DOE/MC/30244 -- 5410
Distribution Category UC-132

Advanced Turbine System (ATS) Program Conceptual Design and Product Development

Quarterly Report
August 25 - November 30, 1993

Work Performed Under Contract No.: DE-AC21-93MC30244

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
General Electric Company
Power Generation Engineering
1 River Road
Schenectady, New York 12345

HK

Disclaimer

REPORTING PERIOD: 8/25/93 -11/30/93

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

General Electric Advanced Turbine Systems Program

GE has achieved a leadership position in the worldwide gas turbine industry in both industrial/utility markets and in aircraft engines. This design and manufacturing base plus our close contact with the users provides the technology for creation of the next generation advanced power generation systems for both the industrial and utility industries. GE has been active in the definition of advanced turbine systems for several years. These systems will leverage the technology from the latest developments in the entire GE gas turbine product line. These products will be USA based in engineering and manufacturing and are marketed through the GE Industrial and Power Systems.

Achieving the advanced turbine system goals of 60% efficiency, 8 ppmvd NOx and 10% electric power cost reduction imposes competing characteristics on the gas turbine system. Two basic technical issues arise from this. The turbine inlet temperature of the gas turbine must increase to achieve both efficiency and cost goals. However, higher temperatures move in the direction of increased NOx emission. Improved coating and materials technologies along with creative combustor design can result in solutions to achieve the ultimate goal.

GE's view of the market, in conjunction with the industrial and utility objectives requires the dvelopment of Advanced Gas Turbine Systems which encompasses two potential products: a new aeroderivative combined cycle system for the industrial market and a comined cycle system for the utility sector that is based on an advanced frame machine.

The GE Advanced Gas Turbine Development program is focused on two specific products.

1. A 70 MW class industrial gas turbine based on the GE90 core technology utilizing an innovative air cooling methodology.

2. A 200 MW class utility gas turbine based on an advanced GE heavy duty machines utilizing advanced cooling and enhancement in component efficiency.

Both of these activities require the identification and resolution of technical issues critical to achieving Advanced Turbine System (ATS) goals. The emphasis for the industrial ATS will be placed upon innovative cycle design and low emission combustion. The emphasis for the utility ATS will be placed upon innovative cycle design and low emission combustion. The emphasis for the utility ATS will be placed on developing a technology base for advanced turbine cooling while utilizing demonstrated and planned improvements in low emissions combustion. Significant overlap in the development programs will allow common technologies to be applied to both products. GE's Industrial and Power Systems is solely responsible for offering GE products for the industrial and utility markets. The GE ATS program will be managed fully by this organization with core engine technology being supplied by GE Aircraft Engines (GEAE) and fundamental studies supporting both product developments being conducted by GE Corporate Research and Development (CRD). GE's worldwide experience in commercialization of these products will ensure that the ATS program can proceed to the marketplace.

ATS ENGINE CYCLES UNDER STUDY

FEATURES	1*	2*	3	4	5	6	7
BOOSTER/DRIVE TURBINE	NONE	YES/LOW PRESSURE TURBINE	YES/LOW PRESSURE TURBINE	YES/LOW PRESSURE TURBINE	YES/LOW PRESSURE TURBINE	YES/LOW PRESSUE TURBINE	YES/HIGH PRESSURE TURBINE
BOOSTER DRIVE TYPE	NONE	DIRECT DRIVE	DIRECT DRIVE	DIRECT DRIVE	DIRECT DRIVE	DIRECT DRIVE	GEARED DRIVE TO 3600 RPM
PRESSURE RATIO OF BOOSTER	0	1.63	1.75	1.75	2.0	1.75	1.75
DRY LOW NOx COMBUSTOR	YES	YES	YES	YES	YES	YES	YES
TURBOCOOLER	NO	NO	NO	YES	YES	YES	YES
NEW LOW PRESSURE TURBINE	NO-GE90	YES	YES	YES	YES	YES	YES
LOW PRESSURE TURBINE SPEED	2000 RPM	3600 RPM	3600 RPM	3600 RPM	3600 RPM	**2000/3600	3600 RPM
LOAD CONNECTION	GEARBOX	DIRECT DRIVE	DIRECT DRIVE	DIRECT DRIVE	DIRECT DRIVE	DIRECT DRIVE	DIRECT DRIVE
COMPRESSOR DISCHARGE TEMP. (^{0}F)	912	1075	1148	1148	1176	1148	1148
TURBINE INLET TEMP. (^{0}F)	2514	2500	2500,2600, 2700, 2800	2500,2600 2700,2800	2500 THRU 2800	2500 THRU 2800	2500 THRU 2800
POWER OUTPUT MW	43.95	59.6	63.6,69.9, 76.4.82.9	64.4,70.8, 77.3,83.4	66.6,73.5 80.4,87.4		
SIMPLE CYCLE EFFICIENCY (%)	41.873	44.53	45.0,45.7, 46.2,46.6	45.5,46.1, 46.6,46.9	46.0,46.2, 46.7,47.1		

*THESE ARE THE BASELINE CONGIFURATIONS

**SPLIT LP TURBINE

TABLE 2

TASK 3 - SELECTION OF A NATURAL GAS FIRED ADVANCED TURBINE SYSTEM (GFATS)

TASK 3A SELECTION OF AN INDUSTRIAL NATURAL GAS FIRED ADVANCED TURBINE SYSTEM (GFATS)

Task Description

Selection and description of an Industrial Natural Gas Fired Advanced Turbine System (GFATS). The selected system will be capable of modification for operation with coal gas.

Progress During Reporting Period

3A.1 Cycle Analysis

Cycle thermodynamic models defining gas turbine steady-state operation have been constructed for a variety of configurations. These designs are built around a GE90 high pressure system incorporating test status compressor and turbine performance. All the configurations incorporate a new (relative to the GE90) or modified GE90 low pressure turbine system and, where applicable, a new booster design. Cooling flows for non-turbocooled designs were set at current GE90 levels. Cooling flows for the turbo-cooled designs were set at the level used in Reference 1 (proposal) and will be updated as design work continues. The matrix of engines are defined in Table 2.

Design point performance data, including gas turbine thermal efficiency and power output, was generated for each design. Data for each model has been generated at four design firing temperatures. All configurations were operated at an HPC physical speed equivalent to GE90 takeoff operation at 88,800 lbs. sea level static thrust and a stall margin (constant flow definition) of 20%. All designs are being reviewed and the most promising configurations will be updated (cooling flows, component performance, firing temperature) for further design work.

Technical Challenge

The objectives of this program are to achieve high power generation thermal efficiency combined with reduced emissions and reduced cost per kilowatt using a GE90 aeroderivative gas turbine utilizing auxiliary turbo-cooling. These goals have a strong influence on the thermodynamic design of the gas turbine engine in terms of firing temperature, compression ratio, component performance and system architecture considerations such as intercooling. In addition, the bottoming cycle is critical in achieving combined cycle thermal efficiency goals. The bottoming cycle design work will be addressed by GEPG. The technical challenges addressed below concern the conflicting requirements of high power output and thermal efficiency with the demand for low cost and low emissions.

Gas turbine cycle thermal efficiency and power output both benefit from increasing firing temperature (HPT rotor inlet temperature) through the use of auxiliary turbo-cooling (ATC). Thermal efficiency benefits from increasing the average temperature at which heat is added and power output benefits due to more work generated per unit airflow. Here is where the bottoming cycle is critical to system thermal efficiency: as firing temperature increases, so does the exhaust gas temperature and hence the heat unrecoverable by a conventional gas turbine. The bottoming cycle captures that heat and uses it for power generation in a separate system. Unfortunately, high firing temperature is not conducive to long life or low emissions. However, the use of auxiliary turbo-cooling counteracts the effects of firing temperature by cooling the cooling air thereby allowing HPT blade metal temperatures consistent with life requirements. In fact, ATC allows for a reduction in cooling flows at constant blade life (relative to using uncooled compressor discharge air) which provides for an increase in combustor dilution air resulting in lower flame temperature and reduced emissions. In this way, ATC is effective in boosting power output and efficiency while reducing cost and emissions.

Another factor affecting gas turbine thermal efficiency is the efficiency of the individual components. The principle effect of increasing component efficiency is the reduction in wasted energy which is manifested as lower exhaust gas temperatures for a given firing temperature. Hence, a gas turbine with high component efficiencies will have a higher power turbine firing temperature (hence power output) for a given exhaust temperature than a cycle with lower component efficiencies. Since the power output per unit airflow of the bottoming cycle is a function of gas turbine exhaust gas temperature only (to first order), the more efficient GT cycle will have a higher combined cycle efficiency as well. In addition, higher compressor efficiencies allow more compression for a given compressor discharge temperature. Since the compressor size is fixed in this study (GE90), higher compressor efficiencies allow more airflow and therefore higher power output and reduced cost per kilowatt. In this respect, it is very important for components new to the GE90 ATS, such as the booster, gearbox (where applicable), and power turbine, to incorporate the most advanced technology available.

Power output was increased further by increasing engine pressure ratio. Since HPC pressure ratio is fixed, engine pressure ratio is raised by increasing booster pressure ratio. Also, since HPC corrected design airflow is essentially fixed by the GE90 HPC design, booster inlet area (hence, airflow) must also increase. It is the increase in airflow which is chiefly responsible for the increase in power output as booster pressure ratio increases. However, since compressor life is tied to compressor discharge temperature (T3), engine max pressure ratio and the resulting airflow size and power output are essentially defined once the limiting T3 is determined .

One further method of boosting power output that eliminates the T3 issue is to cool the booster exit flow using an intercooler. The use of intercooling allows higher output by allowing higher engine physical airflow. The intercooler, which may use feedwater for the bottoming cycle to cool the air, by virtue of the equation of state for a compressible fluid reduces the specific volume of the airflow as it cools the air. Because of this, the GE90 compressor can accept significantly more physical airflow than if the air were at booster discharge temperature. In order to provide more airflow, a larger booster is needed. Also, since the booster exit air is cooled and the GE90 HPC pressure ratio is essentially fixed at the design point, the booster pressure ratio can be greatly increased without fear of violating the compressor discharge temperature (T3) limit. However, there are two limiting parameters to consider with an intercooled cycle: the HPC inlet air temperature is limited by the feedwater inlet temperature and the physical airflow is set by the compressor discharge pressure limit. Still, the intercooled cycle can provide higher power output, and by virtue of lower T3, can provide that power with improvements in life and reduced emissions. Some of the drawbacks include the costs associated with manufacturing an intercooler, the size of an intercooler with a reasonably low pressure loss, as well as the detail design of the GE90 HPT.

Finally, the efficiency of the intercooled cycle can increase due to the more efficient overall compression process and because combustion occurs at a higher pressure. The higher compression efficiency appears as a reduction in T3 for a given compression ratio although the performance of the individual components (booster and HPC) is not improved. Still, an important element of increasing the overall efficiency is the reintroduction of the heat carried away by the feedwater in the bottoming cycle. If this energy is lost, the booster energy used to create that heat is thrown away and combined cycle efficiency is reduced. In addition, the fact that heat is added to the cycle at a higher pressure simply improves performance by reducing exhaust gas temperature for a given firing temperature hence improving gas turbine cycle thermal efficiency. The effect of higher combustion pressure on combined cycle efficiency depends on the trades between intercooler temperature drop, engine pressure ratio, and firing temperature and therefore needs to be evaluated on individual designs.

3A.2 Flowpath Design Studies

Flowpath studies for using the GE90 core with turbocooling have been iniated. the power turbine for this cycle will drive both the low pressure compressor(booster) and supply output power. Since it is envisioned that the engine system could be used in both 60Hz or 50 Hz service, the new low pressure turbine will be sized to operate at both 3600 rpm and 3000 rpm. The low pressure compressor or booster will be scaled using existing technology.

The next step in defining the intial flowpath will be focused on the low pressure turbine design. Different options will be consider which provide the balance of turbine efficiency and number of stages.

3A.3 Combustor Aero-Preliminary Design

Preliminary design models for the combustor and fuel/air mixers have been built to study the impact of combustor air flow on NOx emissions levels, and to provide a preliminary sizing tool for the DCARS type fuel/air premixers. The combustor model is a spreadsheet type model based on a similar model developed and used in the preliminary design of the LM6000 DLN combustor. Appropiate modifications have been made to adapt the model to the GE90/ATS. The flame temperature calculation used in this model takes into account the combustor inlet pressure, inlet temperature, fuel/air stoichiometry, fuel temperature and humidity. The NOx emissions correlation with flame temperature is based on the DCARS III mixer performance. The mixer sizing tool was developed using the DCARS design criteria. This tool provides a preliminary overall size, and some specific size details of the mixer and its components given a set of operating conditions. This tool has been computerized and automated to allow easy and rapid design changes.

Preliminary combustor model studies have suggested that to meet the challenging goal of 8-ppm NOx at the max power operating condition, given the current engine cycle data, will require at least 282 lbm/sec of mixer air flow for the turbocooled engine configuration, and 214 lbm/sec of mixer air for the non-turbocooled engine configuration. For the turbocooled configuration, that amount of air represents approximately 86% of the total compressor discharge flow, while for the non-turbocooled configuration only about 70% of the compressor discharge flow is required. Curves showing estimated NOx emissions as a function of total mixer flow for both engine configurations have been generated to demonstrate the NOx sensitivity if mixer air flow is traded for increased cooling. The high mixer flow requirements of the turbocooled configuration present a combustion stability problem at the lower power operating points. A 40% power point was looked at. Using the same 86% compressor discharge flow with all mixers fueled results in mixer equivalence ratios considerably below the status lean extinction limit for the DCARS mixer. In fact, if fuel flow is assumed to be held constant, the mixer air flow would need to be reduced to a level of 65% compressor discharge flow to provide adequate stability margin at the 40% power operating point. As such, compressor discharge bleed will need to be increased at lower power operating points, and/or some configuration of fuel staging implemented to achieve stability. An alternative could lie in the development and implementation of an advanced radiative flame stabilization system similar to that currently under development at GEAE for military combustor systems. The current DCARS mixer status lean extinction threshold shows that mixer flame temperature required to maintain stability increases rapidly once combustor inlet temperature drops below about 850 F. Along with this increase in flame temperature comes an increase in NOx emissions. NOx emissions at idle operation could be in the 20 to 30 ppm range.

Combustor preliminary flowpath layouts have been developed, and are still in progress. The objective here is to obtain a configuration that fits into the existing GE90 CDN with minimum acceptable mechanical modifications. This is challenging given the need for high mixer flow, and the very short length of the current GE90 engine combustion system. To save some overall length, combustor configurations featuring multiple domes containing up to 60 mixers per dome have been looked at. The greater number of mixers permits reduction in their size. This allows more room to "squeeze" the combustor into the available space, and also reduces the mixer residence time to reduce the threat of autoignition. With the very hot fuel supplied to the mixers, and high combustor operating pressure and temperature associated with the turbocooled configuration, mixer autoignition is a key concern. Very limited autoignition data appears to be available which addresses both the very high operating pressures and temperatures, as well as the very high temperature of the injected fuel. The combustor preliminary designs that have been looked at to date have bulk flow residence times of about 4.4 to 4.6 msec. This compares to 5.6 msec for the LM6000 DLN. Reducing the residence time was done to minimize the required combustor size so as to better fit into the available space. The impact of the higher operating temperatures and pressures of the GE90/ATS relative to the LM6000 DLN is expected to offset the adverse impact on CO emissions from reducing the bulk flow residence time. This needs additional study.

Key Design Challenges

1) Achieving mixer air flow rates sufficient to meet the NOx emissions goals for the turbocooled engine configuration.

2) Autoignition and coking potential of very high temperature natural gas fuel used with the DCARS mixer design at high power operating conditions.

3) Fitting a high dome flow combustor design within the current GE90 engine combustion system space.

4) Maintaining combustion stability at lower power operating conditions.

5) Achieving sufficient CO burnout to meet CO emissions goals in the compact combustor design.

3A.4 Turbine Heat Transfer

Overview

Preliminary turbine cooling designs for the high pressure turbine vane and blade have been developed this reporting period to support the evolution of the ATS cycle and establish the design constraints necessary for a successful detailed design. The turbocooled cycle configuration 4 in table 2 was selected for this study.

	Wc (%W25)
Combustor Inner Liner	1.5*
Combustor Outer Liner	1.5
HPT Vane Inner Band & Leakage	1.5*
HPT Vane Outer Band & Leakage	1.5
HPT Vane Film	1.25*
HPT Shroud	0.5
HPT Stage 1 Blade	2.2*
Forward Combustor	0.4*
Total	10.35

Note: All flows noted with a * pass through the HPT vane: 1.25%W25 is film and 5.6%W25 is non-film which is captured and used to cool the combustor inner liner, vane inner band, HPT stage 1 blade, and forward combustor seal.

Cycle Conditions & Gas Temperature Profiles

The thermal design point cycle conditions at which the high pressure turbine has been evaluated and compared below with the GE90 design point conditions. As can be seen, the ATS design point T3 is 102°F colder and T41 is 95°F warmer than the GE90 at SLTO Mach .25+27°F Ambient Day conditions.

	ATS	GE90
T3 (F)	1148	1250
Tcoolant(F)	719	1250
P3 (PSI)	588.2	592.5
T41 (F)	2700	2605
P4 (PSI)	557.8	563.1

The ATS includes a triple annular Dry Low Nox combustor at considerably lower profile and pattern factors than the GE90 design which results in flatter gas temperature profiles. In particular, the high pressure turbine blade relative gas temperature profile is colder at the pitchline but warmer at the hub and tip. Also, the ATS design includes a high pressure turbine vane cooling design (which will be discussed in detail later) which minimizes the film cooling to achieve metal temperatures required for life. For the same T41, decreasing the vane film cooling flow has less effect of quenching on the gas temperature, meaning a lower T4 is experienced.

HPT Vane

Cooling flow for the high pressure turbine vane is supplied from the turbocooler at much lower temperatures(Tcoolant=719(F)) and higher pressures than the conventional vane coolant supply from CDP air. There are many unique features to the HPT vane cooling design which minimize the cooling flow and film requirements to achieve life. The HPT vane cooling design uses only trailing edge film. The cooling circuit includes two impingement inserts for increased heat transfer but rather than exhausting through film holes as in traditional designs, the post impingement flow is captured at the hub of the airfoil and is used to cool the combustor inner liner and HPT blade. The ability to reuse the spent vane cooling air is only possible due to the increased pressures and lower cooling temperatures supplied by the turbocooler. Typical impingement/film cooled vane designs are limited by backflow margins (Pcoolant/Pgas) at the leading edge of the vane to prevent gas ingestion. This is not a restriction for the ATS design; only the cooling air pressure supplying the combustor inner liner, which is the vane cooling air exhaust pressure, is a design constraint.

A detailed evaluation of the internal cooling concept of impingement with no film cooling (i.e. capturing the post-impingement air) as is impacts cross-flow and heat transfer coefficients will be made at a university facility. This information will be incorporated into the final design of the vane.

The preliminary configuration of the airfoil also includes 20 mils of TBC completely coating the airfoil which is considerably thicker than our experience to date. Five mils of TBC is typical on today's airfoils although up to ten mils have been tested for limited periods. The increased TBC thickness provides a technical challenge in many areas: spallation of the TBC is not fully known; temperature gradients through the TBC as well as the maximum temperature of the TBC are areas of concern. This technology has significant payoff and will require component development work.

A comparison of the ATS vane versus the GE90 follows:

	ATS	GE90
Hot Streak Temperature	3075	3441
Coolant Temperature (F)	719	1250
Pcoolant/Pgas	1.10	1.013
TBC Thickness (mils)	20	5/10
Wc (%W25):	6.85	7.94
- Film (%W25)	1.25	7.94
- Non Film (%W25)	5.60	0.0

The non-film cooling flow which cools the ATS vane is passed through the airfoil and goes on to cool the combustor inner liner and HPT blade; only the 1.25%W25 film flow exhausts through the trailing edge slots into the gas stream. Preliminary metal and TBC temperatures are shown in Figure 1. A mechanical evaluation is still in progress to determine the life of this vane design.

HPT Blade

Once the turbocooler flow has cooled the HPT vane, a portion of that flow is supplied through an inducer to the HPT blade. The flow has picked up some heat from the vane but continues to be considerably cooler and at a much higher pressure than the traditional coolant supply air. In this preliminary study, the blade cooling design includes a cold bridge leading edge, five pass serpentine and cold bridge trailing edge. The airfoil is completely coated with ten mils of TBC whereas the baseline GE90 design utlizes the same cooling passages but does not incorporate any TBC. The combination of lower coolant temperature and TBC permits a design for 25,000 hours of hot time on the ATS blade with only two-thirds the cooling flow requirement of the GE90 blade. As mentioned earlier, the dependence on TBC is a technical challenge, however, GE's experience to date has been with up to ten mils of TBC. The ATS blade design will fully achieve the life goals with ten mils of TBC. A comparison of the ATS blade versus the GE90 follows:

	ATS	GE90
Gas Temperature Ttb (F)	2700	2780
Coolant Temperature (F)	844	1267
Pcoolant/Pgas	1.27	1.07
TBC Thickness (mils)	10	0
Wc (%W25)	2.12	3.34
Tbulk (F)	1538	1808

Metal and TBC temperatures are shown in Figure 2. This component design appears to meet our goals.

Technology/Testing Needs

Vane Impingement With Crossflow Test:

The HPT vane cooling design relies upon impingement air providing enhanced coolant side heat transfer coefficients. Rather than film cooling the airfoil, the flow is captured at the hub of the airfoil and re-used as combustor liner or HPT blade cooling. Intercepting the flow implies that some of the benefit of higher impingement heat transfer coefficients will be reduced due to cross-flow. The vane design will be dependent upon optimization of the internal cooling concept.

Tgas=3075 (LM6000 PF) No Film,Incr H=Himp Reduced TE + Tc=719 ATS

ATS HPT Stage 1 Vane
TBC & Metal
Temperature Distribution

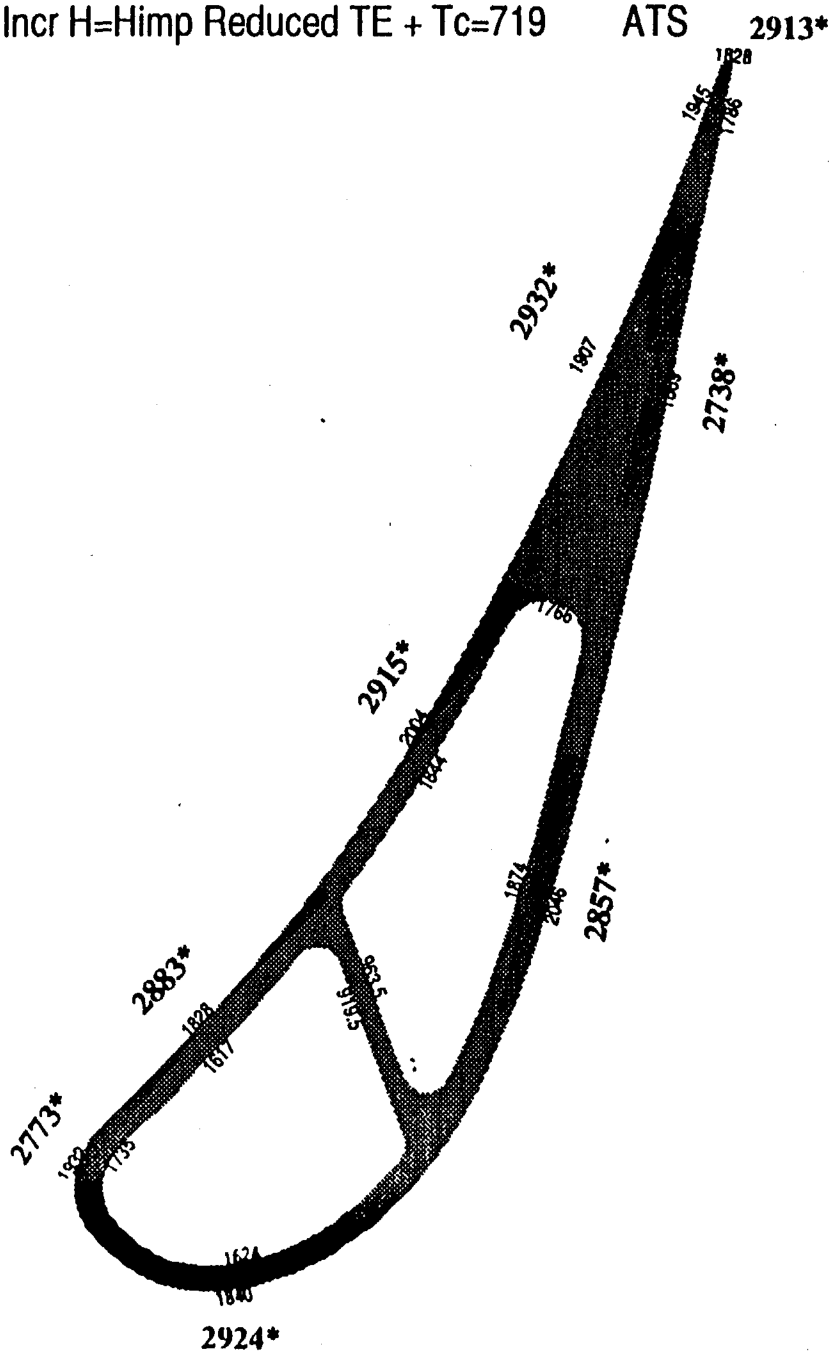


FIGURE 1

T BULK= 1795
SEGMENT= 5
RADIUS= 17.67885

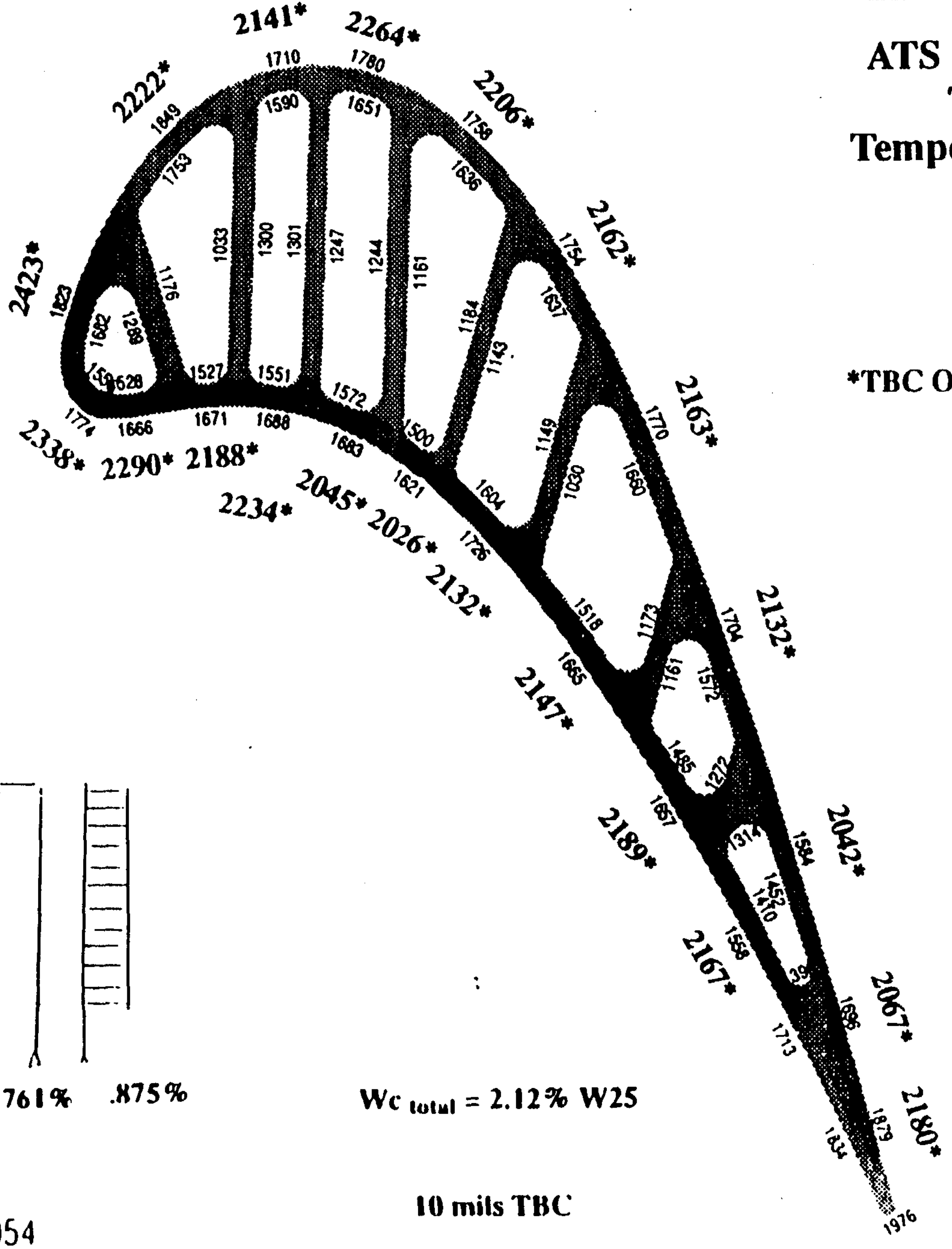
*TBC OUTER TEMPERATURES

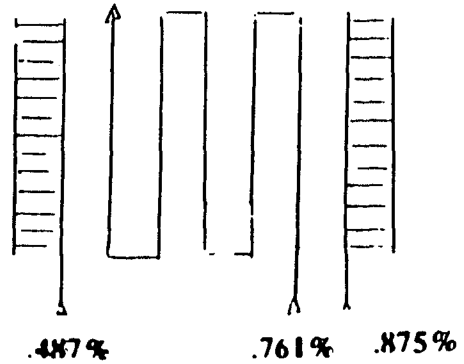
11:58 12 13 93 ml 13110851 bd c0031 PLOT 1
(.S (R 4 4) G 17 MAY 1991 (EGSREP XPOST 4 5E 11 17 93 on ss15)

ATS HPT Stage 1 Blade
TBC & Metal
Temperature Distribution

*TBC OUTER TEMPERATURES

FIGURE 2





Wc $_{total}$ = 2.12% W25

10 mils TBC

T BULK.	1514
SEGMENT.	5
RADIUS.	17 69954

A proposal has been written defining three configurations to be tested for vane impingement with crossflow - a baseline and two variations. A statement of work was prepared and a request for quotation went out to three universities: Texas A & M, Howard and North Carolina A & T. Only Texas A&M provided a quote; the remaining two declined. Work authorization is pending the approval of Tasks 1 & 2 in order for testing to begin in January 1994 on a nine month testing program.

Technology Challenges

Both the HPT vane and blade are dependent on TBC to achieve the 25,000 hours hot time life requirements. As mentioned earlier, the 20 mils of TBC on the HPT vane, in particular, is thicker than our experience to date where five to ten mils of TBC have been tested. The increased TBC thickness provides a technical challenge in many areas: spallation of the TBC is not fully known: temperature gradients through the TBC as well as the maximum temperature of the TBC are areas of concern.

Future Work

Iterations on the HPT vane and blade cooling designs will continue as further information on the life restrictions and the cycle conditions are developed. Preliminary cooling flow designs will be made of the HPT Stage 2 Vane including use of the turbocooling turbine exhaust flows as the coolant supply. Also, the HPT Stage 2 Blade cooling flow definition will be completed.

3A.5 Turbocooler System

The GE industrial system employs a new cooling concept which uses a combination of a high temperature fuel/air heat exhchanger and an external low pressure compressor/turbine combination,(turbocooler), for pressurizing cooling air to be used for the main engines hot section components such as combustor liners,turbine nozzles and blades and turbine shafts. The turbocooler turbomachinery is based on available aircraft environmental system control machines. These machine have been developed to a high degree of reliability. The basic turbocooling circuit uses the supply fuel,natural gas, as the heat sink for cooling air taken from the main engine compressor discharge region, the heat transfer between the fuel and air takes place in the high temperature heat exchanger. Typically the fuel outlet, from the heat exchanger, has been limited to less than 300 ^{O}F in order to avoid coking in the fuel delivery system. Experiments at GE's Corporate Research Center have indicated the coking problem can be mitigated, and consequently the fuel temperature limit, by using a proprietary coke barrier coating(CBC) within the fuel passages of the fuel/air heat exchanger including the fuel injectors. For this design we are utilizing fuel temperatures up to 1000^{O}F.

Design software has been developed to study the impact of changes in cycle design requirements(cooling flow levels and deployment) on the turbocooler system. This software employs the latest data from Allied Signal(ASE). As the principal manufacturer of aircraft ECS units Allied Signal has been selected as the subcontractor for turbocooler and heat exchanger technology and will examine our proposed design ASE compressor and turbine maps form a scaling base for the ATS studies and improved understanding of their heat exchanger design procedures, for pressure losses, have been incorporated.

Studies are ongoing to determine the effect ,on the turbocooler system design, of changes in compressor airflow and turbine exhaust pressure levels.

Plans for Next Reporting Period

Cycle selection will be narrowed to two configurations, and mechanical life analysis will be completed for the turbine components.

TASK 3B SELECTION OF A UTILITY NATURAL GAS FIRED ADVANCED TURBINE SYSTEM (GFATS)

Task Description

Documentation of the Utility GFATS selection. The Utility GFATS will be defined prior to the start of Task 3. The selected system will be capable of modification for operation with coal gas.

Progress During Reporting Period

No progress on Task 3B during this reporting period.

Plans for Next Reporting Period

Work will proceed with Utility ATS cycle selection..

TASK 4 CONVERSION TO A COAL FUELED ATS (CFATS)

Task Description

For both Industrial and Utility systems, select a coal fueled cycle based on adaptation of the GFATS and identify the work required to modify the GFATS to perform optimally in the CFATS.

Progress During Reporting Period

No progress on Task 4 during this reporting period.

Plans for Next Reporting Period

Work will begin on identification of changes needed for conversion to coal gas.

TASK 5 MARKET STUDY

Task Description

Conduct market studies for the Industrial and Utility GFATS systems selected in Task 3.

Progress During Reporting Period

No progress on Task 5 during this reporting period.

Plans for Next Reporting Period

Work will begin on determining preliminary market configuration.

TASK 6 SYSTEM DEFINITION AND ANALYSIS

Task Description

Develop a conceptual design of the GFATS, providing engineering analysis to define and specify the GFATS.

Progress During Reporting Period

No progress on Task 6 during this reporting period.

Plans for Next Reporting Period

Work will begin on gas turbine conceptual design and power plant analysis.

TASK 7 INTEGRATED PROGRAM PLAN

Task Description

Preparation of an integrated program plan.

Progress During Reporting Period

No progress on Task 7 during this reporting period.

Plans for Next Reporting Period

Work will begin on determining the most effective approach to commercialization of both GFATS configurations.

TASK 8 DESIGN AND TEST OF CRITICAL COMPONENTS

Task Descriptions

The component Tasks of Task 8 are:

8.1 Steam Particulate Flow Deposition
8.2 Steam Particle Centrifugal sedimentation
8.3 TBC Mechanical Test and Analysis
8.4 Advanced Seal Technology
8.5 Enhanced Impingement Heat Transfer
8.6 Rotating Heat Transfer
8.7 Turbine Inlet Nozzle Heat Transfer

Write-ups for Tasks 8.1 - 8.7 are given in the Project Plan, along with milestone schedules.

Progress During Reporting Period

Planning proceeded for all Tasks (8.1-8.7). Work on each task has been delayed awaiting acceptance of the NEPA report.

Plans for Next Reporting Period

Work will be in progress on all seven (7) component tasks.

Department of Energy
Advanced Turbine Systems Program
Contract DE–AC21–93MC30244

Presented to:
Morgantown Energy Technology Center

October 19, 1993

Program Kick–Off Meeting
Conceptual Design & Product Development

John Nourse
GE Power Generation

Agenda

☐ *Overview – Review of Systems Configuration*

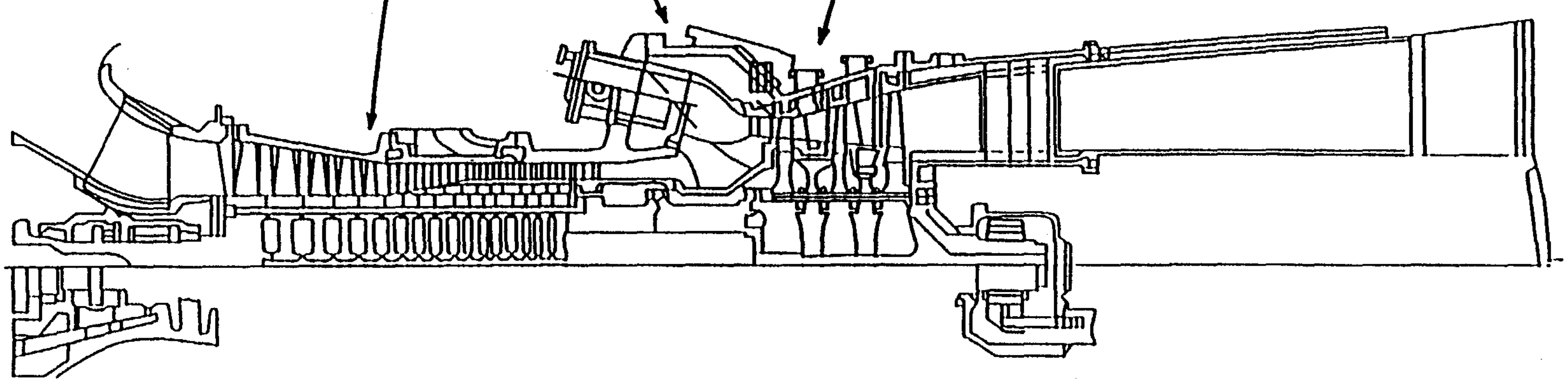
☐ *GE Program Management and Organization*

☐ *Marketing Plan*

☐ *Program Technical Approach and Issues*
  - **Task Objectives and Deliverables**
  - **Utility GFATS Program**
  - **Industrial GFATS Program**
  - **Test Program — Task 8**

☐ *Proprietary Information*

☐ *Schedule Acceleration*



LOW EMISSIONS COMBUSTOR
- GE DRY LOW NOx, HIGH FIRING TEMP TECHNOLOGY

DEVELOPMENT PROGRAM IN PLACE

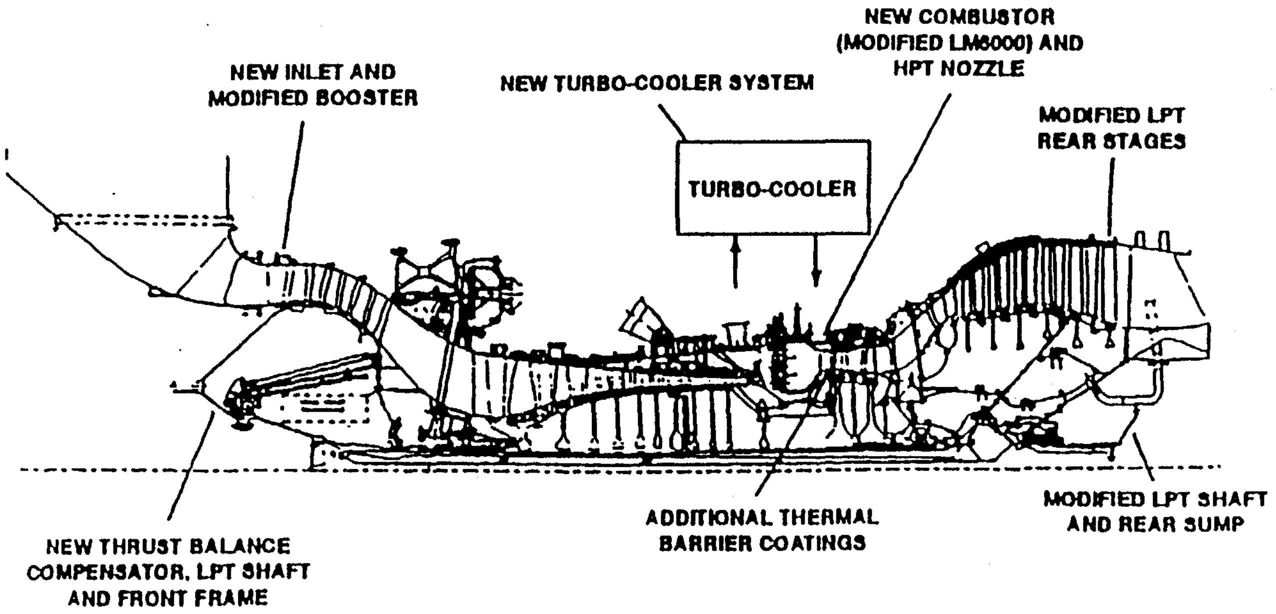
ADVANCED COMPRESSOR
- HIGH EFFICIENCY
- 20:1 PRESSURE RATIO

DEVELOPMENT PROGRAM IN PLACE

ADVANCED HIGH TEMPERATURE TURBINE
- HIGH TEMPERATURE MATERIALS
- ADVANCED COOLING METHODS

BASIS TO DEFINE TECHNOLOGY DEVELOPMENT NEEDS

Utility GFATS Gas Turbine



Turbo-Cooled GE90 Direct-Drive Configuration

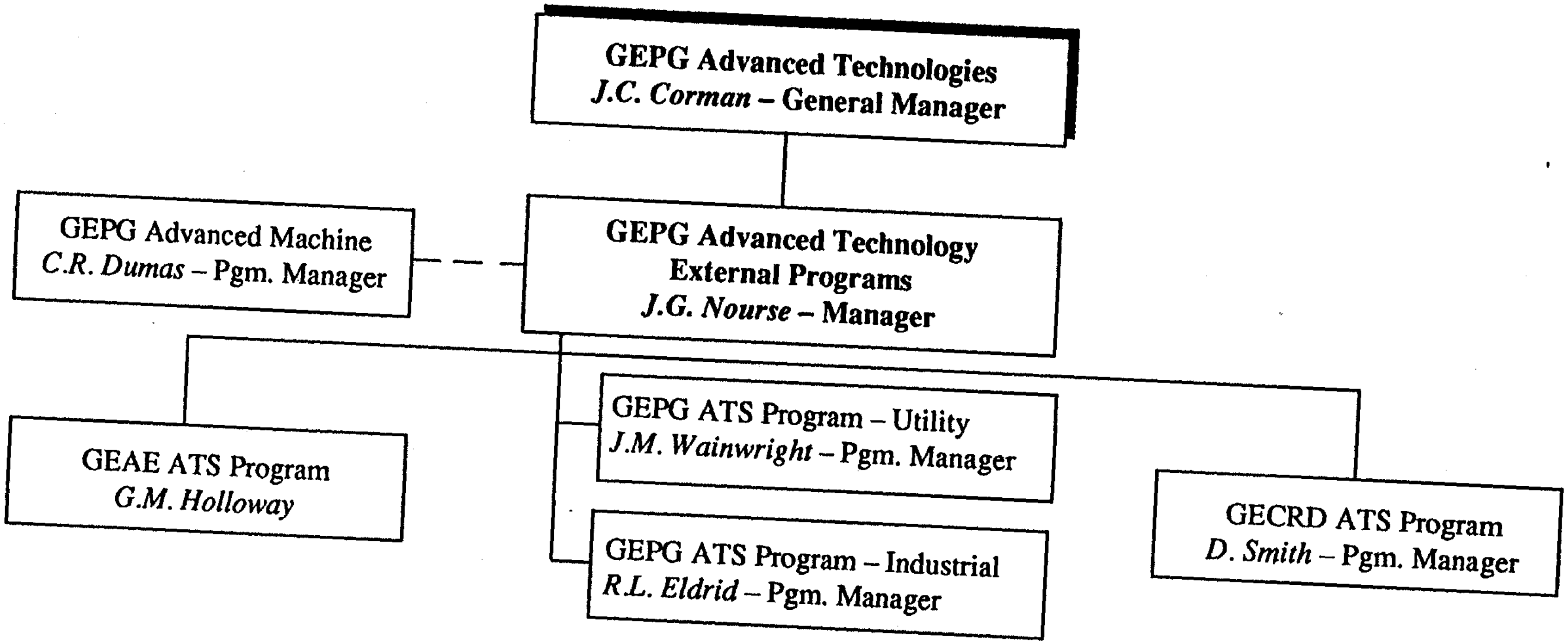
GE ATS Program Management
Task Functional Responsibilities

	GEPG	GEAE	GECRD
Task 1 – Project Plan	✓		
Task 2 – NEPA Information			✓
Task 3 – GFATS Selection	✓	✓	
Task 4 – Conversion to CFATS	✓	✓	
Task 5 – Market Study	✓		
Task 6 – System Definition & Analysis	✓	✓	
Task 7 – Integrated Program Plan	✓	✓	
Task 8 – Component Tests			
8.1 – 8.4			✓
8.5		✓	
8.6 – 8.7			✓

GE ATS Program Management
GEPG / GEAE / GECRD Team

Power Generation	*Aircraft Engines*	*Corporate Research & Devel.*
J.G. Nourse	G. Leonard	G. Kimura
R.L. Eldrid	G. Holloway	D. Smith
T.F. Chance	N. Castells	
J.M. Wainwright	T. Tucker	
C.R. Dumas		

ATS Program Organization



GEPG Advanced Technologies
J.C. Corman **– General Manager**

GEPG Advanced Technology
External Programs
J.G. Nourse **– Manager**

GEPG Advanced Machine
C.R. Dumas – Pgm. Manager

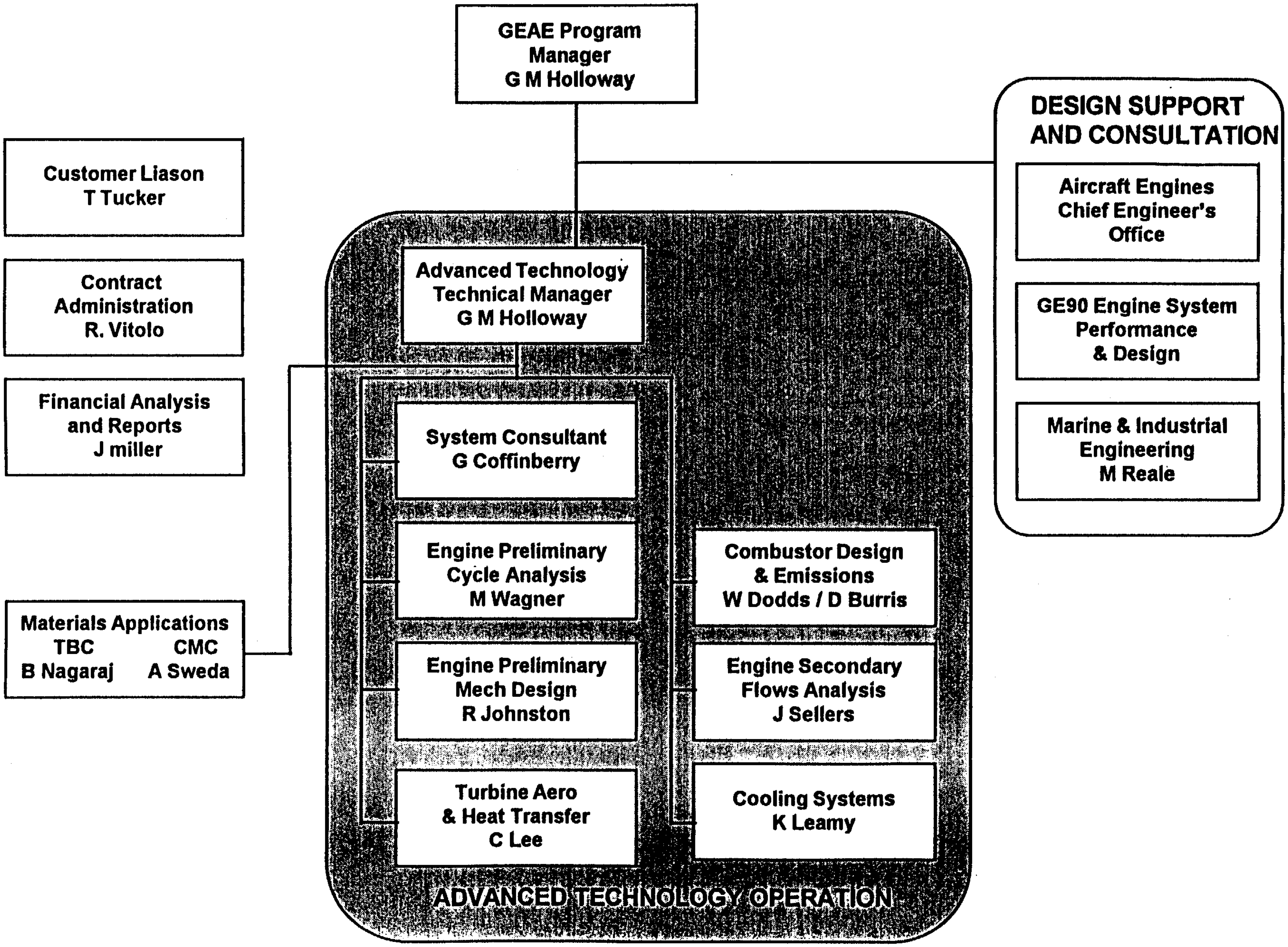
GEAE ATS Program
G.M. Holloway

GEPG ATS Program – Utility
J.M. Wainwright – Pgm. Manager

GEPG ATS Program – Industrial
R.L. Eldrid – Pgm. Manager

GECRD ATS Program
D. Smith – Pgm. Manager

GE Aircraft Engines ATS Functional Program Organization



GEAE Program Manager
G M Holloway

DESIGN SUPPORT AND CONSULTATION

Aircraft Engines Chief Engineer's Office

GE90 Engine System Performance & Design

Marine & Industrial Engineering
M Reale

Customer Liason
T Tucker

Contract Administration
R. Vitolo

Financial Analysis and Reports
J miller

Materials Applications
TBC B Nagaraj
CMC A Sweda

ADVANCED TECHNOLOGY OPERATION

Advanced Technology Technical Manager
G M Holloway

System Consultant
G Coffinberry

Engine Preliminary Cycle Analysis
M Wagner

Engine Preliminary Mech Design
R Johnston

Turbine Aero & Heat Transfer
C Lee

Combustor Design & Emissions
W Dodds / D Burris

Engine Secondary Flows Analysis
J Sellers

Cooling Systems
K Leamy

GE ATS Marketing Plan

Objective

— Assess market potential of the gas fired advanced turbine system

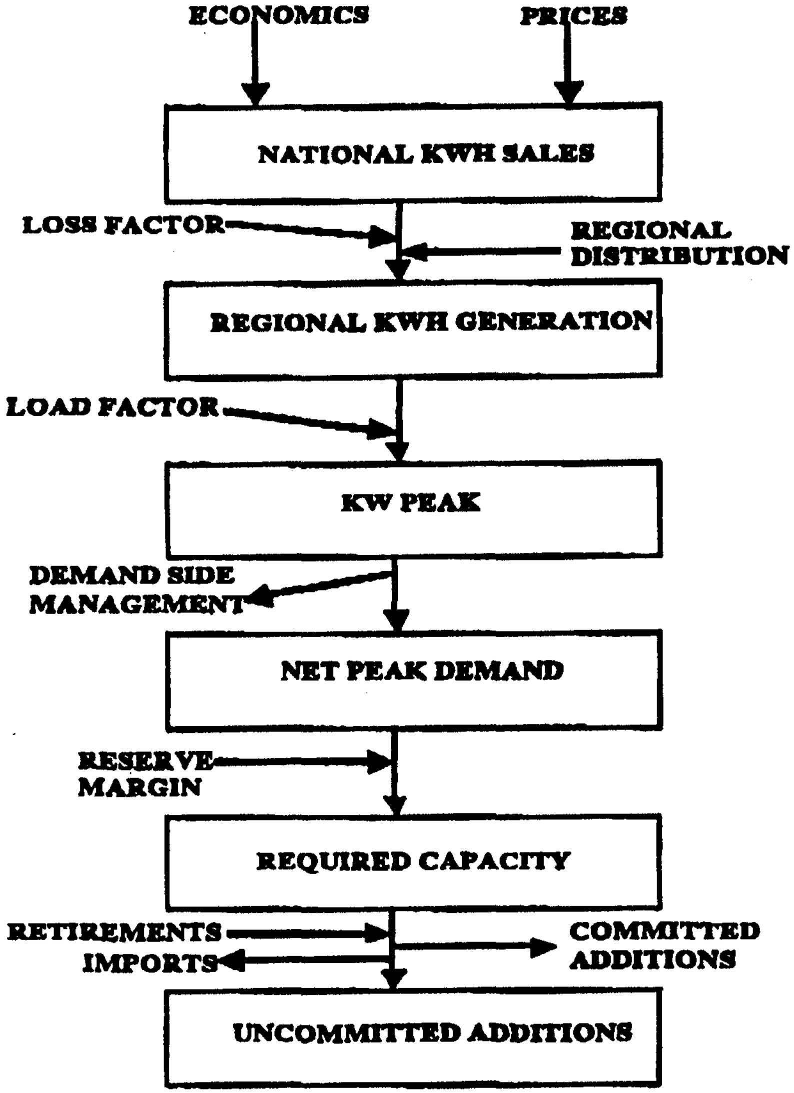
Approach

— *Overall* — Address the ability of GFATS to complete for base load application in Utility, IPP and Industrial Market

— *Specific*

- Compare bus–bar costs of electricity for GFATS to early 1990's power systems
- Utilize GE forecast for load growth and future needs
- Utilize GE FASTPLAN capacity expansion model
- Competing systems include coal fired, nuclear, gas fired cycles

CAPACITY FORECAST MODEL



ECONOMICS

PRICES

NATIONAL KWH SALES

LOSS FACTOR

REGIONAL DISTRIBUTION

REGIONAL KWH GENERATION

LOAD FACTOR

KW PEAK

DEMAND SIDE MANAGEMENT

NET PEAK DEMAND

RESERVE MARGIN

REQUIRED CAPACITY

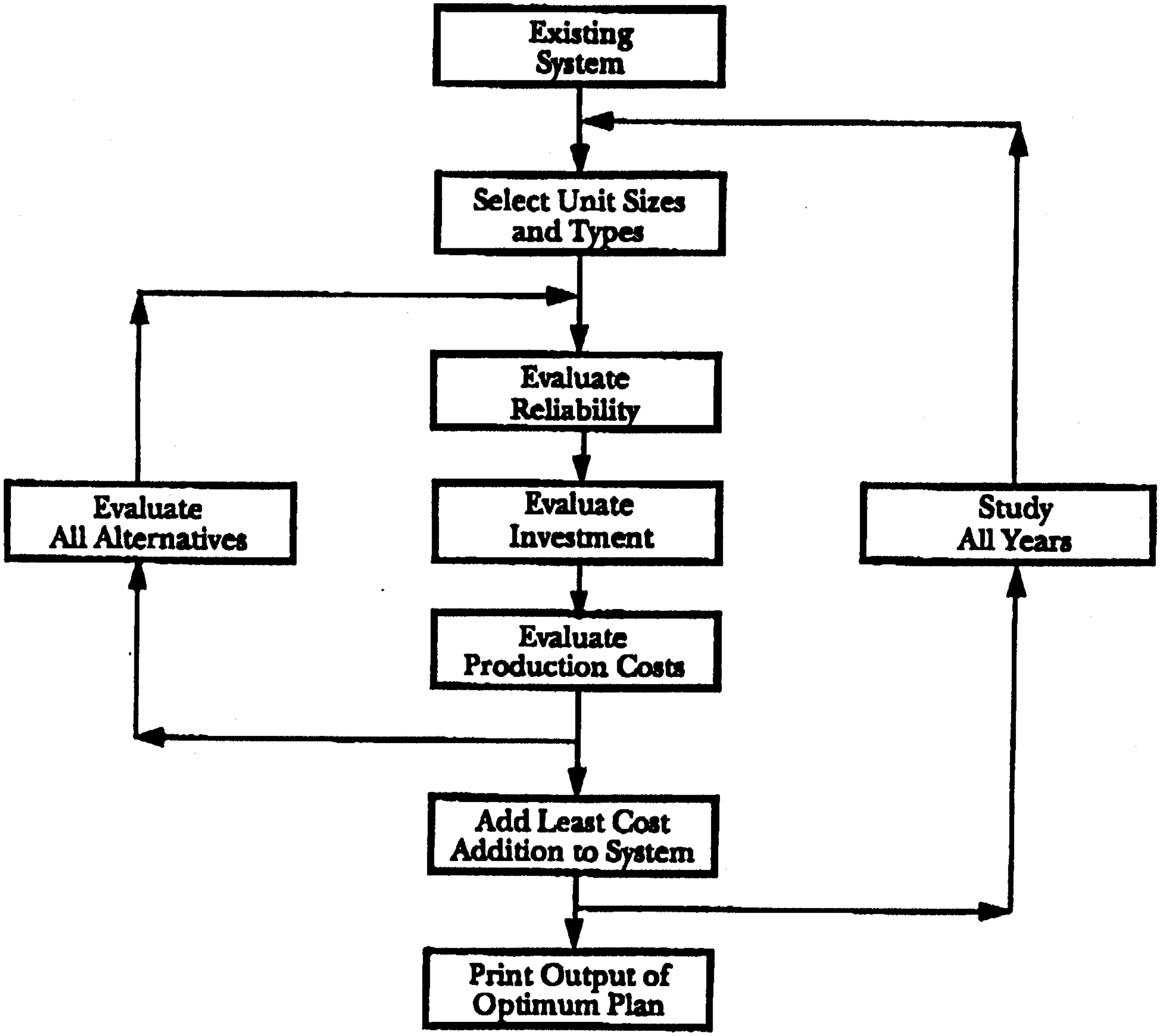
RETIREMENTS

IMPORTS

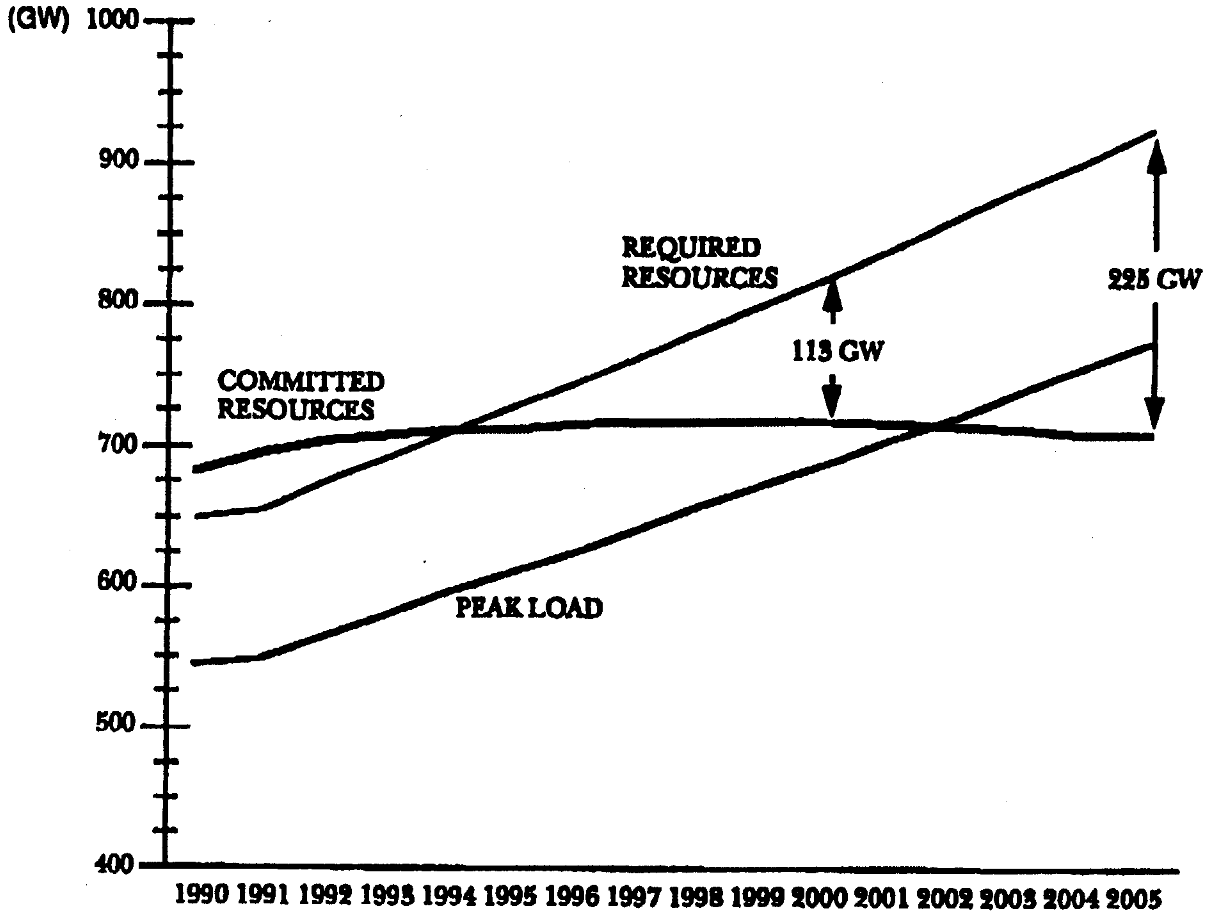
COMMITTED ADDITIONS

UNCOMMITTED ADDITIONS

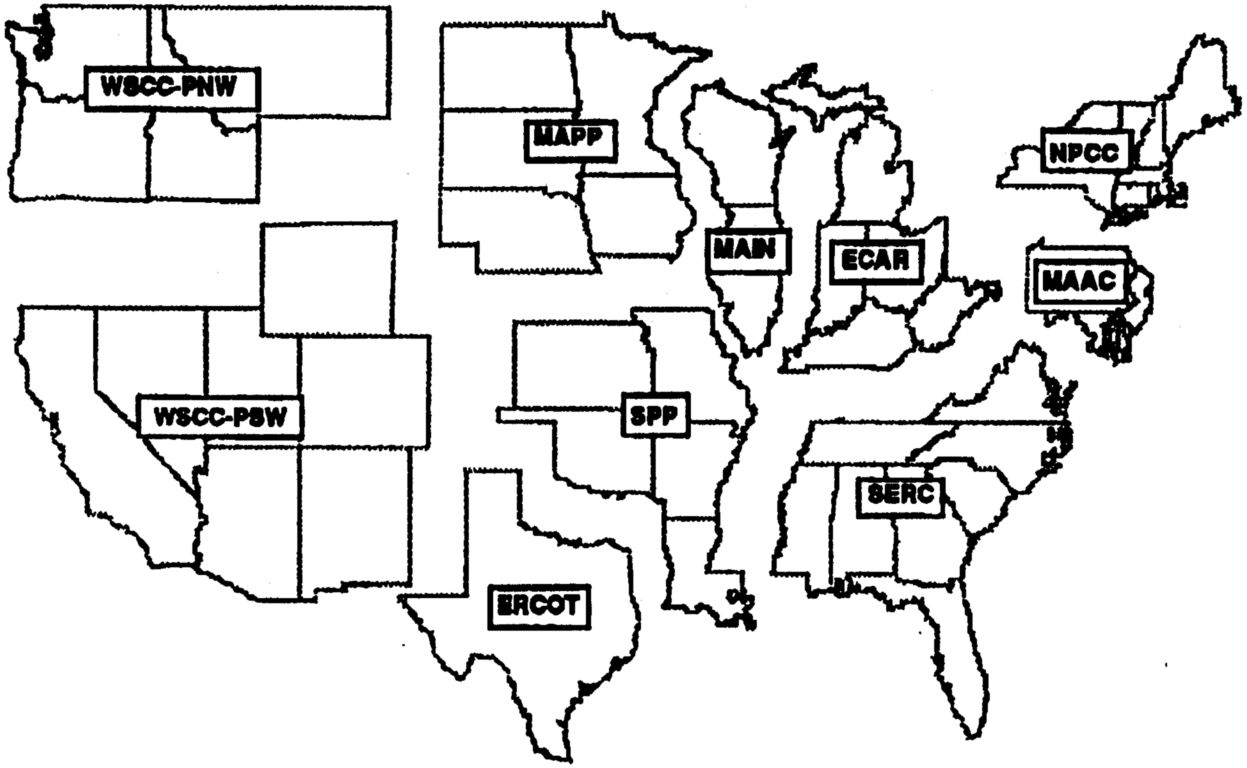
FASTPLAN PROGRAM - SIMPLIFIED FLOW CHART



TOTAL U.S. GENERATING CAPACITY NEEDS FROM 1991 TO 2005



REGION DEFINITIONS



ECAR = East Central Area Reliability Coord.
ERCOT = Electric Reliability Council of Texas
MAAC = Mid-Atlantic Area Council
MAIN = Mid-American Area Council
MAPP = Mid-Continent Area Power Pool
NPCC = Northeast Power Coordinating Council
PNW = Northwestern part of Western States Coordinating Council
PSW = Southwestern part of Western States Coordinating Council
SERC = Southeastern Electric Reliability Council
SPP = Southwest Power Pool

Task 1: Project Plan

Objective

- Produce project plan that identifies major tasks and sub–tasks for effective project management

Approach

- Develop a combined project plan for Industrial and Utility GFATS
- Describe required analyses and development for critical ATS component demonstrations
- Define Program Management Structure for task execution

Deliverable

- Detailed project plan including multi–level gant charts

Task 2: Information Required for NEPA

Objective

- Document the environmental health and safety information required by NEPA

Approach

- Develop a report containing a description of the project including Task 8 (component test) plans and facilities
- Discuss current environmental characteristics of the test site and potential environmental impacts

Deliverable

- A topical report providing information required for NEPA

Task 3A: Selection of the Industrial Natural Gas Fired ATS

Objectives

- Select and define the industrial GFATS
- Identify critical components and technical issues for advanced cycles and high temperature components

Approach

- Two candidate arrangements will be studied
  - Booster and power output shaft driven by the LP turbine
  - Booster driven by a gear connected to the HP turbine. Power output driven by LP.

Task 3A: Selection of the Industrial Natural Gas Fined ATS

(continued)

Cycle Trade–Off Factors

Option 1

— Power output and booster direct drive from LP

- Commonality with GE90 components
- HPT power loading and LPT temperature
- Gearbox losses of option 2 versus HPT & LPT efficiency

Option 2

— Booster gear drive from core with free turbine driving output

- Output shaft speed control for 50/60 HZ output
- LPT critical speeds
- Exhaust gas routing
- Environment and equipment accessibility

Task 3A: Selection of the Industrial Natural Gas Fined ATS

(continued)

Component and Technology Issues

- Emissions and efficiency
  - Heat sinks – fuel or materials such as steam bottoming source
- Hot gas path materials

Deliverables

- Topical report will be submitted
  - Description of selected industrial GFATS
  - Performance, environmental, operation and maintenance and reliability characteristics
  - List of critical components and technical issues

Task 3B: Selection of a Utility GFATS

Objectives

- — Define the selected utility GFATS and provide evidence of improvements in efficiency emissions and costs
- — Identify system enhancements to achieve ATS goals
- — Identify critical components and technical issues

Approach

- — Describe selection process of a next generation utility system
    - Trade-off alternate means of hot gas path cooling
    - Consider alternate materials and coatings
    - Define and quantify system enhancements from baseline performance and related technical risks

Deliverables

- — A topical report will be submitted
    - Description of the utility GFATS
    - Performance environmental, operation and maintenance and reliability
    - List of critical components and technical issues
    - Specific enhancements will be defined for achieving ATS goals

Task 4: Conversion to Coal Fueled CFATS

Objectives

- Select and define CFATS based on the gas fired ATS most marketable after the year 2005. Define changes or necessary provisions to GFATS to minimize impact of conversion to coal gas usage.

Approach

- Evaluate alternatives for coal usage in advanced gas turbines
- Select reference coal gas based on heating value and coal gas properties
- Define performance and design impact of coal gas usage
- Quantify CFATS vs. GFATS performance
- Estimate life cycle costs and development needs
- ***Likely system selections:***
    - IGCC cycle
    - Cooling air heat exchanger for industrial CFATS
    - Coal gas clean up system

Deliverables

- Two topical reports will be submitted — one each for Utility and Industrial CFATS
    - Discussion of CFATS selection rationale
    - Description of CFATS and design changes
    - List of required developments
    - Costs and schedule for development work

Task 5: Market Study

Objective

- Assess market potential for the gas–fired advanced turbine systems (GFATS) selected in Task 3

Approach

- Calculate bus–bar costs of electricity using GE's FASTPLAN for the GFATS, and compare to early 1990's power systems in the same market class to assess cost–competitiveness

Deliverables

- Two Topical Market Study Reports (one for Industrial GFATS, one for Utility GFATS) will be submitted in accordance with contract requirements

Task 6: System Definition and Analysis

Objective

— Develop conceptual designs for both GFATS systems

Approach

— Develop conceptual designs of both systems selected in Task 3, including:

- Flange to flange gas turbine and accessories
- Hot gas path component cooling system
- Bottoming cycle and power plant equipment
- Preliminary plant layout
- Preliminary performance calculations
- Preliminary estimate of installed cost

Deliverables

— Topical Report will be provided in accordance with contract requirements

Task 7: Integrated Program Plan

Objective

- Define in detail the most effective approach to commercialize both selected GFATS systems

Approach

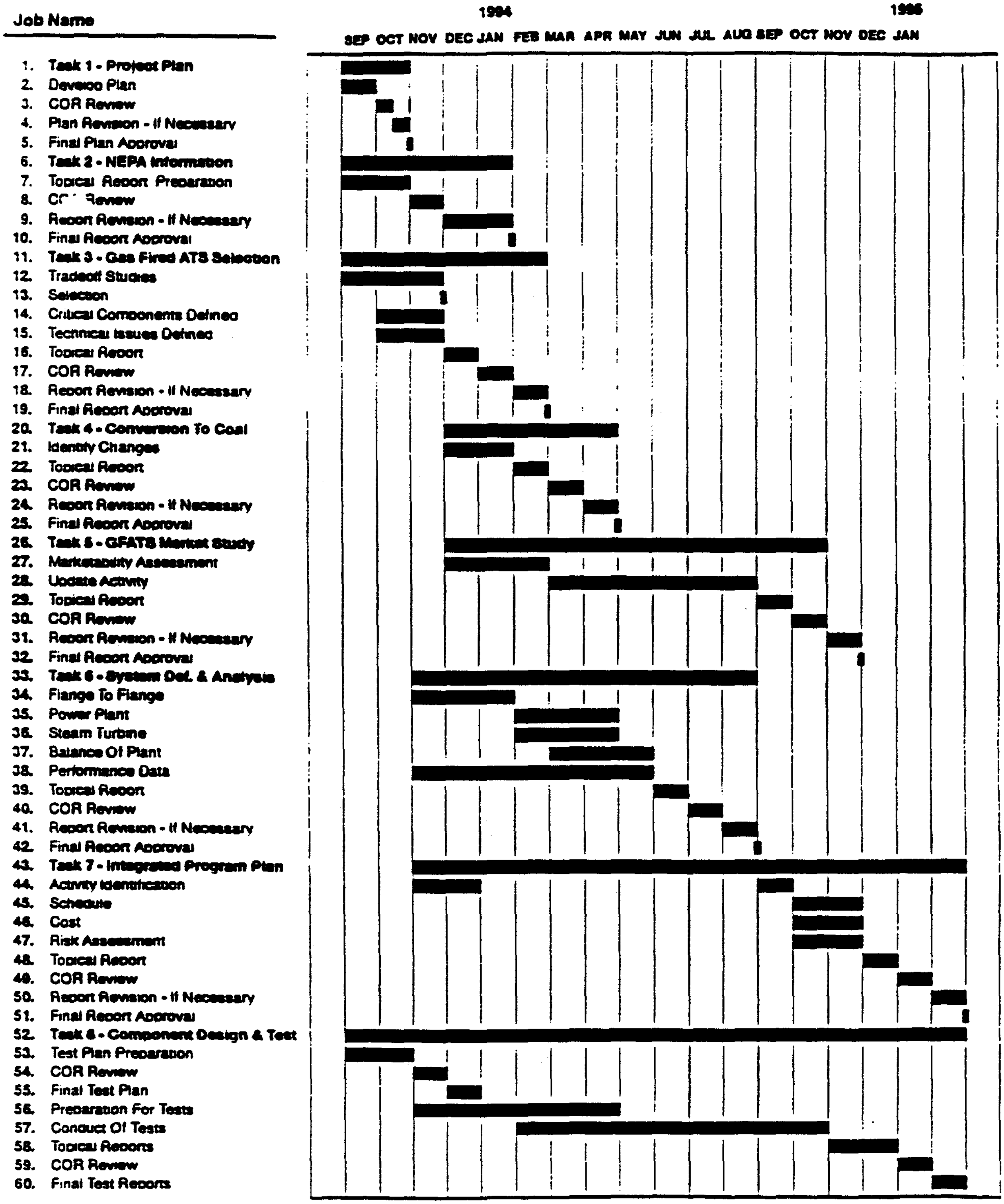
- Prepare a research and development plan supporting commercialization of GFATS systems selected in Task 6
- Prepare a schedule, cost description and risk assessment for components selected under conceptual Design and Product Development phase of ATS
- Perform component technology tests in Task 8

Deliverables

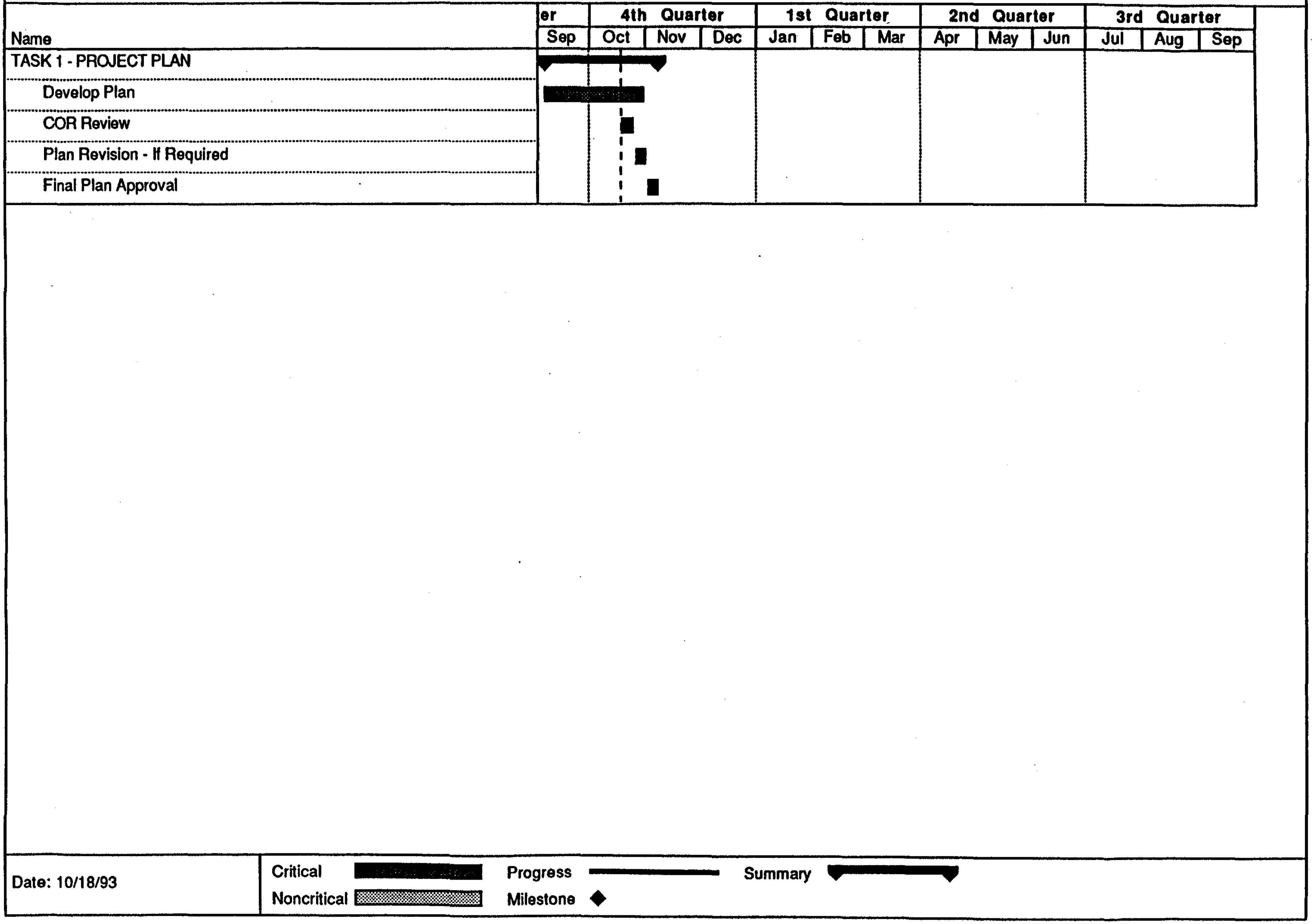
- An integrated program plan will be submitted in accordance with contract requirement

UTILITY GFATS

TECHNICAL PROGRAM PLAN

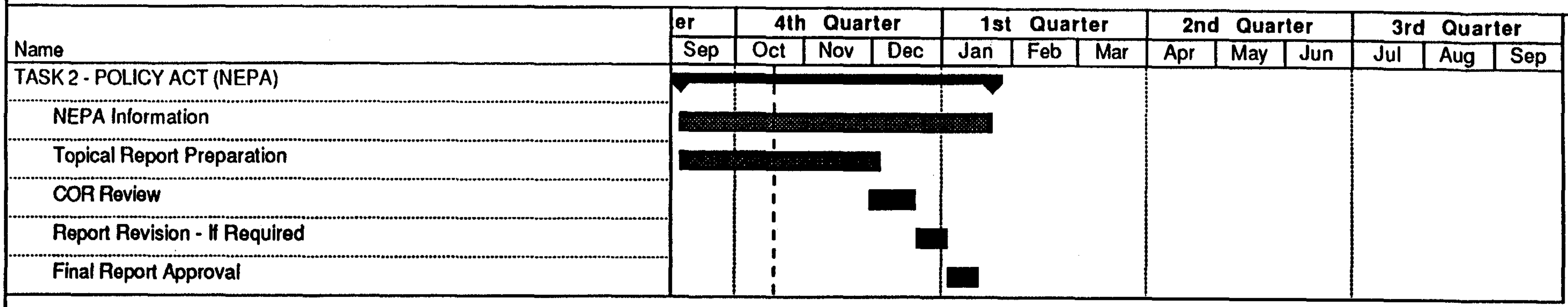

Job Name
1994
1995
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
1. Task 1 - Project Plan
2. Develop Plan
3. COR Review
4. Plan Revision - If Necessary
5. Final Plan Approval
6. Task 2 - NEPA Information
7. Topical Report Preparation
8. COR Review
9. Report Revision - If Necessary
10. Final Report Approval
11. Task 3 - Gas Fired ATS Selection
12. Tradeoff Studies
13. Selection
14. Critical Components Defined
15. Technical Issues Defined
16. Topical Report
17. COR Review
18. Report Revision - If Necessary
19. Final Report Approval
20. Task 4 - Conversion To Coal
21. Identify Changes
22. Topical Report
23. COR Review
24. Report Revision - If Necessary
25. Final Report Approval
26. Task 5 - GFATS Market Study
27. Marketability Assessment
28. Update Activity
29. Topical Report
30. COR Review
31. Report Revision - If Necessary
32. Final Report Approval
33. Task 6 - System Def. & Analysis
34. Flange To Flange
35. Power Plant
36. Steam Turbine
37. Balance Of Plant
38. Performance Data
39. Topical Report
40. COR Review
41. Report Revision - If Necessary
42. Final Report Approval
43. Task 7 - Integrated Program Plan
44. Activity Identification
45. Schedule
46. Cost
47. Risk Assessment
48. Topical Report
49. COR Review
50. Report Revision - If Necessary
51. Final Report Approval
52. Task 8 - Component Design & Test
53. Test Plan Preparation
54. COR Review
55. Final Test Plan
56. Preparation For Tests
57. Conduct Of Tests
58. Topical Reports
59. COR Review
60. Final Test Reports

DOE ATS TASK 1



Date: 10/18/93

DOE ATS TASK 2

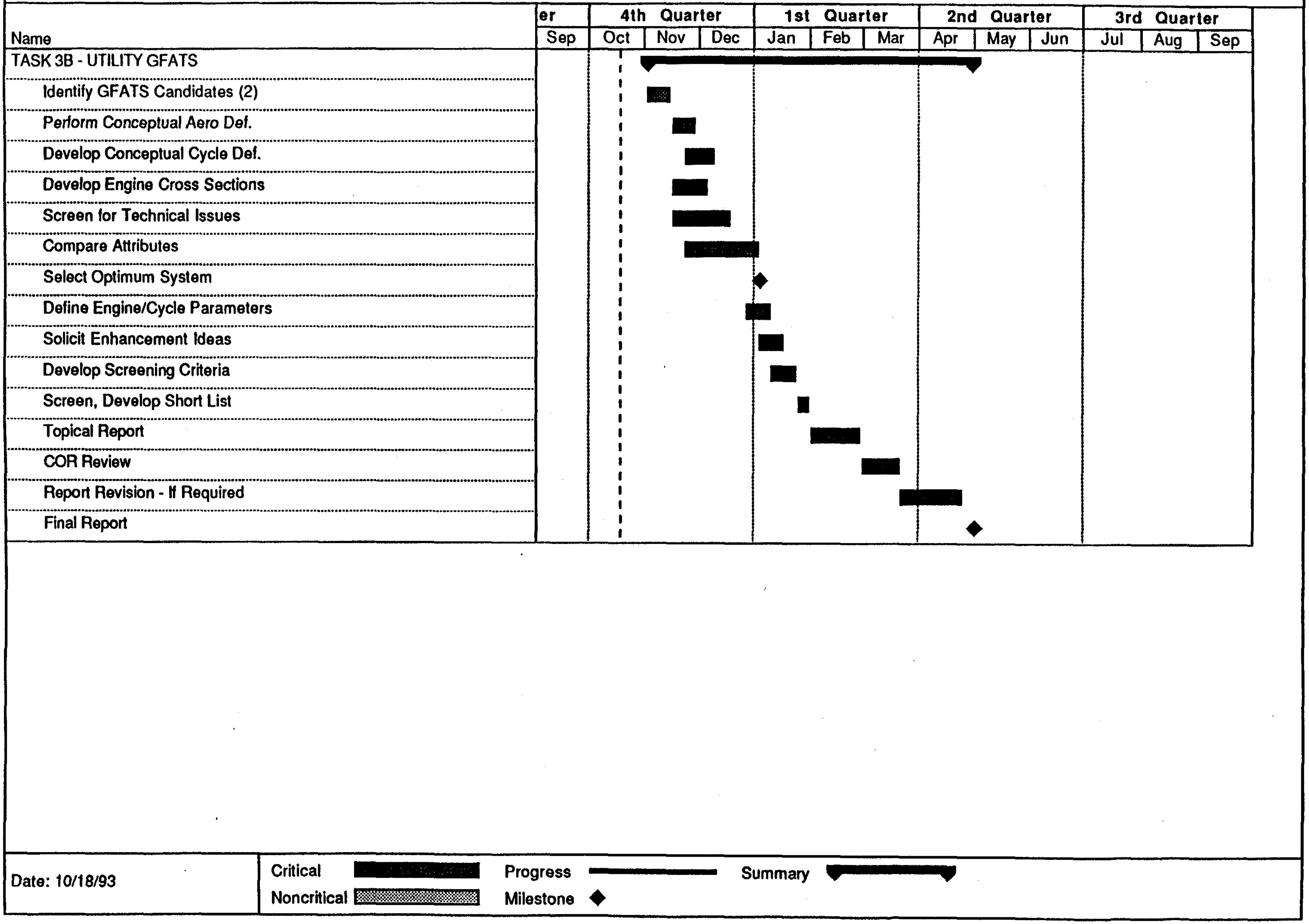


Date: 10/18/93

Critical ■ Progress — Summary ▬

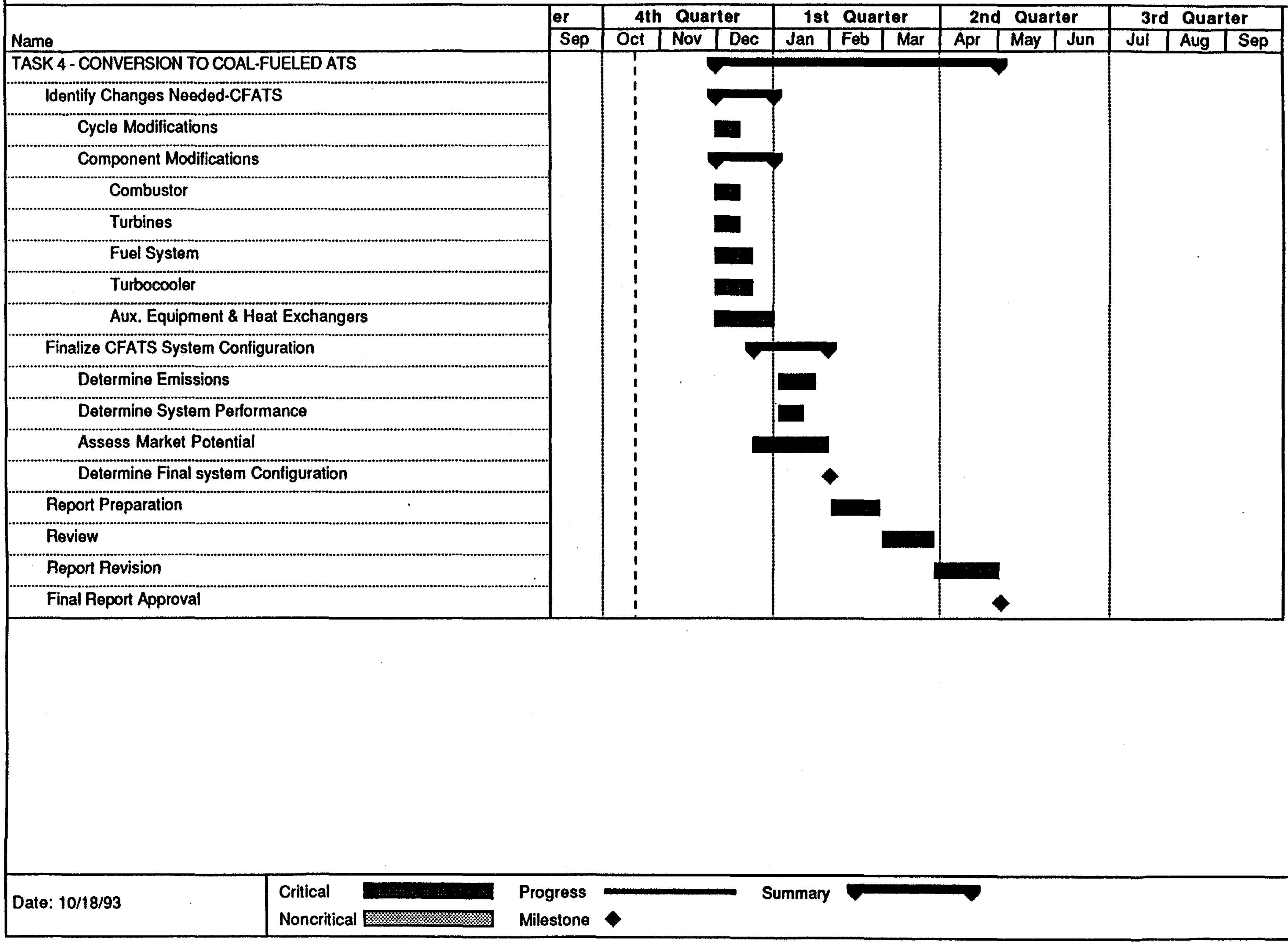
Noncritical ▨ Milestone ◆

DOE ATS TASK 3B



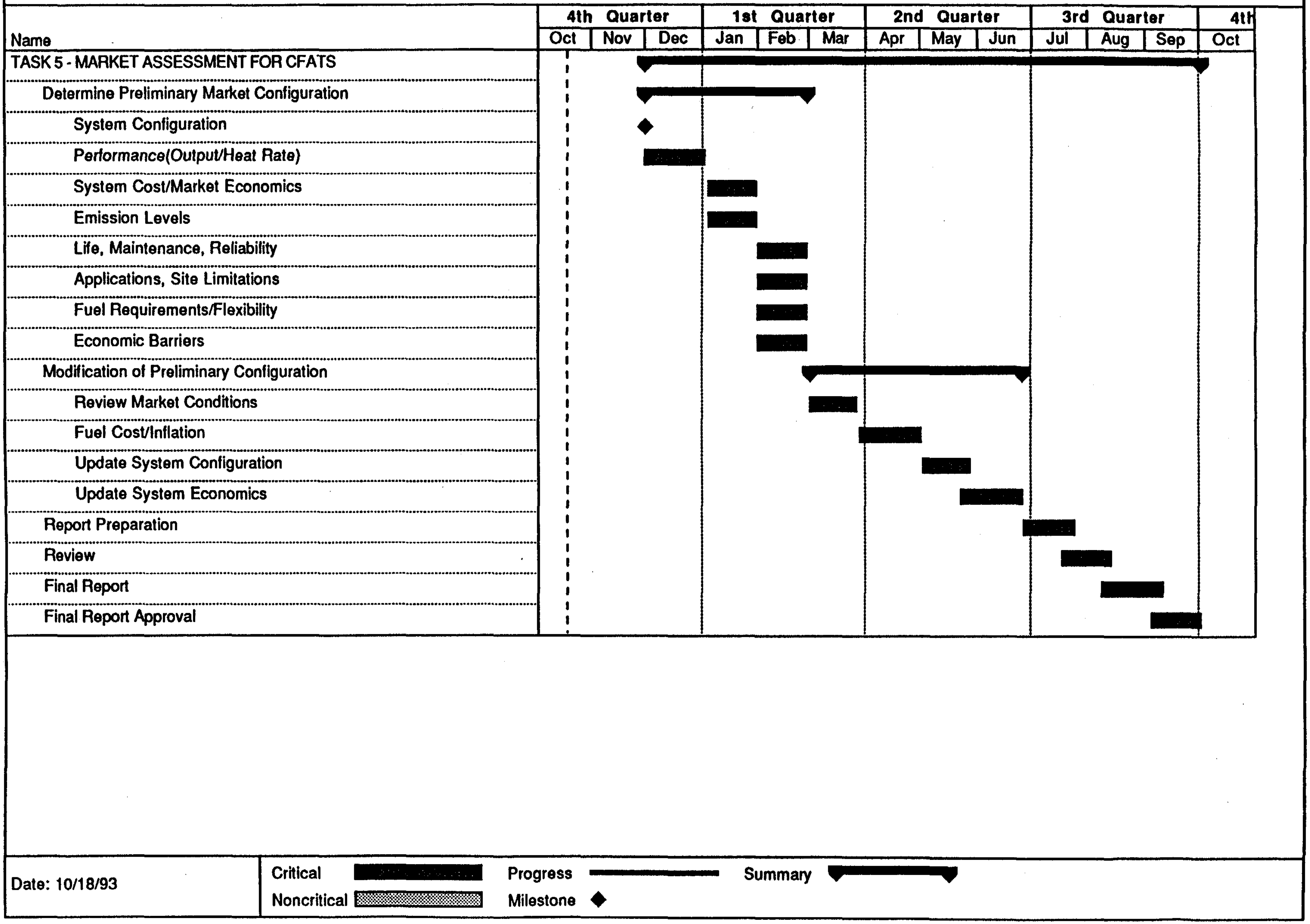
Date: 10/18/93

DOE ATS TASK 4



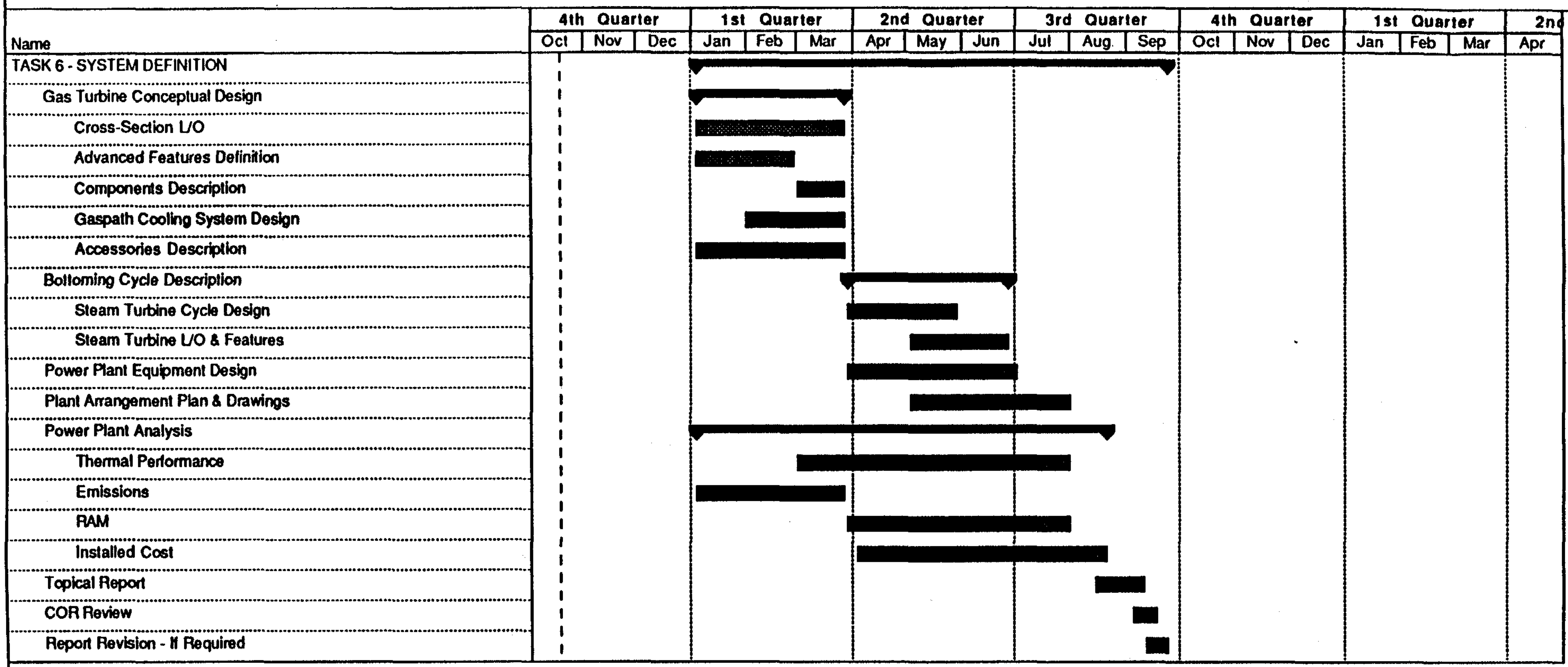
Date: 10/18/93

DOE ATS TASK 5



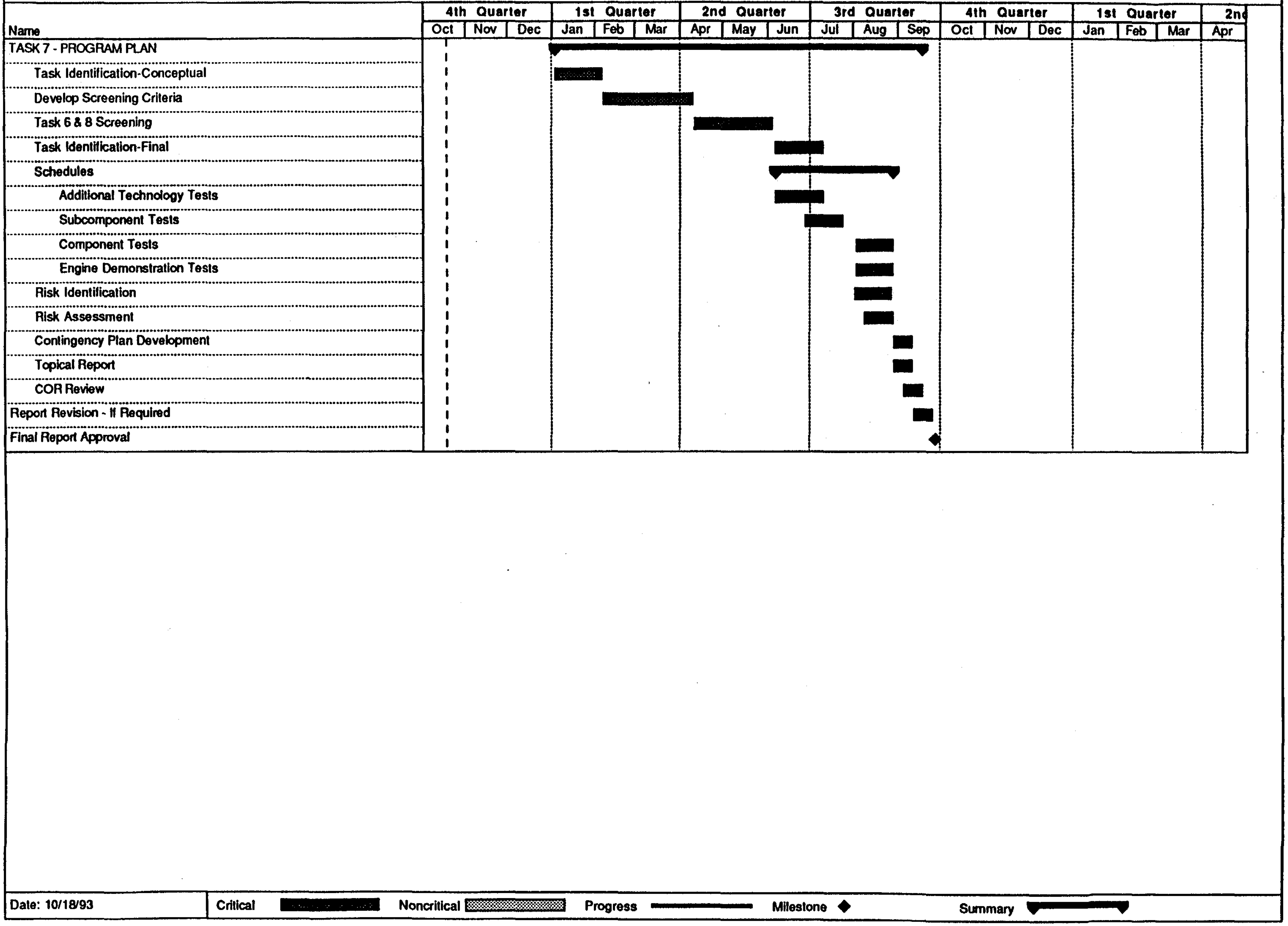
Date: 10/18/93

DOE ATS TASK 6

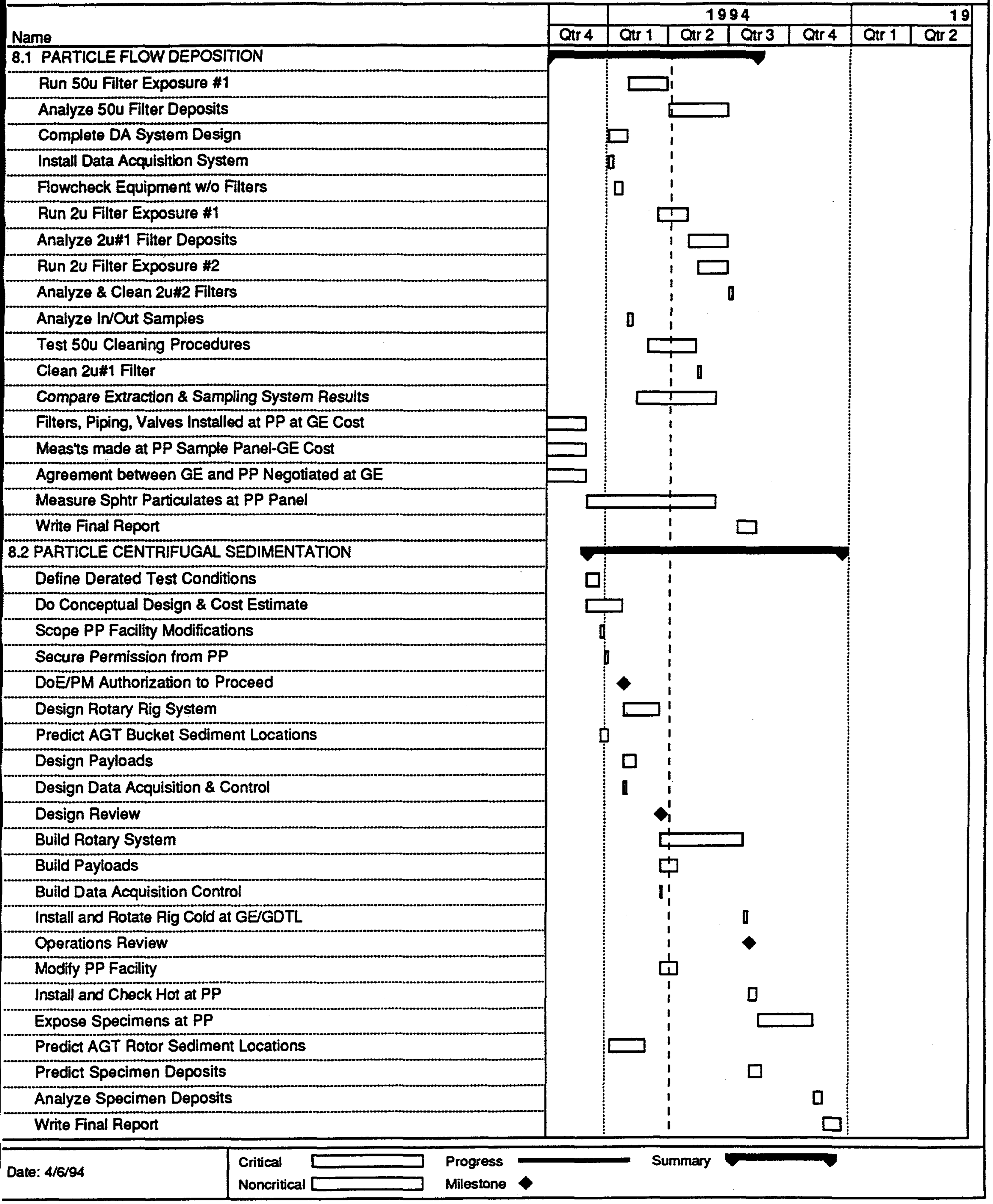


Date: 10/18/93	Critical ■	Noncritical ▨	Progress —	Milestone ◆	Summary ▼━▼

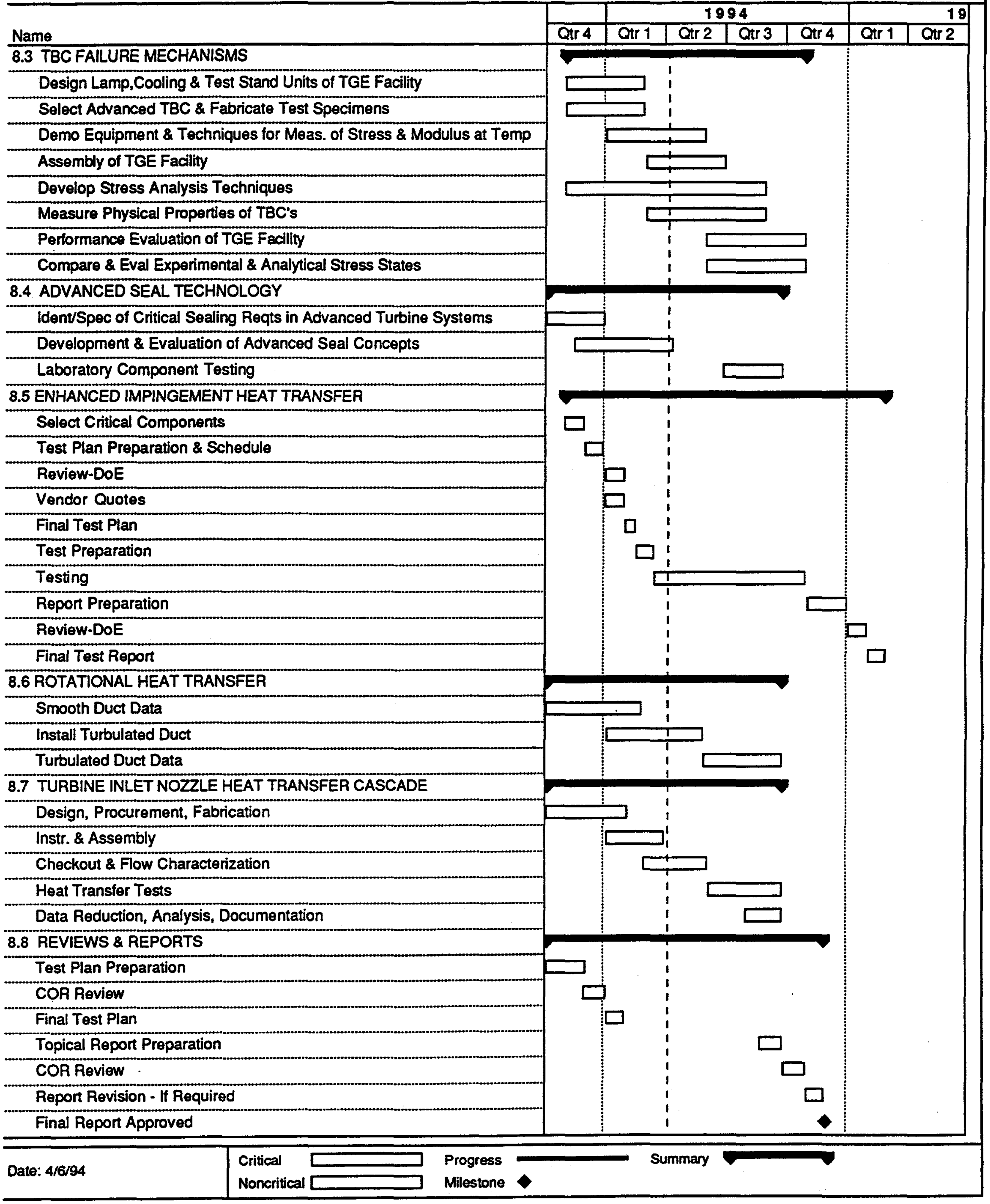
DOE ATS TASK 7



ATS TASK 8


Name
1994
19
Qtr 4
Qtr 1
Qtr 2
Qtr 3
Qtr 4
Qtr 1
Qtr 2
8.1 PARTICLE FLOW DEPOSITION
Run 50u Filter Exposure #1
Analyze 50u Filter Deposits
Complete DA System Design
Install Data Acquisition System
Flowcheck Equipment w/o Filters
Run 2u Filter Exposure #1
Analyze 2u#1 Filter Deposits
Run 2u Filter Exposure #2
Analyze & Clean 2u#2 Filters
Analyze In/Out Samples
Test 50u Cleaning Procedures
Clean 2u#1 Filter
Compare Extraction & Sampling System Results
Filters, Piping, Valves Installed at PP at GE Cost
Meas'ts made at PP Sample Panel-GE Cost
Agreement between GE and PP Negotiated at GE
Measure Sphtr Particulates at PP Panel
Write Final Report
8.2 PARTICLE CENTRIFUGAL SEDIMENTATION
Define Derated Test Conditions
Do Conceptual Design & Cost Estimate
Scope PP Facility Modifications
Secure Permission from PP
DoE/PM Authorization to Proceed
Design Rotary Rig System
Predict AGT Bucket Sediment Locations
Design Payloads
Design Data Acquisition & Control
Design Review
Build Rotary System
Build Payloads
Build Data Acquisition Control
Install and Rotate Rig Cold at GE/GDTL
Operations Review
Modify PP Facility
Install and Check Hot at PP
Expose Specimens at PP
Predict AGT Rotor Sediment Locations
Predict Specimen Deposits
Analyze Specimen Deposits
Write Final Report
Date: 4/6/94
Critical
Noncritical
Progress
Milestone
Summary

ATS TASK 8



8.3 TBC FAILURE MECHANISMS
- Design Lamp,Cooling & Test Stand Units of TGE Facility
- Select Advanced TBC & Fabricate Test Specimens
- Demo Equipment & Techniques for Meas. of Stress & Modulus at Temp
- Assembly of TGE Facility
- Develop Stress Analysis Techniques
- Measure Physical Properties of TBC's
- Performance Evaluation of TGE Facility
- Compare & Eval Experimental & Analytical Stress States

8.4 ADVANCED SEAL TECHNOLOGY
- Ident/Spec of Critical Sealing Reqts in Advanced Turbine Systems
- Development & Evaluation of Advanced Seal Concepts
- Laboratory Component Testing

8.5 ENHANCED IMPINGEMENT HEAT TRANSFER
- Select Critical Components
- Test Plan Preparation & Schedule
- Review-DoE
- Vendor Quotes
- Final Test Plan
- Test Preparation
- Testing
- Report Preparation
- Review-DoE
- Final Test Report

8.6 ROTATIONAL HEAT TRANSFER
- Smooth Duct Data
- Install Turbulated Duct
- Turbulated Duct Data

8.7 TURBINE INLET NOZZLE HEAT TRANSFER CASCADE
- Design, Procurement, Fabrication
- Instr. & Assembly
- Checkout & Flow Characterization
- Heat Transfer Tests
- Data Reduction, Analysis, Documentation

8.8 REVIEWS & REPORTS
- Test Plan Preparation
- COR Review
- Final Test Plan
- Topical Report Preparation
- COR Review
- Report Revision - If Required
- Final Report Approved

Date: 4/6/94

GE ATS Program
Proprietary Information Issues

GE Utility ATS

- — Development well underway at GEPG
- — Detailed technical information requires protection due to competitive market situation
- — DOE contract terms provide protection
- — Task 3 — System Selection and Task 8 — System Definition
    - Data review will be provided
    - Detailed data not for publication

GE Industrial ATS

- — System development being initiated
- — Same issues as above

GE ATS Program
Proposed Schedule Acceleration

GE ATS Original Proposal

- 18 month program
- September ’93 — February ’95

Proposal to Accelerate GE ATS Program

- 14 month program Tasks 1 – 7
- September ’93 – October ’94
- Begin next phase program October ’94
- *Objectives*
  - Supplement Task 8 testing for next phase
  - Accelerate detailed designs of GE ATS