip time was incorporated into a hypothetical timetable based on the schedules in effect May 23, 1977. Twenty-minute service was to be provided in the peak periods, hourly service in the off-peak periods. From this data, fleet size, car miles, and turbine hours were determined. Table 2.5-1 summarizes the operating statistics for the high-performance New York-Port Jefferson through service.

The length of trains required to provide the service were determined by the LIRR using available passenger counts. A sufficient number of M-1 cars would have been used to provide seats for all passengers. The same numbers of cars would also have provided seats for all passengers on the Garrett GT/E cars but would have resulted in standees on the GE GT/E cars because they seat only 112 passengers. The minimum train length was set at four cars.

A shop margin of 10% was allowed for both the M-1 and the GT/E fleets. However, because of the higher maintenance requirements and smaller fleet size GTE, a higher margin and resulting larger fleet size might have been necessary for GT/E operation.

The method of installing the service would also have affected the fleet size. If existing M-1 trains originating from Huntington were to be started from Port Jefferson the number of *new* M-1 cars required would have been reduced by eight. The GT/E alternative could not take advantage of the existing Huntington trains in the same manner; however, the GT/E fleet would have replaced eight M-1 cars originating from Huntington since the diesel shuttles they usually meet at Huntington would have been replaced by GT/E through trains. Rather than comparing a reduced M-1 car purchase to a GT/E car purchase less an eight-car credit, the full fleet size actually required to carry Port Jefferson passengers was used for both.

TABLE 2.5-1

NEW YORK-PORT JEFFERSON THROUGH SERVICE OPERATING STATISTICS

Cars Required:	60
Daily Car-Trips:	212
Annual Car-Hours w/Turbines Operating:	49,600
Annual Car-Miles:	
Third Rail Territory	2,405,000
Turbine Territory	1,492,000
Total Car-Miles:	3,897,000

TABLE 2.5-2

NEW YORK-PORT JEFFERSON THROUGH SERVICE DIFFERENTIAL COST SUMMARY ($1000)

	Third Rail Electrification Alternative	GT/E-Car Alternative	
		Garrett Car	G.E. Car
I. CAPITAL COST			
A. Fueling Facility	$ —	$ 10	$ 10
B. Equipment (Components Related to Turbine Power Only)	—	18,000	18,000
C. Electrification	$40,061	2,931	2,931
DIFFERENTIAL CAPITAL COST	$40,061	$20,941	$20,941
II. ANNUAL OPERATING COST			
A. Power/Fuel			
Power	$ 919	$ 650	$ 650
Fuel	—	1,059	1,038
B. Maintenance of Electrification	511	36	36
C. Maintenance of Equipment (Components Related to Turbine Power Only)	—	1,383	1,709
D. Maintenance of Fueling Facility	—	1	1
E. Operation of Fueling Facility	—	111	111
DIFFERENTIAL ANNUAL OPERATING COST	$ 1,430	$ 3,245	$ 3,545

The unit-cost factors of Section 2.4 were applied to the New York-Port Jefferson route requirements to estimate the total differential costs of the alternative methods of providing the high-performance service. The capital costs and annual costs are summarized in Table 2.5-2. The analysis showed that third rail extension with M-1 service would have required a $19 million greater capital expenditure, and would have been $1.8 million per year less costly to operate than the GE GT/E alternative and $1.5 million per year less costly to operate than the Garrett GT/E alternative. The difference in capital costs was the high cost of extending the third rail electrification to Port Jefferson for M-1 car operation. The cost more than offset the savings of the less expensive M-1 car.

On the other hand, a fleet of either GE or Garrett GT/E cars would have been more costly to maintain and to power than a fleet of M-1 cars. These costs would have been much higher than the cost of maintaining the new electrified trackage between Huntington and Port Jefferson.

2.6 NEW YORK-OYSTER BAY THROUGH SERVICE COST COMPARISON

2.6.1 Operating Statistics for High-Performance Through Service

Computer-simulated operation of M-1 trains between New York and Oyster Bay indicated a trip time of 57 minutes, based on 80 mph operation and M-1 performance settings, for both the M-1 and the GT/E trains. A hypothetical timetable was developed based on the computed trip time and the schedules in effect May 23, 1977. Train lengths were determined by the LIRR based on available passenger counts, fully seated loads and minimum consists of four cars.

Fleet size, car miles, and turbine hours were estimated from the data and are summarized in Table 2.6-1 for the high-performance New York-Oyster Bay service. No economy would be realized by coordination with existing M-1 service, only the number of M-1 or GT/E cars required to replace the existing diesel service, plus a 10% shop margin, was shown.

TABLE 2.6-1

NEW YORK-OYSTER BAY THROUGH SERVICE OPERATING STATISTICS

Cars Required:	30
Daily Car Trips:	156
Annual Car Hour w/Turbines Operating:	28,600
Annual Car-Miles:	
Third Rail Territory:	1,066,000
Turbine Territory:	644,000
Total Car-Miles:	1,710,000

2.6.2 Differential Costs Comparison

The unit-cost factors of Section 2.4 were applied to the New York-Oyster Bay route requirements to estimate the total differential costs of the alternative methods of providing the high-performance service. The capital costs and annual costs are summarized in Table 2.6-2. As with the Port Jefferson analysis, the M-1 alternative would be required a larger capital investment, but would have been less costly to operate. The M-1 alternative would require a $5.7 million greater investment, and the Garrett and General Electric GT/E alternatives would have cost $0.85 and $1.0 million more each year to operate.

2.7 NEW YORK POUGHKEEPSIE THROUGH SERVICE COST COMPARISON

2.7.1 Operating Statistics for High-Performance Through Service

Computer-simulated operation of M-1 trains between New York and Poughkeepsie indicated a trip time of 93 minutes, based on 1977 speed restrictions 60-70 mph over most of the route, and no stops between Grand Central Terminal and Croton-Harmon.

A hypothetical timetable was developed based on the computed trip times and the schedule in effect October 30, 1977. The practice of turning trains at Peekskill and Montrose during peak periods was retained. Approximately half-hour service was to be provided in the peak periods, hourly and bihourly service in the off-peak periods. Present train lengths, rounded up to an even number, were used. While RDCs operate singly, two car minimums would be required for the M-1s and GT/Es, since both operate as married pairs.

TABLE 2.6-2

NEW YORK-OYSTER BAY THROUGH SERVICE DIFFERENTIAL COST SUMMARY ($1000)

		Third Rail Electrification Alternative	GT/E-Car Alternatives	
			Garrett Car	G.E. Car
I.	CAPITAL COST			
	A. Equipment (Components Related to Turbine Power Only)	—	$ 9,000	$ 9,000
	B. Electrification	$15,270	1,556	1,556
	C. Fueling Facility	—	30	30
	DIFFERENTIAL CAPITAL COST	$15,270	$10,586	$10,586
II.	ANNUAL OPERATING COST			
	A. Power/Fuel			
	Power	$ 526	$ 335	$ 335
	Fuel	—	653	611
	B. Maintenance of Electrification	528	42	42
	C. Maintenance of Equipment (Components Related to Turbine Power Only)	—	794	985
	D. Maintenance of Fueling Facility	—	1	1
	E. Operation of Fueling Facility	—	83	83
	DIFFERENTIAL ANNUAL OPERATING COST	$ 1,054	$ 1,908	$ 2,057

Fleet size, car miles, and turbine hours were estimated from the data and are summarized in Table 2.7-1 for the high-performance New York-Poughkeepsie service.

TABLE 2.7-1

NEW YORK-POUGHKEEPSIE THROUGH SERVICE OPERATING STATISTICS

Cars Required:	36
Daily Car-Trips: (to/from Poughkeepsie)	80
(to/from Montrose & Peekskill)	16
Annual Car-Hours w/Turbines Operating:	26,300
Annual Car-Miles:	
Third Rail Territory:	1,000,000
Turbine Territory:	1,043,000
Total Car-Miles	2,043,000

2.7.2 Differential Costs Comparison

The unit-cost factors of Section 2.4 were applied to the New York-Poughkeepsie route requirements to estimate the total differential costs of the alternate methods of providing the high-performance service. These costs are summarized in Table 2.7-2.

These figures show that GT/E service would have been lower both in initial cost and in annual operating cost. The costs of construction and maintenance of third-rail electrification would make the use of M-1 prohibitively expensive for the light commuter traffic on the upper Hudson line (Amtrak's service to Albany was not considered in this study). Of the two GT/E cars, the car with the industrial-type turbine would consume more fuel, but would be less costly to maintain and more overall economical than the car with the aircraft-type turbine.

As with the Port Jefferson analysis, comments regarding fleet size are in order. The existing M-1 trains would have been originated at Poughkeepsie for the high-performance service, replacing the RDC shuttles and reducing the number of *new* M-1 cars required. On the other hand, purchase of a GT/E fleet would have reduced the number of M-1 cars required on the Croton-Harmon trains, and the M-1 cars would have been free to replace older EMU equipment still operating on the Harlem-Hudson line.

This analysis assumed that train crew requirements would be the same for both M-1 and GT/E consists for the Poughkeepsie service. It is possible, however, that an extra crew member—a fireman—might be required on GT/E trains. Current labor agreements have the effect of requiring a fireman on multiple-unit RDC trains. If this rule were applied to GT/E trains, firemen would be required on all trains since the minimum train length is two cars. Because most RDC cars operate as one-car trains, firemen are usually not required. Firemen would be eliminated altogether in the third-rail extension alternative. At the time of this report, the question of whether firemen would be required on GT/E trains had not been resolved.

TABLE 2.7-2

NEW YORK-POUGHKEEPSIE THROUGH SERVICE DIFFERENTIAL COST SUMMARY ($1000)

		Third Rail Electrification Alternative	GT/E-Car Alternatives	
			Garrett Car	G.E. Car
I.	CAPITAL COST			
	A. Equipment (Components Related to Turbine Power Only)	—	10,800	10,800
	B. Electrification	$77,633	1,921	1,921
	C. Fueling Facility	—	30	30
	DIFFERENTIAL CAPITAL COST	$77,633	$12,751	$12,751
II.	ANNUAL OPERATING COST			
	A. Power/Fuel			
	Power	$ 377	$ 209	$ 209
	Fuel	—	570	537
	B. Maintenance of Electrification	1	27	27
	C. Maintenance of Equipment (Components Related to Turbine Power Only)	—	730	906
	D. Maintenance of Fueling Facility	—	1	1
	E. Operation of Fueling Facility	—	83	83
	DIFFERENTIAL ANNUAL OPERATING COST	$ 1,524	$ 1,630	$ 1,763

2.8 CONCLUSIONS

The analyses indicated that providing service to Oyster Bay and Port Jefferson with Gas Turbine/Electric cars similar to the prototypes built by General Electric Co. and by Garrett Corp. is not an attractive alternative to extending third-rail electrification to the points and providing service with M-1 cars. Despite the high capital cost of third-rail electrification, in these cases the higher annual operating costs of GT/E service are significant enough that the cost of electrification could be recovered within a few years.

The analyses indicated that providing service to Poughkeepsie with GT/E cars would be cost effective, compared to a third-rail extension and M-1 cars, from both a capital and operating cost standpoint. This conclusion does not, however, take account of the continuous increase in fuel costs that have occurred since then.

Many factors could influence and change the estimated cost and relative economy of the alternatives. For example, the cost of diesel fuel may increase at a rate faster than the cost of electric power, eroding the relative value of the GT/E car in all three cases.

Another factor which would affect the economies of all three cases is the lack of certainty as to the reliability and the maintenance cost of the turbine power unit in rail service. Maintenance of the turbine power-related components is added to the maintenance of the rest of the car which should be equal to the M-1 car. If the M-1 fleet requires a 10% shop margin, the GT/E fleet with additional maintenance requirements might require a 15 or 20% shop margin or a large inventory of quick-exchange turbine modules. If so, the capital costs of the GT/E alternative would increase.

The short (nine-month) period of GT/E operation examined in this study and the low availability of the equipment during the study period made full analysis of corrective maintenance costs difficult. Major repairs required following extended periods of operation could not be examined. With only 500-1000 hours on each turbine the major repairs that were required were considered to be due to design problems that would need to be corrected or due to manufacturing defects. Thus, the experience with the prototype GT/E equipment did not provide a firm base for estimating the unscheduled maintenance costs.

A factor which would affect the relative costs for the Port Jefferson and Poughkeepsie services is that the number of new M-1 cars required for the service is less than the number of GT/E cars required. This would reduce the capital costs, making the third rail extension and M-1 service more attractive.

For the Poughkeepsie service three other factors could also affect the differential costs.

First, if firemen are required on GT/E trains, the difference in operating costs would be reduced.

Second, cost development was based on LIRR costs, rather than on costs experienced by Conrail in the Metropolitan Region.

Third, the analysis was based on existing levels of service. As ridership increases in response to improved service and car miles are increased accordingly, the relative economics of electrification would improve. While costs of electrification would remain fixed, the differences in power costs, equipment maintenance costs, and equipment purchase costs could shift to favor third-rail electrification and M-1 service.

Finally, the number of subsystems and consequent vehicle complexity made necessary by the different wayside configurations encountered on the MTA system (i.e., high-low level step system, retractable third rail system), contributed greatly to the in-service unreliability of the GT/E cars. This unreliability, considered with the economic analysis, has removed the GT/E concept from consideration at MTA. As the requirements for additional subsystems may not exist on other transit systems, an independent analysis of vehicle configuration and economic parameters (ridership levels, length of route) should be made for any projected use of the GT/E concept.

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