GAS TURBINE MONITORING SYSTEM

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ABSTRACT

GAS TURBINE MONITORING SYSTEM

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In this study, a new gas turbine monitoring system being able to carry out appropriate run process is set up for a gas turbine with 250 kW power rating and its accessories. The system with the mechanical and electrical connections of the required sub-parts is transformed to a kind of the test stand. Performance test result calculation method is described. In addition that, performance evaluation software being able to apply with the completion of the preliminary performance tests is developed for this gas turbine.

This system has infrastructure for the gas turbine sub-components performance and aerothermodynamics research. This system is also designed for aviation training facility as a training material for the gas turbine start and run demonstration. This system provides the preliminary gas turbine performance research requirements in the laboratory environment.

Keywords: Gas turbine monitoring system, Performance evaluation.

ÖZ

GAZ TÜRBİN İZLEME SİSTEMİ

Özmen, Teoman
Yüksek Lisans, Havacılık ve Uzay Mühendisliği Bölümü
Tez Yöneticisi : Prof. Dr. İ. Sinan Akmandor

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Bu çalışma ile 250 kW gücünde gaz türbin ve aksesuarlarının uygun çalıştırma şartlarını gerçekleştiren yeni bir gaz türbin izleme sistemi kurulmuştur. Sistem, gerekli olan alt parçaların mekanik ve elektrik bağlantılarının yapılması ile bir test standı haline getirilir. Performans test sonuçları hesaplama metodu tanımlanmıştır. Buna ilave olarak bu motor için performans testlerinin tamamlanmasıyla uygulanabilen bir başlangıç performans değerlendirme programı geliştirilmiştir.

Bu sistem gaz türbin parçalarının aero-termodinamik performans araştırmalarının da yapılabileceği alt yapıya sahiptir. Eğitim faaliyetlerinde bir gaz türbinin start ve çalışmasını gösteren eğitim malzemesi olarak ta dizayn edilmiştir. Bu sistem laboratuvar ortamında gaz turbin başlangıç performans geliştirme araştırmalarının gereksinimlerini sağlar.

Anahtar Kelimeler: Gaz türbin izleme sistemi, performans değerlendirme.

To My Wife
Who patiently put up with my study.

ACKNOWLEDGEMENTS

First of all, I wish to express my sincere appreciation to Prof. Dr. İ. Sinan Akmandor for opening the golden doors of such a special topic arousing the interest of the modern industry and for his guidance and insight throughout the research.

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SHP	Shaft Horse Power
N1	Gas Producer Turbine Speed
N2	Power Turbine Speed
N_R	Main Rotor Speed
T_{T5}	Gas Producer Turbine Outlet Temperature (GPTOT)
P_{T2}	Compressor Air Inlet Pressure
P_{S7}	Exhaust Gas Static Pressure
TT2, T_0	Compressor Air Inlet Temperature
SFC	Specific Fuel Consumption
SHPCF	Shaft Horse Power Correction Factor
WF	Fuel Flow
RPR	Ram Pressure Ratio
RPRWF	Ram Pressure Ratio Effect On Fuel Flow
RPR T_{T5}	Ram Pressure Ratio Effect On GPTOT
RPRSHP	Ram Pressure Ratio Effect On Shaft Horse Power
WFCF	Fuel Flow Correction Factor
GPTOT (TT5)	Gas Producer Turbine Outlet Temperature
TT5CF	Gas Producer Turbine Outlet Temperature Correction Factor
SG	Specific Gravity
ΔSG	Specific Gravity Change
LHV	Lower Heating Value
READSHP	Reading Shaft Horse Power

CSHP	Corrected Shaft Horse Power
CTT5	Corrected Gas Producer Turbine Outlet Temperature
CWF	Corrected Fuel Flow
SHP CURVE	Shaft Horse Power Curve Slope
SHP CONST VAL	Shaft Horse Power Constant Value
SHP T/O	Shaft Horse Power Take Off
WF CURVE	Fuel Flow Curve Slope
WF CT	Fuel Flow Constant Value
WF T/O	Fuel Flow at Take Off
$TORQ_{LIMIT}$	Torquemeter Limit
EPES	Engine Performance Evaluation Software
CONSTVAL T_{T5}	Gas Producer Turbine Outlet Temperature Constant Value

CHAPTER 1

1. INTRODUCTION

The large numbers of helicopters powered by gas turbines are in use for both military and civilian applications. The power ranges of gas turbines specifically designed for helicopter propulsion systems are from 300 up to 11400 horsepower. There are only a few flight-qualified turbine engine of less than 400 horsepower rating. For this reason, most of helicopters which weigh less than 3000 pounds or below, such as the new Robinson R22, continue to use a reciprocating engine.
Although significant advances have been made in rotor, airframe aerodynamics and structures of the helicopter, the gas turbine with its high horsepower output per unit weight and volume, good efficiency, and virtually unlimited power output potential attract designers in the development of helicopter [1].

The primary requirement for any aircraft is to carry its load over a specified distance or for a given period of time. The helicopter with a good operating range and endurance should have an engine with low fuel consumption, particularly at cruise conditions. Actually, two main factors affect the level of fuel consumption. One is the efficiency of engine itself, as determined by its cycle and component efficiencies. The other is the matching of the engine to the aircraft. The design requirements for the engine cycle efficiencies, in terms of component performance, and higher pressure, and temperature ratios need to be confirmed by complete engine performance results [2].

Major airworthiness requirements are durability and integrity. Therefore endurance tests are required for this purpose. Additional structural tests are also required to confirm components subject to low cycle fatigue. The engine component life limit can be determined in several ways; measuring low cycle fatigue (LCF) damage (disc failures), creep and thermal fatigue (turbine blade failures), and wear-out damage.

The objective of the present thesis is to set up a gas turbine monitoring system. Required sub-systems and performance test results calculation method are described. Gas turbine preliminary performance and evaluation are performed for 250C-18 engine. A gas turbine monitoring system is designed preliminary for evaluating possibly the aero-thermodynamic performance of the engine compressor, combustion chamber and turbines.

The complete engine performance results and endurance tests can be performed by means of this setup after adding a loading system and its accessories. It can be used for training students to demonstrate start-up and run procedure. In addition to this gas turbine monitoring system, the test stand will allow smaller, or lighter engines to be tested. The gas turbine test stand is established in METU Aerospace Engineering Department Propulsion Lab (METU-AEPL).

1.1 Previous Research And Study About Methods Of Gas Turbine Performance Analysis And Monitoring Systems

High Performance Condition Monitoring Of Aircraft Engines; a similarity-based modeling (SBM) method is demonstrated that provides very early annunciation of gas path faults in aircraft engines. This model is used to generate real-time estimates of sensor (pressure transducers, thermocouples, flow meters, etc.) values that represent normal system operation. A series of sophisticated tools compares these very high fidelity estimates to the actual sensor readings to detect discrepancies. As engine wear occurs, or specific mechanical faults develop, these estimates show a departure from the actual readings, indicating that the inter-relationships encoded in the state matrices change [3].

Lost Thrust Methodology For Gas Turbine Engine Performance Analysis; A method is presented for assessing the impact of component loss on overall engine performance. The lost thrust method works by iterative cycle re-balance. The technique generally starts from the back and sweeps through to the front of the engine. At each step, a single component loss is deleted from the model and the cycle performance is re-calculated. The difference in thrust of the previous iteration and the current iteration is taken to be the impact of that component loss mechanism on overall engine performance. Since the entire model is re-balanced at each step. The component interactions are automatically accounted for without the need for any special action on the part of the analyst. The lost thrust method is fundamentally a comparison between an actual engine and a hypothetical ideal engine. Iterative cycle re-balance; loop through the ordered list of model losses, removing one loss at each iteration:

a. Remove losses at component i
b. Rebalance engine and calculate thrust or power output
c. Calculate and store difference in thrust (power, SFC, etc.) from previous iteration
d. Move to element i+1
e. Go to a. until all losses are deleted from cycle model
f. Plot analysis results

The method used herein is intended for analysis of component performance assuming an ideal cycle [4].

How To Create A Performance Model Of A Gas Turbine From A Limited Amount Of Information; It is possible to create from a limited amount of data full thermodynamic models. A methodology is presented which minimizes the effort needed for creating such models. It consists of four steps: Firstly a suitable cycle reference point is chosen and the model is tailored to the data of this point. Secondly compressor and turbine maps are added and scaled such that they fit exactly to the cycle reference point. In this step a second operating point is considered and the location of the cycle reference point in the component maps is adapted such that the simulation fits optimally to the given data of the second point. In a third step, the rest of the data are compared graphically with the simulation. All graphics show discrepancies. This makes the adaptation of the model to the data an extended iterative process. If one uses for the model checks a primary thermodynamic parameter - like corrected mass flow, overall pressure ratio or thrust respectively shaft power - as basis then the task is very much simplified. In the fourth and final step the speed values in the estimated compressor maps are adjusted. This has little effect on the matching accuracy of the previous steps, so the model is finished quickly [5].

Data Normalization For Engine Health Monitoring; engine parameter deviations from nominal is modeled. Key parameters modeled include fuel flow, rotor speeds (NH), and measured temperatures. These method can result in significant reductions in bias and variance modeling errors. Reducing the error variance increases the signal-to-noise ratio, thereby increasing the reliability and speed of fault-detection algorithms. The overall objective function is to reduce the measurement variances without masking faults. The measured (Control and health monitoring) signals estimate the condition of the engine, it is crucial that the information content in these signals is exploited to the maximum.

This is done constantly generating an independent estimate of the signal levels using a model. This gives reference values from measured deviations. It can be reduced the variances by more than 65% in certain cases over current methods. These empirical methods consist of techniques, such as neural networks (NN), partial least squares (PLS), and support vector machines (SVM) [6].

Gas Path Analysis Study For Overhaul Engines; The performance part of an acceptance test is what is called a performance curve, which consists in a set of scans at different power levels. The manufacturer procedure is to correct the observed turbine gas temperature (TGT), rotor speeds (NH) and fuel flow (FN) to sea level conditions. At that point the corrected data are compared against the limit obtaining the engine margins. Positive margins indicate that the engine is accepted, while negative margins reject the engine. The margin definition for turbine gas temperature (TGT) is described as TGT marg = TGT lim- TGT corr.

A performance analysis is implicitly associated with test stand data. For given sensors data, an analysis reveal the engine state. Once an analysis is done and a diagnostic is available, it is possible to simulate the impact of the maintenance actions and check if an engine will be accepted or not. Running a performance model is commonly known as synthesis. In those cases where test data is not available, model simulations with estimations about the initial state is the only. In this procedure, it does not matter what happens with the remaining measurements, fuel flow and the rest of temperatures and pressures. Only sensors that define ambient conditions, power conditions (NL), FN, TGT and NH are taken into account. The preferred way to calculate margins by the Gas Path Analysis code is the ANSYN method and later correction to the ambient conditions and power settings where the limits are defined. All available measurements are taken into account. The differences between these methods are not high, except when a sensor deviation is encountered in TGT, FN or NH [7].

Results and Experience From GE Energy’s MS5002E Gas Turbine Testing And Evaluation; This study presents how the test program has been built on the GE Energy NPI (New Product Introduction) Development Process and how results from tests are fed back to the gas turbine design process. The study discusses test rig and facilities layout, gas turbine operation experience and lessons learned [8].

1.2 The Gas Turbine Under Test: 250C-18 Model Engine

The engine consists of a multi stage axial-centrifugal flow compressor, a single combustion chamber, a two-stage gas producer turbine, a two-stage power turbine, an exhaust collector, and an accessory gearbox as shown in Figure 1.1 [9]. In the turbine engine, the cycle is continuous, with the combustion process being continuous. The absorption of energy from the gases of combustion and the development of shaft horsepower are accomplished in the engine by means of four turbine stages which are located between the combustion and exhaust sections.

Air Intake: Air intake section consists of the engine compressor front support, and air inlet duct. One of the turbine engine power factors is the weight of air that flows through the engine per unit of time. Due to this fact, the intake section should offer minimum restriction to the flow of air. The compressor front support has seven radial struts that serve as entrance guide vanes to direct air on the first stage compressor blades.

Compressor Section: The compressor section is that portion of the engine which produces an air pressure rise. The compressor is comprised of six axial stages and one centrifugal stage. The first stage compressor rotor blades accelerate the air rearward into the first stage stator vane assemblies. The energy transfer from compressor shaft to air flow through rotor blades and the subsequent stator vanes allows the increase in static pressure and repeat itself all along stages 2 onward through the compressor rotor blades and vanes until air enters the impeller. The impeller accelerates the air into the scroll which collects the air and delivers it two diffusing compressor discharge air tubes.

The highest total air pressure is at the inlet of the diffuser scroll. As the air passes rearward through the diffuser and compressor discharge air tubes, the velocity of the air decreases and the static pressure increases.

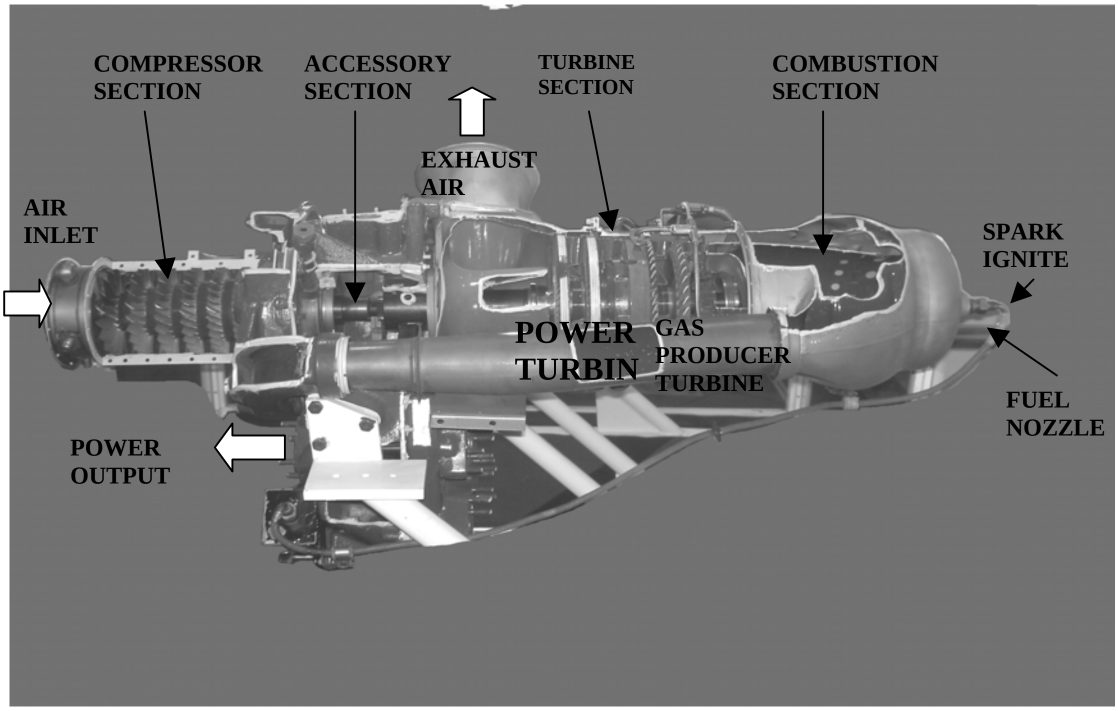


Figure 1.1 250C-18 Model Engine

The highest static pressure is at the inlet of the combustion section. At any specified speed within the designed range of operation, the volume of air pumped by the compressor rotor will be a definite amount. The density of air will affect the weight of specified volume of air. The following factors affect air density;

a. Compressor air inlet temperature; an increased temperature reduces air density,
b. Compressor air inlet pressure; an increased pressure increases air density,
c. Humidity; an increased humidity reduces air density. This is a relatively small factor when compared to temperature and pressure changes.
d. Ram; an increased ram increases air density. Ram is due to aircraft forward speed. Air temperature and air pressure are both increased as ram increases,

but the increase in pressure has a considerable greater effect on increasing air density than the temperature increase has in reducing it.

At 100% gas producer turbine speed, N1 (51120 rpm), the compressor rotor pumps air approximately 51 ft^3/sec. With NACA standard day static sea level conditions "15ºC (59 ºF) outside air temperature, 101.32 kPa (29.92 inHg) barometric pressure, 0% relative humidity, and zero ram" air density is 1.225 kg/m^3 (0.0765 lb/ft^3).
Thus, approximately 1.764 kg/sec (3.84 lb/sec) air flows through the engine on a standard NACA day at sea level conditions and 100% N1 rpm.

If the air density at the compressor inlet is less than 1.225 kg/m^3 (a standard day), the weight of airflow per second through the engine will be less than 1.764 kg/sec (3.84 lb/sec) at 100% N1 rpm. If N1 is less than 100% rpm on a standard day, the weight of air flow per second through the engine will be less than 1.764 kg/sec (3.84 lb/sec) due to decreased volume flow at power rpm [9].

On this engine, the N1 rpm varies with the output power. If the output power is increased, N1 rpm will increase and vice versa. Thus, the weight of air pumped by the compressor rotor is determined by rpm and air density. As the air is pumped through the compressor by the rotor, the air pressure and temperature are increased due to compression. With NACA standard day static sea level conditions and 100% N1 rpm, the temperature rise across the compressor (inlet to outlet) is approximately 266 ºC (510 ºF) and the pressure rise is approximately 6.2: 1.0.
The compressor rotor requires a considerable amount of shaft horsepower to pump air and give this air a pressure and temperature rise. On a standard day, the compressor rotor requires approximately 447 kW (600 SHP) at 100% N1 rpm. The required SHP for the compressor rotor varies directly with air density and N1 rpm. The gas producer turbine must develop the horsepower required by the compressor rotor.

Combustion Section: The air pumped by compressor is required for the combustion of fuel, internal cooling, and mass flow for power development. Approximately, 20% to 25% of air is required to burn the fuel in the combustion process. The remaining air is used for cooling. Most of the cooling air enters the combustion liner, as it is shown in Figure1.1, in such a manner that the flame pattern is prevented from impinging on the wall of the combustion liner. Air enters the single combustion liner at the aft end, through holes in the liner dome and skin. The air is mixed with fuel sprayed from the fuel nozzle and combustion takes place. Thus, combustion gases move forward out of the combustion liner to the 1st stage gas producer turbine nozzle within desired limits.

Turbine Section: The turbine section consists of a gas producer turbine support, a power turbine support, a turbine and exhaust collector support, a gas producer turbine rotor, and a power turbine rotor. The two-stage gas producer turbine drives the compressor and accessories gear train. The gas producer gear train drives the compressor, fuel pump, gas producer tachometer and gas producer fuel control. The starter drive and a spare drive are in this gear train. The amount of fuel flow changes temperature of the gases passing through the turbine section and the amount of energy in the gas stream. Any increase in gas temperature will result in an increase in torque produced by the turbines. As the torque developed by the gas producer turbine increases, the N1 rpm increases. The torque developed by the power turbine is delivered to the helicopter rotor system.

The temperature of the gases passing through the turbine is sensed by means of four thermocouples at the outlet of the gas producer turbine. This temperature is called gas producer turbine outlet temperature (GPTOT) T_{T5}.

Exhaust Section: The expanded gas discharges in an upward direction through the twin ducts of the turbine and exhaust collector support. These ducts are 40° on either side of a vertical line. The engine produces a little jet thrust from the gas energy remaining in the exhaust gases.

1.3 250C-18 Model Engine Operation in A Helicopter

The engine control system for helicopter installations must control the power output of the engine such that the rotor rpm N_R remains within established limits. The clutch allows the engine to drive the rotor when normal operation, but it prevents the rotor from driving the engine if rotor speed percentage exceeds engine speed percentage. This is generally called freewheeling unit. When the engine delivers power to the rotor system, the percentage of rotor rpm (N_R) and the percentage of power turbine rpm (N2) will be the same. (100% N2=35000 rpm and 100% N_R =395 rpm) N_R and N2 rpm's are indicated on the same instrument. When N_R and N2 percentage are the same, the tachometer indicator N_R and N2 needles are locked. Split needles describe a condition where the percentage of N_R is greater than the percentage of N2.

Starting; when starting an engine, it is always desirable have a minimum starter load. Helicopters powered by reciprocating engines incorporate a clutch system, which enables the starter to crank the engine and not crank the rotor. Helicopters powered by gas turbine do not incorporate a clutch system, because the free turbine design permits the starter to crank the gas producer system without any rotor load.

Collective Pitch Stick is a kind of control lever which has an up and down adjustable twisted handle (Figure1.2).

Figure 1.2 Collective Pitch Stick

Increase Collective Pitch; assuming that the engine has been started and it is running at stabilized ground idle and that take-off power is required. The operator must move the twisted handle from the ground idle to full open. This results in an increase in N1 rpm, an increase in N2 rpm to 100% and a relatively low shaft horsepower with the collective pitch stick in minimum. As the collective pitch stick is pulled up, the rotor pitch changes such that the rotor power requirements increase. Thus, the rotor rpm will tend to descent as N2 falls. The power turbine governor senses this falling and initiates the necessary action. The gas producer fuel control to increase fuel flow. As the fuel flow increases, N1 rpm increases. Thus the power turbine develops more power which is delivered to the rotor system in order to prevent excessive N2 rpm falling. This is the characteristic of the power turbine governor.

On helicopters, it is highly desirable to vary rotor system power requirements without having a change in N_RN2 speed. N_RN2 speed variation must be prevented when a power change is made. So helicopter manufacturer provides a compensator which acts on the power turbine governor. N_RN2 speed is held constant by means of the compensator while the rotor system power is varied. When the operator increases collective, the power delivered to the rotor system will increase. Stabilized N_RN2 speed will remain the same.

1.4 Necessary Parts Of 250C-18 Engine For Aircraft Operation [10]

The below parts are required for the aircraft with 250C-18 model engine;

a. Gas producer fuel control lever linkage controlled by twist grip,
b. Power turbine governor lever linkage controlled by compensator system,
c. Tachometer indicator for indication of power turbine N2 rpm,
d. Tachometer indicator for indication of power turbine N1 rpm,
e. Gas temperature indicator for the indication of gas producer turbine outlet temperature,
f. Torque indicator for the indication of power delivered to the helicopter,
g. Oil pressure indicator for the indication of engine oil pressure,
h. Ignition switch for the control of the ignition system,
i. Starter control system for control of starter.
j. Oil temperature indicator for the indication of engine oil temperature,
k. Chip detector lights in the cockpit.

CHAPTER 2

2. GAS TURBINE TEST STAND DESIGN

Gas turbine monitoring system is composed of engine test frame, fuel system, oil system, control panel, start system and electrical system. The gas turbine monitoring system is shown in Figure 2.1.

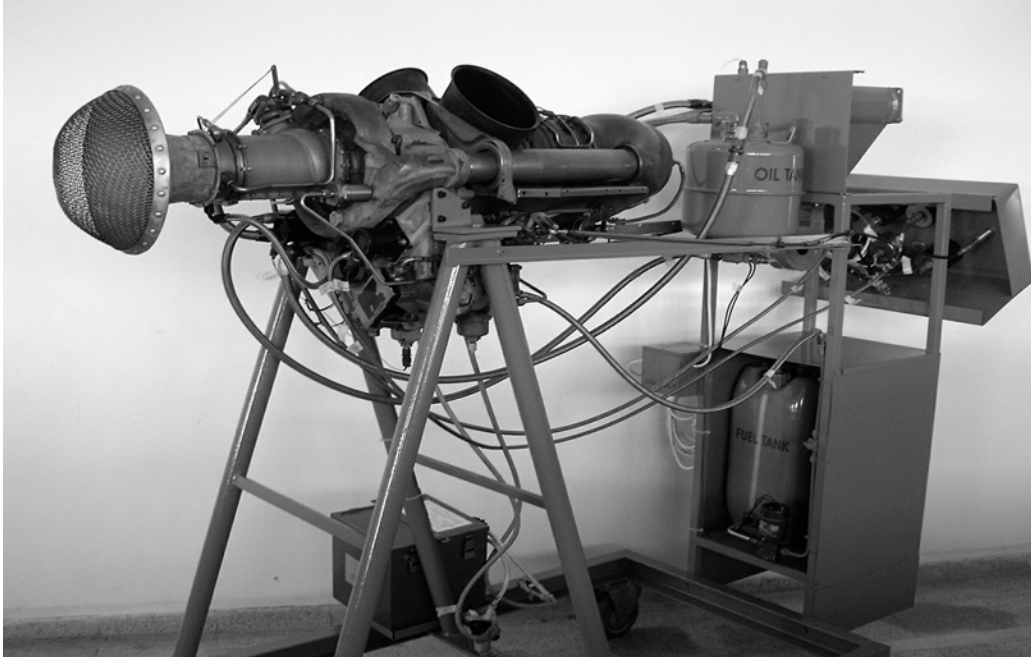


Figure 2.1 Gas turbine monitoring system

2.1 Engine Test Frame

The engine test frame is the main part of the gas turbine test stand. The frame is designed Rolls Royce model 250C-18 and its accessories in horizontal position. It is fixed with two side engine mounts on the test frame. Each mount is secured with three bolts. Structural analysis of the engine test frame are given below (Figure 2.5 and Figure 2.6).

The engine test frame consists of base frame made of steel (I) profile and support elements made of steel tubes.

2.1.1 Structural Analysis Of The Engine Test Frame

ABAQUS is a simulation software that calculates structural, dynamic, thermal, modal and vibration problems of the models. The geometry of the model is created either by importing or drawing in the Abaqus. After that, determined material properties, boundary conditions and loads applied to the model. Then, the solution, stresses, strains, displacements, total energy, strain energy, reaction forces are calculated and simulated.

Using ABAQUS/CAE module creates solid model of the structure (Figure 2.2). Material property is defined as steel.

Density: 7.8 gr/cm3
Elasticity Module: E: 207000
Poisson Ratio: 0.3

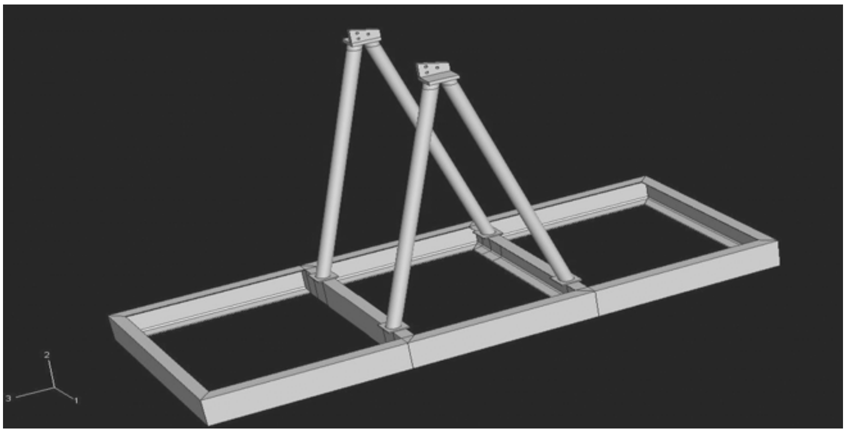


Figure 2.2 Solid Model and Material

Loads and boundary conditions are as follows; engine weight applied as load to attachment bolts, and corners of the structure are fixed in all degree of freedom (Figure 2.3).

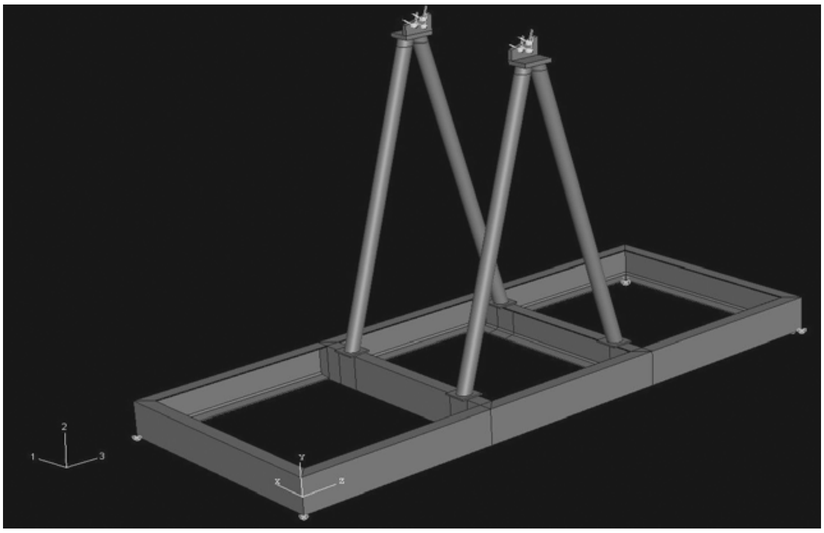


Figure 2.3 Loads and Boundary Conditions

After, finite element model of the structure is created (Figure 2.4). Number of Nodes: 59985, Number of elements: 41515 (Hexahedral elements: 35054, Wedge elements: 68, Tetrahedral elements: 6393)

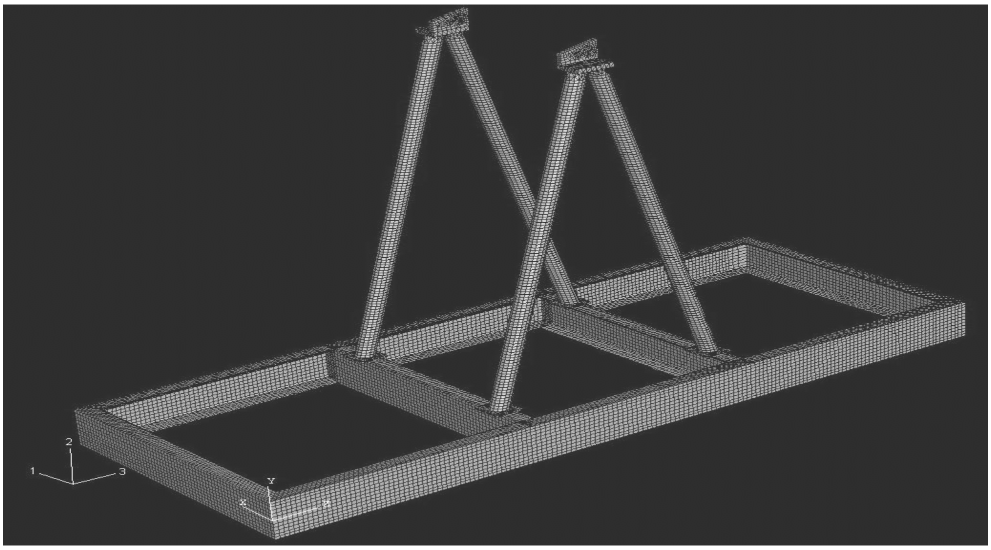


Figure 2.4 Finite Element Model

According to structural analysis results in Figure 2.5 and Figure 2.6 (Von Mises Stress) the structure does not have any risk. Maximum stress is about the middle of the structure and has a value of 65 MPa. And the maximum strain is 1.79 mm around the boltholes.

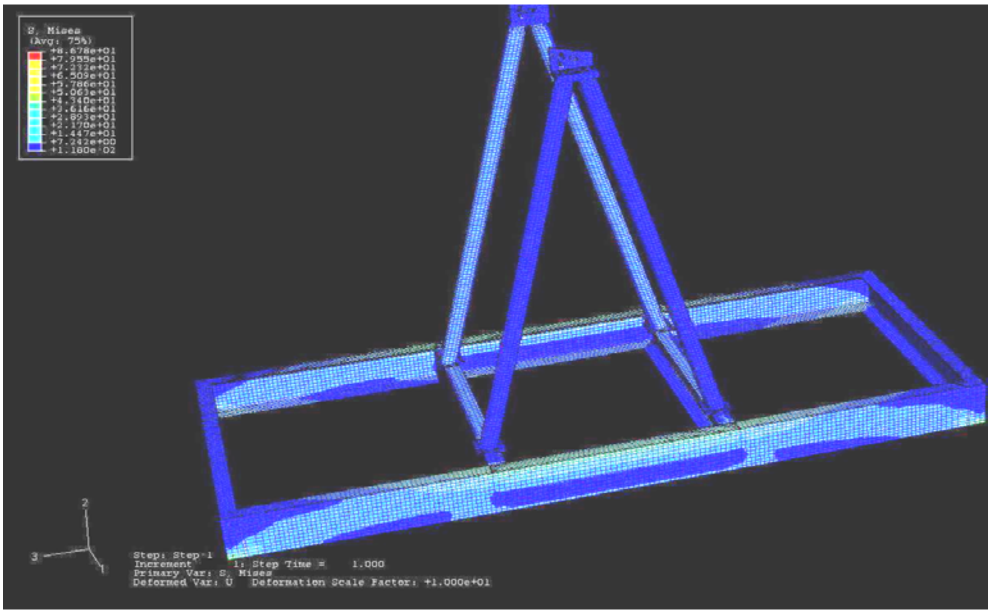


Figure 2.5 Stress

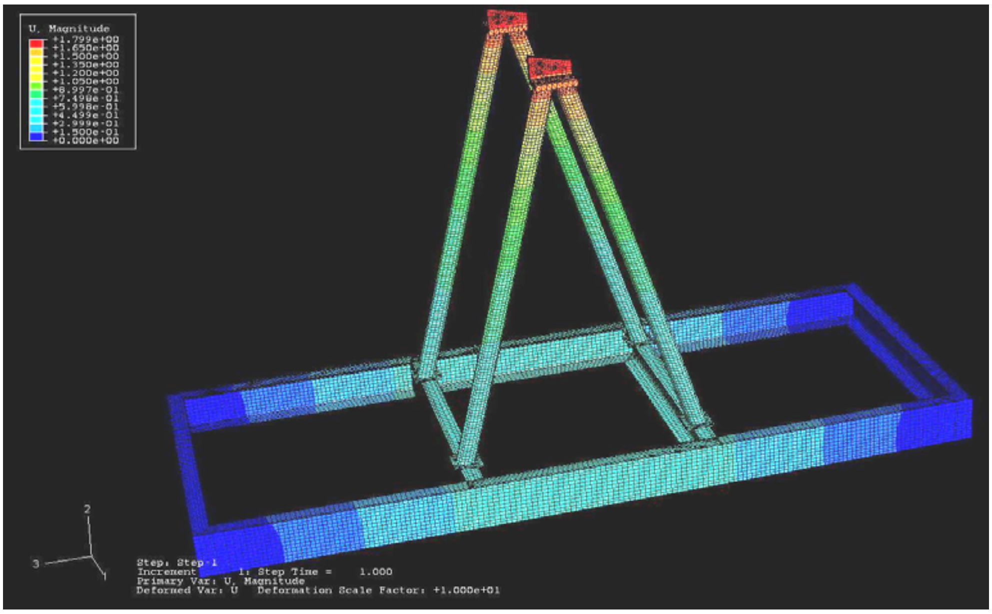


Figure 2.6 Strain

2.2 Fuel System

The fuel system (Figure 2.7) includes the following;

(1) Fuel Pump and Filter Assembly: Bottom rear sides of the accessory gearbox assemble,
(2) Gas Producer Fuel Control: Right rear side of accessory gearbox assembly,
(3) Power Turbine Governor: Left rear side of accessory gearbox assembly,
(4) Fuel Nozzle: Center rear side of combustion outer casing,
(5) Fuel Tank: Front side of the engine test frame,
(6) Low Pressure Fuel Pump: Outside of the fuel tank.

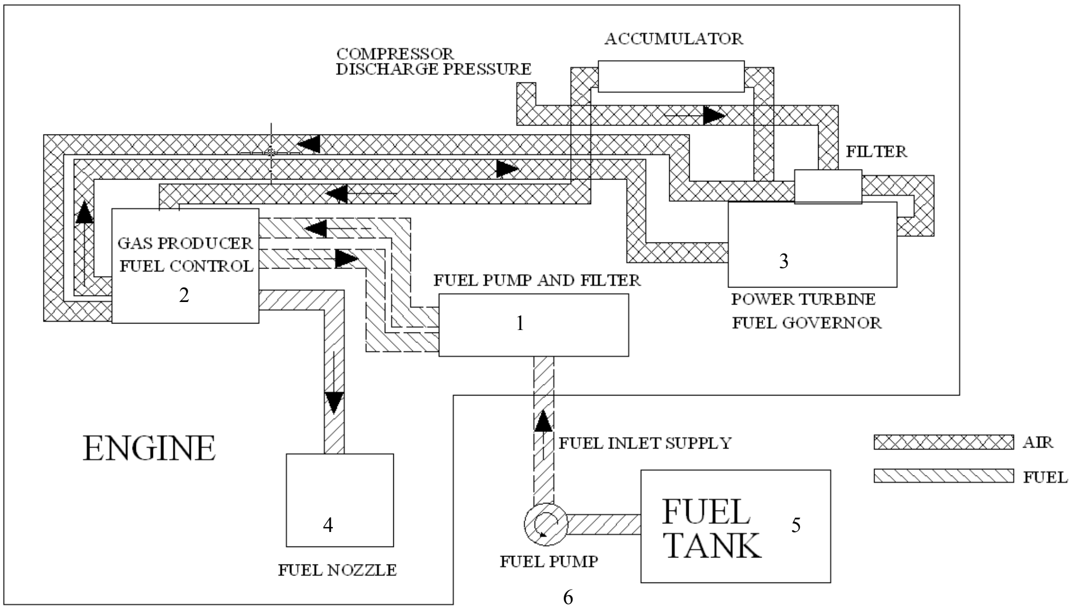


Figure 2.7 Fuel System

Fuel Specifications: Primary fuel; MIL-DTL-5624T, grades JP-4, JP-5, and JP-8. Jet-A, Jet-B or A1, JP-1 fuel conforms to ASTM D-1655, Arctic Diesel Fuel DF-A (VV-F-800B) conforming to ASTM D-1655 [11]. Emergency; all grades can be used maximum 6 hours. Fuel flow is adjusted with N1 speed during ground idle operations when the gas producer fuel control pointer is at 30°. Fuel flow is adjusted with N2 speed when the gas producer fuel control pointer is at 90° as shown in Figure 2.8.

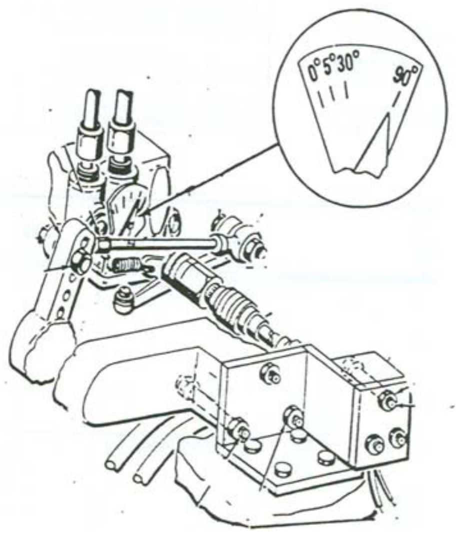


Figure 2.8 Gas Producer Fuel Control

The fuel system has the following capability;

Fuel inlet pressure is maintained between 34.5 and 276 kPag (5 and 40 psi). Fuel inlet pressure of the gas turbine monitoring system is designed for 159 kPa (23 psi). Maximum fuel flow limit of the system is measured approximately 111 to 113 kg/hr (245-250 lb/hr).

At Ground Idle position, gas producer turbine outlet temperature is measured 399 ± 55°C (750±100°F), fuel flow is observed as maximum 27.67 kg/hr (61 lb/hr).

At Maximum Continuous Position, gas producer turbine outlet temperature is measured between 620 and 693°C (1148-1280°F) and fuel flow is measured as 50-66 kg/hr (111-146 lb/hr).

At Takeoff Position, gas producer turbine outlet temperature is taken 749°C (1380°F) and fuel flow is measured as 82 kg/hr (181 lb/hr).

Other fuel flow data are measured for the observed gas producer turbine outlet temperature;

462°C – 26.17 kg/hr; 523°C – 27.96 kg/hr; 547°C – 34.47 kg/hr;

605°C – 47.62 kg/hr; 620°C – 50.38 kg/hr; 688°C – 66.22 kg/hr.

2.3 Engine Control

Engine controls are the gas producer lever (adjust gas producer speed N1) and the power turbine governor lever (adjust power turbine speed N2). The push-pull rod operates the gas producer control and the power turbine governor control with knob on the control panel (Figure 2.9).

The system regulates engine power output by controlling the gas producer (N1) speed. Gas producer speed levels are established by the action of the power turbine fuel governor that senses power turbine (N2) speed. The operator selects the power turbine (load) speed, and power turbine governor automatically maintains the power required to maintain this speed.

Power turbine speed is adjusted by the knob- rod on the power turbine governor. The power turbine governor plans the gas producer speed for a changed power output to maintain output shaft speed. Gas producer control lever controls the position of the gas producer fuel control that has three positions: closed, idle (flight idle) and full open.

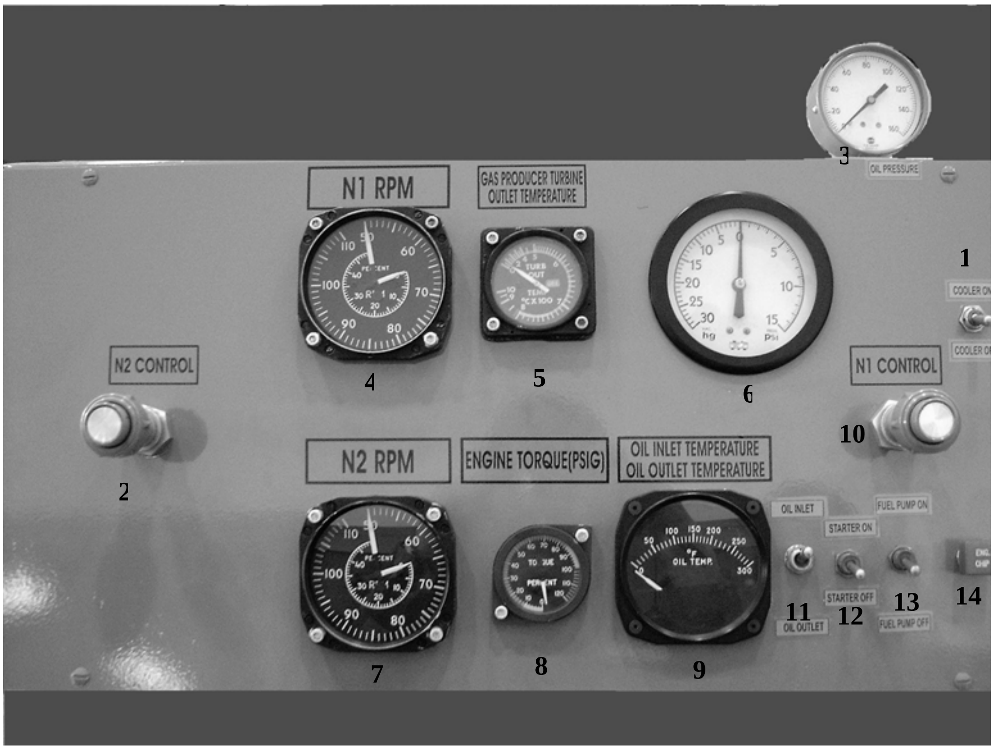


Figure 2.9 Control Panel

1- oil fan on-off switch 2- power turbine control knob 3- main oil pressure gage 4-gas producer turbine speed indicator 5- gas producer turbine output temperature indicator 6- compressor inlet pressure and exhaust static pressure gage 7-power turbine speed indicator 8- torquemeter oil pressure 9- engine oil inlet and outlet temperature indicator 10- gas producer turbine control knob 11- engine oil inlet and outlet temperature indicator switch 12- starter on/off switch 13- fuel pump on/off switch 14-chip detector light.

2.4 Oil System

The oil system of the gas turbine monitoring system consists of an externally mounted oil supply tank, hoses, oil inlet& outlet temperature indicator, oil pressure gage, and oil cooler (Figure 2.10). Oil is supplied by tank to gear type pressure and scavenge pump mounted within the engine accessory gearbox. Return oil is routed from engine oil outlet port to the cooler. Torque indicating system measures oil pressure inside the torquemeter oil chamber which is directly proportional to the torque. Torquemeter gear shaft and piston are arranged in the accessory gearbox.. if an increase axial thrust acting on the piston is counter-balanced by the torquemeter pressure in oil chamber. Indicating type magnetic chip detector is installed at the bottom of the accessory gearbox.

Oil specification; the engine lubricating oil is MIL-L-23699. [11]

Oil pressure limits are based on an oil inlet temperature of 82 to 107°C and an oil inlet pressure 0 to 12.4 kPa during normal operation. A positive main oil pressure indication must be observed when the ground idle position (59 % N1 speed) is reached during start.

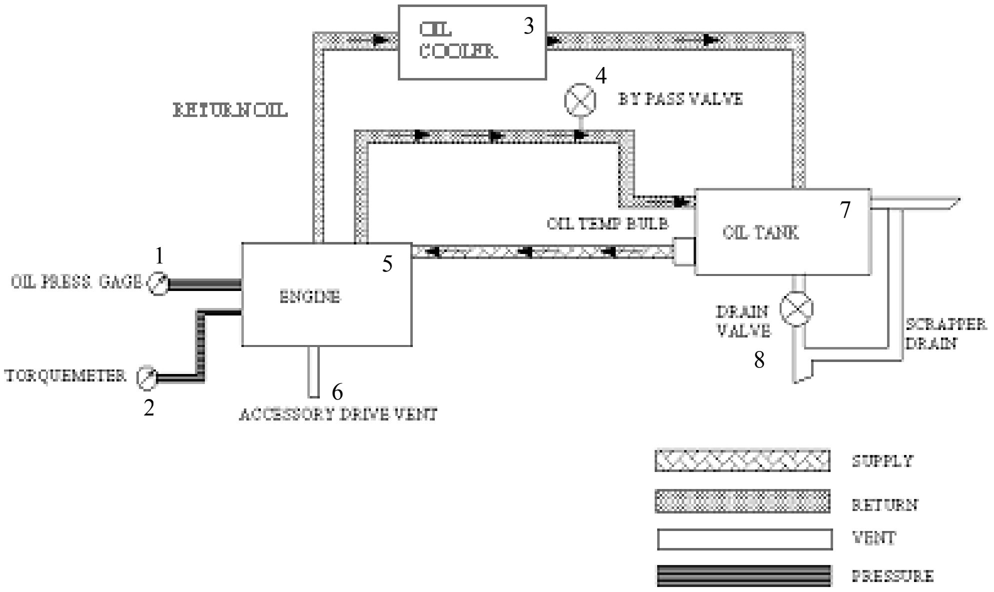


Figure 2.10 Oil System

1- oil pressure gage 2- torquemeter 3- oil cooler 4- by-pass valve 5- engine 6- accessory drive unit 7- oil tank 8- drain valve

The engine main oil pressure is 758-896 kPa (110-130 psig) when the 97 % N1speed and above are reached. The engine main oil pressure is 621-896 kPa (90-130 psig) when the 78 % to 97 % N1 speed is reached. The engine main oil pressure is 345 kPa min. (50 psig) for below the 78 % N1 speed.

Oil consumption is maximum 0.17 kg/hr. Minimum starting oil temperature is -40°C (-40°F), and maximum oil temperature of the gas turbine monitoring system is 107°C (225°F). The observed oil temperatures are under 107°C by means of the oil cooling system on the gas turbine monitoring system.

The engine main oil pressure is taken from the pump mounted within the engine accessory gearbox. The observed engine main oil pressure is between 345 and 896 kPa (50-130 psig).

2.5 Start System

The starter serves two independent functions: the first is to spin the gas turbine until it reaches its self-sustained speed, and the second is to drive the gas turbine compressor to purge to the gas turbine and the exhaust duct of any volatile gases prior to initiating the ignition cycle. The starting sequence consists of the following:

- Engage starter
- Purge inlet and exhaust ducts
- Energize igniters
- Switch fuel on.

The primary function of the starting system is to accelerate the gas turbine from rest to a speed point just beyond the self–sustaining speed of gas turbine. To accomplish this the starter must develop enough torque to overcome the drag torque of the gas turbine’s compressor and turbine, any attached loads including accessory loads and bearing resistance. Rotating the compressor starts the gas turbine. This is accomplished by the starter indirectly connected to the compressor shaft via the accessory gearbox.

To start a gas turbine engine, electric (alternating current, and direct current) motors, pneumatic motors, hydraulic motors, diesel motors, and small gas turbines used. In this work, direct current motor was used.

The source of power for the DC motor is a battery bank of sufficient capacity to carry the cranking and starting loads of the gas turbines. Battery is located in right section of the test frame. The gas turbine monitoring system battery supplies 24 DC Volt, 15 Amp.

2.6 Ignition System

The engine ignition system consists of a low-tension capacitor discharge ignition exciter, a spark igniter lead, and a shunted surface gap spark igniter. The system derives its input power from 14 to 29 volt, DC external power source. All components are engine mounted, connected, and function as integral part of the engine.

The purpose of the ignition system is to transfer energy to the fuel-air mixture in the combustion liner in the form of a high temperature, high amperage arc at the spark igniter gap, and thus ignite the fuel-air mixture. Operation of the ignition system is only required during engine starting, because once engine is started, continuous combustion provides continuous ignition. Ignition system is essentially a high-energy power supply that is connected to a circuit designed to transfer maximum energy to the engine’s combustible fuel mixture during an engine start. A starter is used as a DC motor to crank the engine during the starting cycle. The starter is capable of 500 Amps and 28volt.

2.7 Electrical System

The gas producer and the power turbine speed indicators are installed on the system control panel (Figure 2.11). The tachometer generators are used for the gas producer and the power turbine speed measurement. The tachometer generator is a two-pole permanent magnet rotor which is driven from the engine.

The counter type rotating magnet rotor converts mechanical motion to ac voltage without an external power source. This self-contained magnetic rotor produce a magnetic field that, when in motion, generates a voltage. When the rotor is mounted the gear on a rotating shaft, the voltage output frequency is directly proportional to the rotational speed of the gear.

A frequency-to-voltage converter converts the signal to a voltage. An engineering unit conversion from voltage to velocity provides an actual velocity measurement. The generator controls the tachometer indicator which governs position of the pointer [12].

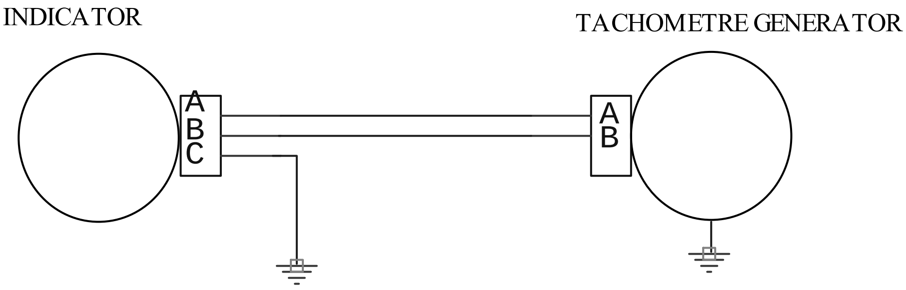


Figure 2.11 Tachometer Generator and Indicator Wiring Diagram

The gas producer turbine outlet temperature is measured with four alumel-chromel thermocouples in the power turbine support (Figure 2.12). Each thermocouple probe generates DC voltage that is directly proportional to gas temperature it senses. The thermocouples and thermocouple harness provide an average of the four voltages representative of the gas producer turbine outlet temperature. This temperature is read on an indicator with a range of 316-982ºC (600-1800ºF) [12].

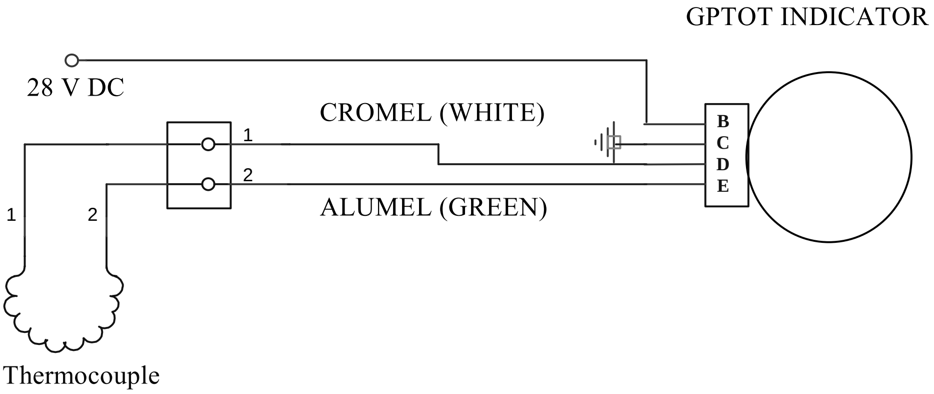


Figure 2.12 Gas Producer Turbine Outlet Temperature (GPTOT) Wiring Diagram

The starter and fuel pump are activated by means of ON/OFF switches mounted on the gas turbine monitoring system control panel.

The chip warning light is on when the detector encounters any chip in the engine accessory gearbox.

Starter, Fuel Pump, and Chip Detector Diagram are shown in Figure 2.13.

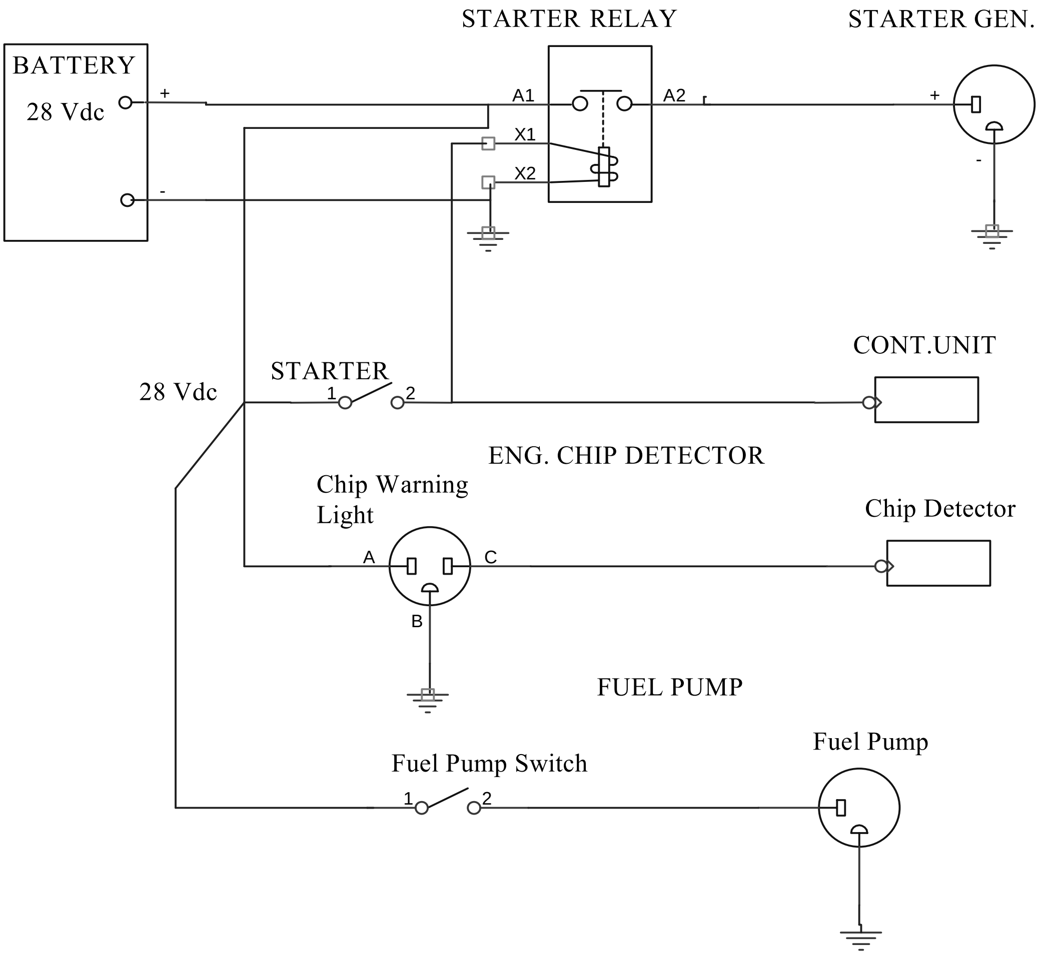


Figure 2.13 Starter, Fuel Pump, and Chip Detector Diagram

CHAPTER 3

3. ENGINE PERFORMANCE CALCULATION

3.1 The Instruments Installed On The Engine

There are positions of the instruments installed to the engine in Figure 3.1.a and Figure 3.1.b. Limit values of the instruments required for measurement and their locations are shown in Table 3.1. Indicated numbers in Figure 3.1.a and Figure 3.1.b are related with Table 3.1.

Table 3.1 Instruments Characteristics [14]

No	Parameter	Units	Min. Limit	Max. Limit
1	Exhaust Static Pressure	mmHg (inHg)	660 (26)	762 (30)
2	GP Fuel Control Connection	-	-	-
3	GP Turbine Outlet Temperature	Deg C (Deg F)	316 (600)	982 (1800)
4	Gearbox Vent Connection	-	-	-
5	Inlet Bell ΔP	kPa (inH2O)	0 (0)	14.95 (60)
6	Inlet	mmHg (inHg)	660 (26)	762 (30)
		Deg C (Deg F)	-60 (-75)	302 (575)
7	Starter Pad	-	-	-
8	Drain Plug Connection	-	-	-
9	After Filter Pressure	kPa (psi)	0 (0)	207 (30)

Table 3.1 (Continued)

No	Parameter	Units	Min. Limit	Max. Limit
10	Before Filter Pressure	kPa (psi)	0 (0)	207 (30)
11	Fuel Pump Drain Connection	-	-	-
12	Fuel Inlet Temperature & Pressure	Deg C (Deg F)	-60 (-75)	302 (575)
		kPa (psi)	0 (0)	207 (30)
13	Firewall Shield Connection	-	-	-
14	Burner Valve Connection	-	-	-
15	Comp. Discharge Pressure & Temperature	kPa (inHg)	0 (0)	1016 (300)
		Deg C (Deg F)	-60 (-75)	302 (575)
16	Anti-Icing Valve Connection	-	-	-
17	Turbine Vibration	m/sec (in/sec)	0 (0)	0.07 (3)
18	PT Governor Connection	-	-	-
19	Exhaust Collector Connection	-	-	-
20	Power Turbine Speed	% PERC	0	110
21	Gearbox Pressure	kPa (inH2O)	0	8.96 (36)
22	Drain Plug Connection	-	-	-
23	Gas Producer Turbine Speed	% PERC.	0	110
24	Scavenge Oil Pressure	kPa (psig)	0	413.7 (60)
25	Engine Oil Inlet Pressure	kPa (psig)	0	34.5 (5)
26	Main Oil Pressure	kPa (psig)	0	1103 (160)
27	Torquemeter Oil Pressure	kPa (psig)	0	758 (110)
28	Anti-Ice Air Temperature.	Deg C (Deg F)	-60 (-75)	302 (575)
29	Compressor Vibration	m/sec (in/sec)	0	0.07 (3)
30	Compressor Seal Pressure	kPa (psig)	0	34.5 (5)
31	Gearbox Vibration	m/sec (in/sec)	0	0.076 (3)

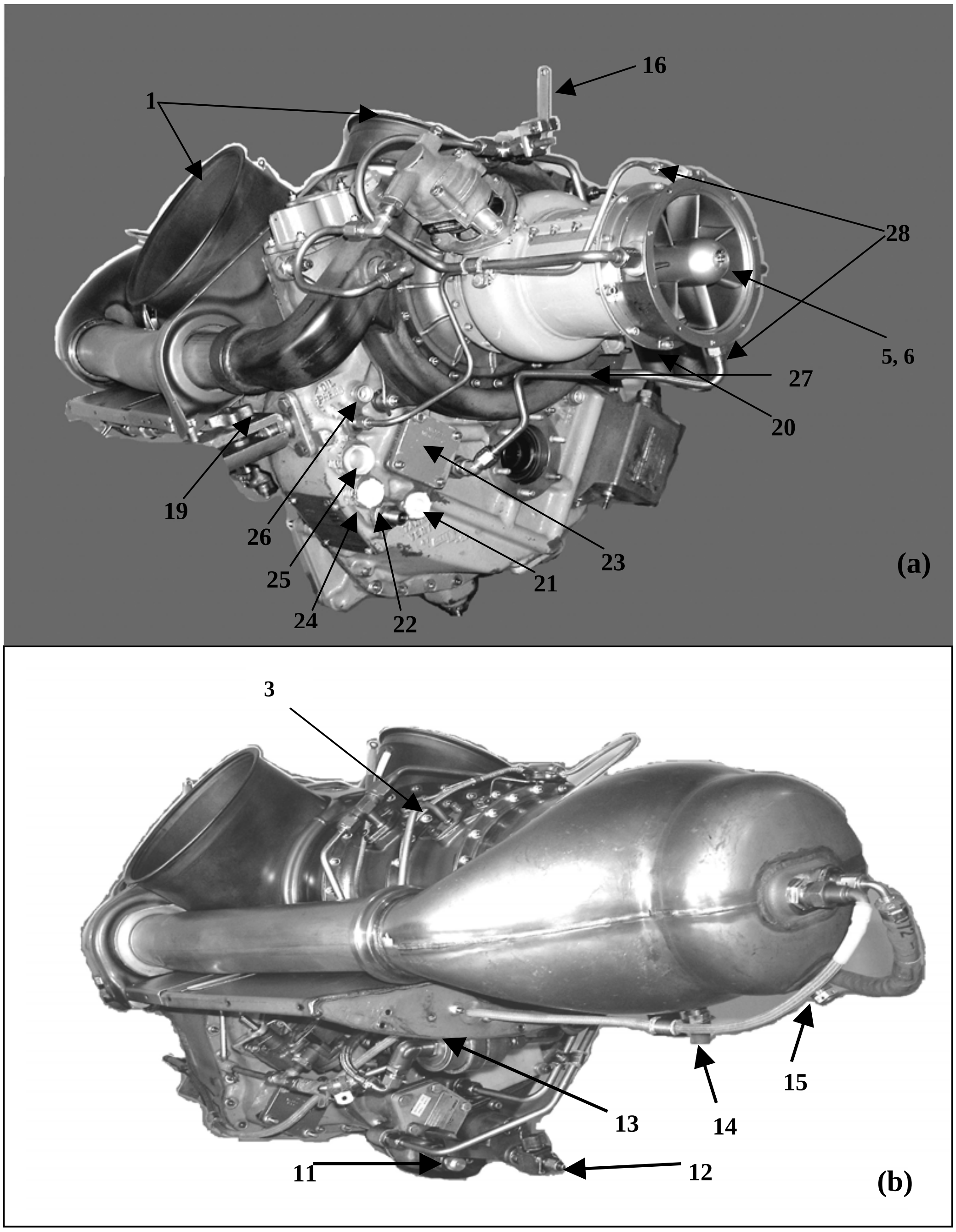


Figure 3.1.a, b The Places Of The Instruments On The Engine

3.2 Test Requirements And Engine Limits [14]

The following test requirements and engine limits that are to be observed during all phases of engine testing.

Maximum Average Velocity- Vibration (29, 31 in Table 3.1)

Compressor transient	30.5 mm/sec, 1.2 in./sec
Compressors steady state	15.2 mm/sec, 0.6 in./sec
Turbine transient	45.1 mm/sec, 1.8 in./sec
Gearbox steady- state	12.7 mm/sec, 0.5 in./sec
Gearbox transient	25.4 mm/sec, 1.0 in./sec,

Gas Producer Turbine Outlet Temperature (GPTOT) (3 in Table 3.1) ;

Max. Takeoff (30 min.)	749ºC (1380 ºF)
Max. Continuous and below	693ºC (1280 ºF)
Max. Starting	843ºC (1550 ºF)
Max. Transient	843ºC (1550 ºF)

Speed

Gas Producer Rotor (N1) (20 in Table 3.1); 100% N1 speed is 51120 rpm. 104% N1 speed is 53165 rpm at maximum continuous position. 105% N1 speed is 53676 rpm (15 sec. max.) at maximum transient position.

Power Turbine Rotor (N2) (23 in Table 3.1) ; 100% N2 speed is 35000 rpm. 103% N2 speed is 36050 rpm at maximum continuous position. 108% N2 speed is 37800 rpm at flight autorotation position. 105% N2 speed is 36750 rpm at takeoff position.

Torque

Torque is 338 N.m (249 lb.ft) at maximum continuous position. Torque is 397 N.m (293 lb.ft) at maximum30 minute duration; Torque is 434 N.m (320 lb.ft) at maximum 10 second duration.

Power Oscillation

Maximum power oscillation; ±1.5% (At takeoff power)

Speed Oscillation

Steady state operation on the power turbine governor oscillation is ± 500 rpm.

Power Settings

All power settings are made with the gas producer control lever in the maximum position (except ground idle and flight autorotation). The dynamometer load control and the power turbine governor lever are manipulated to obtain the desired setting.

Power Transients

Power transients are considered accomplished when the power is maintained within ± 2% of the final value. The required power level change with gas producer lever movements shall not exceed the following time values : Ground Idle-to-Takeoff 7 sec. (0.117 min.), Flight Autorotation-to-Takeoff 3 sec.(0.05 min.), Takeoff-to-Ground Idle 6 sec.(0.10min.)

Gearbox Case Pressure (21 in Table 3.1)

Maximum gearbox case pressure is 3 kPa (12.0 in.H_2O) above ambient.

Compressor Seal Vent Pressure (30 in Table 3.1)

Compressor seal vent pressure is between 6.1- 25 kPa (1.8 to 7.4 inHg) at takeoff power.

Preliminary Checks and Adjustments Prior to Testing

The following checks and adjustments prior to testing are performed the engine.

a. The gas producer lever travel is checked for the following positions: 0 to 5 º cutoff position, 30º idle, and 90º (full travel).
b. The power turbine governor control lever is checked for full 90º travels,
c. The gage is standardized.
d. Just before starting the engine, the engine fuel pump is primed, the air is allowed to escape from the fuel system.

3.3 Test Run [14]

For any newly overhauled engine a test is performed in accordance with the following schedule:

Setting No. 1: Start engine and accelerate to ground idle. Record Unit 1Data for the start.

Unit 1 (Start Data)

a. Total running time and cumulative number of starts,
b. Date, operating schedule, engine model and unit serial number,
c. Time, in minutes, from starter on until engine reaches 30000 rpm.
d. Max. Indicating the gas producer turbine outlet temperature during start, (ºF)
e. Actual stabilized speeds (rpm) for both rotors (N1 and N2),
f. Barometer reading, specific gravity and type of fuel used and outside air temperature (engine inlet total temperature) (ºF).

Record Unit 2 Data at Ground Idle after stabilizing. Recorded data must be within acceptable limits. Observe the engine for abnormal conditions such as vibration, noise or leakage. Ground Idle - 2 minutes; 36000 N1 rpm - 30 seconds; 42000 N1 rpm - 30 seconds; 45000 N1 rpm - 30 seconds.

Unit 2 (Main Line)

a. Time of day, hours and minutes,
b. Power setting,
c. Gas producer rotor speed (N1) rpm,
d. Power turbine rotor speed (N2) rpm,
e. Dynamometer forcemeter torque ft.lb,
f. Engine torquemeter oil pressure psig,
g. Gas producer turbine outlet temperature (GPTOT) ºF,
h. Main oil pressure psig,
i. Fuel flow lb/hr,
j. Oil inlet temperature ºF,
k. Compressor discharge pressure inHg abs.

Setting No. 2: Advance the gas producer control lever to the maximum position while adjusting the turbine governor lever to maintain N2 at 32000 rpm. The maximum gas producer N1 rpm must be 50000 rpm or more; if it is not, adjust the gas producer fuel control max. stop screw until this limit is met. Record the amount of the adjustment and the final N1 max. rpm. Stabilize and record Unit 2 Data.

Setting No. 3: Shut down. Record Unit 3 Data. Inspect for visible damage or leaks. Record oil level.

Unit 3 (Shutdown Data)

a. Time of day, hours and minutes,
b. Reason for shutdown,
c. Record any adjustment, changes, etc.

Setting No. 4 : Start engine and accelerate to Ground Idle. Record Unit 1 Data for start, stabilize for thirty seconds. Record Unit 2 Data at Ground Idle after stabilizing. Recorded data must be within engine limits.

Setting No. 5 : Advance Gas Producer lever to max while adjusting Power Turbine Governor maintain at 35000 rpm. Increase power setting to 250 kW (335 hp), 749 ºC (1380 ºF) or 53165 rpm N1 speed, whichever occurs first. Monitor vibration to be sure it does not exceed limits. Stabilize for one minute at the above obtained setting. Record Unit 2 Data.

Setting No. 6 (Anti-ice air check) : Decrease the power setting to an indicated 186.4 kW (250 hp) (218.2 ft lb on the dynamometer forcemeter), N2 = 35000 rpm. Stabilize, and then record Unit 6 Data.

Unit 6 (General Test Data)

a. Date ; day, month, year,
b. Operator's name,
c. Barometer reading,
d. Wet bulb temperature,
e. Dry bulb temperature,
f. Fuel type,
g. Fuel lower heating value BTU/lb,
h. Laboratory fuel specific gravity,
i. Oil type,
j. Test type,
k. All incidents of the run such as leaks, vibration, any irregular functioning of engine, or equipment and corrective measures taken, or reasons for shutdowns.

Turn on anti-ice air, do not change load unless GPTOT exceeds 749 ºC (1380°F) or N1 exceeds 53165 rpm. If GPTOT or N1 exceeds the limits, reduce the load to maintain the offending parameter at its maximum limit. Record Unit 6 Data. Turn off anti-ice air. If it was necessary to decrease the load with anti-ice air on, return to the original 186.4 kW (250 hp) power setting before proceeding. With the introduction of anti-ice air to the compressor front support there will be a rise in GPTOT, and a decrease in speed and torque. If thermocouples are used on the anti-ice lines, an increase in line temperature will be noted when anti-ice is turned on. After stabilizing record Unit 4 Data.

Unit 4 (Full Data)

a. Time of day,
b. Power setting,
d. Gas producer rotor speed (N1) rpm,
e. Power turbine rotor speed (N2) rpm,
f. Dynamometer forcemeter torque ft.lb,
g. Observed fuel flow lb/hr,
h. Fuel inlet pressure psig,
i. Fuel pressure before the filter psig,
j. Fuel pressure after the filter psig,
k. Fuel inlet temperature ºF,
l. Engine inlet total pressure inHg abs,
m. Engine inlet total temperature ºF,
n. Static exhaust pressure inHg abs,
o. Test cell reference pressure inHg abs,
p. Test cell reference temperature ºF,
q. Engine oil inlet temperature ºF,
r. Engine oil inlet pressure psig, (nearest 1/4 psig)
s. Main oil pressure psig,
t. Scavenge oil pressure psig,
u. Scavenge oil temperature ºF,

v. Oil level lb,
w. Oil flow lb/min,
x. Inlet bell ΔP, inH_2O
y. Indicated average gas producer turbine outlet temperature (GPTOT) ºF,
z. Compressor, turbine, and gearbox vibration in./ sec,
aa. Compressor discharge pressure inHg abs,
bb. Compressor discharge temperature ºF,
cc. Anti-ice lines average temperature ºF,
dd. Compressor seal vent pressure inHg,
ee. Gearbox case pressure inH2O,
ff. Compressor bleed air exhaust temperature ºF.

Setting No. 7 : Decrease the load (at a rate that will not be permit N2 to over speed) to the minimum load value 0-11.2 kW (0-15 hp) without changing the power turbine governor lever or gas producer control lever setting. Record Unit 4 Data. The N2 speed must be between 34417 and 37800 rpm. The GPTOT (T_{T5}) must be within the flight autorotation limits of Figure 3.2.

Setting No. 8 (Takeoff power) : Return to indicated 749 ºC (1380 ºF) GPTOT (Take-off power), N2 35 000 rpm. Stabilize approximately one minute and record

Unit 5 Data.

Unit 5 (Power Transient Data)

a. Time of day, hours and minutes (from the initiation of load change until 95% of the N1 speed change),
b. Max. gas producer turbine outlet temperature (ºF) value,
c. Max. torque value obtained from the dynamometer forcemeter ft.lb,
d. Max. gas producer rotor speed (N1) value,
e. Max. power turbine rotor speed (N2) value for deceleration, minimum power turbine rotor speed (N2) value for acceleration.

Setting No. 9 (Deceleration) : Decelerate from Takeoff to Ground Idle by retarding the gas producer lever to the idle band and when N2 starts to slow down decrease the load control to zero. Do not move the power turbine governor lever for this transient. Record Unit 5 Data. The time for deceleration shall not exceed six seconds. The time of the gas producer fuel control lever movement must be less than one second. Load control is to be decreased to zero in approximately two seconds. Start the timer at the same time as the gas producer lever is moved and stop timer when N1 reaches 35000 rpm.

Setting No. 10 : Move the gas producer lever forward to a setting of Flight Autorotation conditions; N1 32000 rpm, N2 34417 to 37800 rpm, T_{T5} in accordance with Figure 3.2, power 0-11.2 kW (0-15 hp), WF = 27.7 kg/hr (61 lb/hr) max.

Setting No. 11 (Acceleration) : From the Flight Autorotation setting accelerate to Takeoff power (749 ºC (1380 ºF) GPTOT) by increasing the load. When N2 starts to slow down, move the gas producer lever to the maximum position. Record Unit 5 Data for the transient. The time for the acceleration shall not exceed four seconds. The gas producer control lever and the load control must be moved in not more than one second. Start the timer at the same time the load control is moved and stop the timer when N1 has accomplished 95 % of its speed change.

Setting No. 12 : Decrease power setting and stabilize (approximately two minutes) at indicated 195 hp or 1148°F GPTOT whichever occurs first, Record Unit 4 Data. Record oil level was read at the end of the period in order to obtain an oil consumption check at the end of setting 15. If the bleed valve is not fully closed at the prescribed temperature, select a GPTOT for this setting that will ensure that the bleed valve is closed.

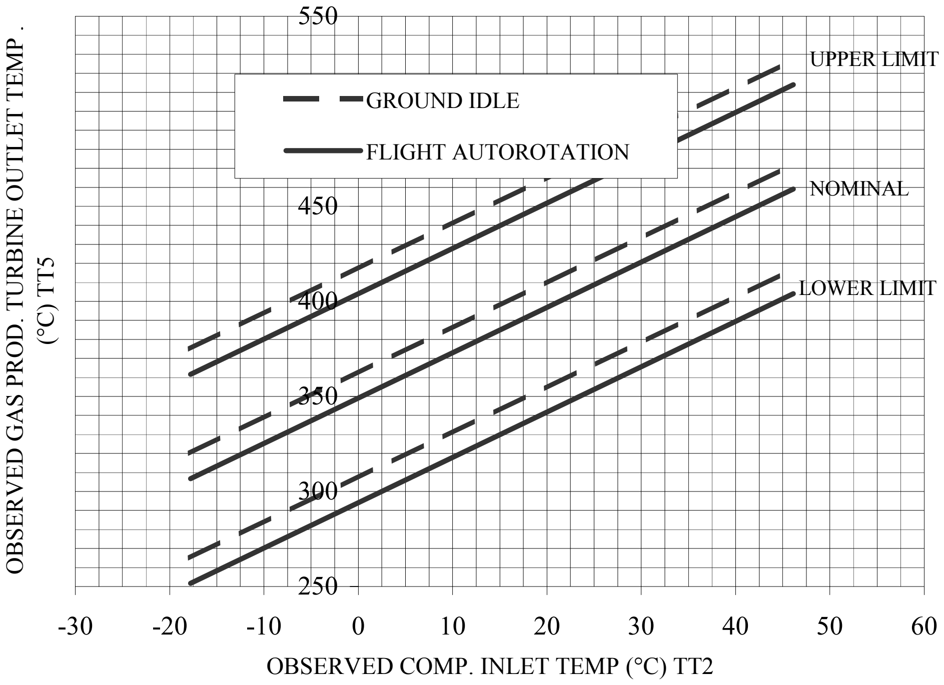


Figure 3.2 Observed GPTOT Limits For Observed Comp. Inlet Temperatures [9]

Setting No. 13 : Stabilize (approx two minutes) at indicated 275 hp or 1280°F GPTOT (Max continuous), whichever occurs first, N2 = 35000 rpm. Record Unit 4 Data. Recorded data must be within engine limits.

Setting No. 14 : Stabilize (approx. two minutes) at indicated 336 hp or 1380°F GPTOT (Takeoff Power), whichever occurs first, N2 = 35000 rpm. Record Unit 4 Data. Recorded data must be within engine limits.

Setting No. 15 : Decelerate to indicated 1148°F GPTOT (approx.) and set N1 at the same speed as was obtained in Setting 12. Stabilize as necessary; record oil level and time of day that oil level was read and compute the oil consumption utilizing the value obtained for oil level in Setting 12.

There is to be no shutdown during oil consumption check and the power calibration (Setting 12 through 15). If a shutdown is made for any reason it will be necessary to start again at Setting 12 and continue the test from there. Each power setting of the power calibration (Setting 12 through 15) must be approach from the previous.

Setting No. 16 : Decelerate and stabilize at Ground Idle. Record Unit 4 Data.

Setting No. 17 : Shut down and inspect unit for leaks, visible damage, or smoke emitting from the exhaust collector. Repair leaks or visible damage as dictated by the cause. Inspect drain bottles, measure and record the amount and location of drainage. Check chip detector plugs for continuity. Inspect the fuel pump filter for contamination.

Drainage from the fuel pump and filter assembly shall not exceed 0.5 cc per minute (1 cc = 20 drops). The combined fuel drainage from all drain ports shall not exceed 1 cc per minute (average).

Leak Run Check

Start engine, stabilize; then slowly accelerate to indicated takeoff power. Stabilize for five minutes. Oil pressure and temperature must be within test requirements during the full five-minute check period.

Reduce power to Ground and stabilize for two minutes. Shut down and inspect the engine for effectiveness of the repair.

Functional Check Run

This procedure provides a test schedule for functionally testing engines for purposes other than post overhaul and/or performance test runs. This procedure applies only to normal operable engines. Applicable parts of the Preliminary Checks and Adjustments Prior to Testing paragraph shall be done before starting the Functional

Check Run.

Setting No.1: Start engine and accelerate to Ground Idle. Record Unit 1 Data. Record Unit 2 Data at Ground Idle after stabilizing. Recorded must be acceptable limits. Observe the engine for abnormal conditions such as vibrations, noise or leakage.
Setting No. 2: Same as Setting No. 2 in the overhauled engine test run.
Setting No. 3: Same as Setting No. 7 in the overhauled engine test run.
Setting No. 4: Same as Setting No. 9 in the overhauled engine test run.
Setting No. 5: Same as Setting No. 11 in the overhauled engine test run.
Setting No. 6: Same as Setting No. 2 of this Functional Check
Setting No.7: Repeat settings 3 through 6 of this Functional Check Run.
Setting No.8: Same as Setting No. 17 in the overhauled engine test run.

Engine test sheet in Table 3.2 is prepared for each power settings data (Unit 1, Unit 2, Unit 3, Unit 4, Unit 5).

Engine Shutdown

All shutdowns are accomplished from Ground Idle after stabilizing for two minutes, except emergencies.

Idle time prior to shutdown is important to prevent harmful accumulation of carbon in the engine, which can result in complete engine stoppage.

Table 3.2 Engine Test Sheet [14]

TIME:			OIL TYPE:				
TRUE BAROMETER:			FUEL TYPE:				
OUTSIDE TEMP:			SETTING 1	SETTING 2	SETTING3	SETTING4	SETTING5
DATA REQUIRED							
GENERAL	TIME OF DAY						
	POWER SETTING	%					
	N1 SPEED (N1)	RPM					
	N2 SPEED (N2)	RPM					
HP	DYN.FORCEMETER(TORQ1)	N.m (FT.LB)					
	DYN.FORCEMETER(TORQ2)	kW(HP)					
	TORQUEMETER (TORQ3)	kPa (PSIG)					
FUEL	FLOW (Wf)	Kg/h (PPH)					
	PRES.BEFORE FILT.(PFPI)	kPa (PSIG)					
	PRES.AFTER FILT. (PFPO)	kPa (PSIG)					
	FUEL IN TEMP. (TWFI)	˚C (ºF)					
	FUEL INLET PRES.(PWFI)	kPa (PSIG)					
COMPRESSOR	INLET PRES. (P0)	kPa (IN.HG)					
	EXH. STATIC PRES. (PS7)	kPa (IN.HG)					
	CELL REF. PRES. (PT2)	kPa (IN.HG)					
	INLET TEMP. (T0)	˚C (ºF)					
	CELL REF. TEMP.(T0)	˚C (ºF)					
	OUT COMB.CASE TEMP.	˚C (ºF)					
	OUT COMB.CASE PRES.	kPa (IN.H_2O)					
TURB	GPTOT (TOT)	˚C (ºF)					
OIL	MAIN OIL PRES. (PTQ)	kPa (PSIG)					
	RETURN OIL PRES.(PSPO)	kPa (PSIG)					
	OIL INLET PRES. (POPI)	kPa (PSIG)					
	OIL IN TEMP. (TOPI)	˚C (ºF)					
	OIL OUT TEMP. (TSPO)	˚C (ºF)					
	GEARBOX PRES.(PGBO)	kPa (IN.H_2O)					
VIBR.	COMP. VIBRATION	m/s (IN/SEC)					
	TURBINE VIBRATION	m/s (IN/SEC)					
	GEARBOX VIBRATION	m/s (IN/SEC)					

3.4. Performance Evaluation

3.4.1 General

During the overhaul acceptance test, the shaft horsepower and the specific fuel consumption are recorded and corrected to standard day conditions at the three power settings of 1380 ºF (takeoff), 1280 ºF (maximum continuous), and 1148 ºF (normal cruise) gas producer turbine outlet temperature (GPTOT).

Additional data points may be used for performance analysis and/or correlation [15]. The design (cruise) point performance characteristics of the components are shown in Table 3.3.a, b.

3.4.2 Data reduction method [14]

Performance data shall be corrected to standard day, sea level, static (unity ram) conditions by the following method:

Ram Pressure Ratio(RPR): Figure 3.3
PT2 (COMPRESSOR INLET PRESSURE)
PS7(EXHAUST GAS STATIC PRESSURE)
The Ram Pressure Ratio (RPR) is the difference in pressure between the bellmounth inlet total and the exhaust gas static pressure. Both are measured as absolute values. The bell inlet total pressure determines the loss across the (Foreign Object Damage) FOD screen (if one is used) as well as test cell depression, if the inlet air is restrictive. This total pressure is less than the barometer and normally in the range of 24.9 to 373.62 Pa (0.1 - 1.5 inH2O)

Table 3.3.a, b Performance Ratings [14] (Standard Static Sea Level Condition)

RATING	POWER (MIN)		N1 SPEED	N2 SPEED	OUTPUT SHAFT
	HP	kW	% RPM	% RPM	% RPM
TAKEOFF	317	236	100.9 (51600)	100 (35000)	100 (6000)
MAX.CONT (M.C)	270	201	97.3 (49760)	100 (35000)	100 (6000)
NORMAL CRUISE	203	151	91.8 (46950)	100 (35000)	100 (6000)
GROUND IDLE	35	26	62.6 (32000)	75-105 26250-36750	75-105 (4500-6300)
FLIGHT AUTO ROTATION	0	0	62.6 (32000)	983-106 34417-37100	98,3-106 (5900-6360)

RATING	SPECIFIC FUEL CONSUMPTION (MAX.)		TORQUE AT OUTPUT SHAFT MAX.		MEASURED RATED GAS TEMP.
	lb/SHP.hr	mg/W.hr	ft.lb	N.m	°F (°C)
TAKEOFF	0.697	423.97	293	397	1380 (749)
MAX.CONT (M.C)	0.706	429.44	249	338	1280 (693)
NORMAL CRUISE	0.762	463.5	249	338	1148 (620)
GROUND IDLE	61 lb/hr	27.67 kg/hr	-	-	750±100 (399±55)
FLIGHT AUTO ROTATION	61 lb/hr	27.67 kg/hr	-	-	725±100 (385±55)

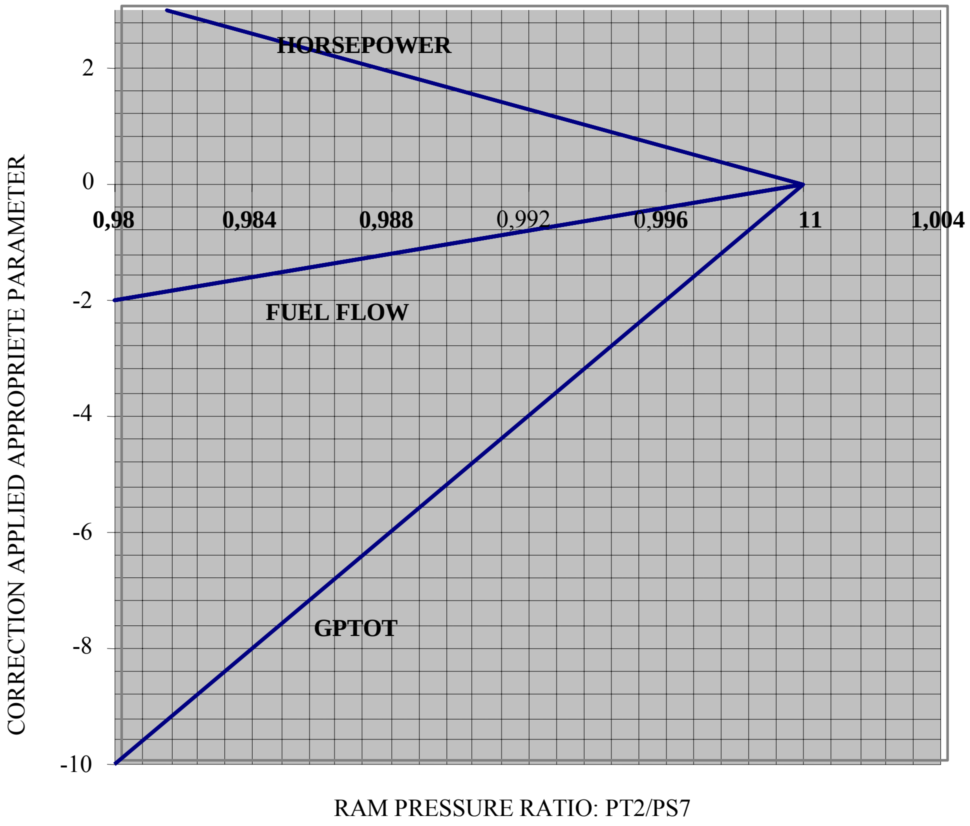


Figure 3.3 Correction For Ram Pressure Ratio Effects

Ram Pressure Ratio = P_{T2} (Compressor Inlet Pressure) ÷ P_{S7} (Exhaust Gas Static Pressure)

The engine exhaust static pressure is usually very closed to barometric or slightly higher depending on the exhaust system configuration backpressure.

In the case of outside test facility, the engine operates in the same inlet and exhaust pressure, therefore the RPR=1.0 and no correction factor is necessary. When a different pressure exists across the engine in a closed test cell environment, a correction factor is necessary to compensate and correct the engine performance.

Fuel Flow :

Figure 3.4 provides a correction for change in specific gravity versus fuel temperatures as measured at the flowmeter. Fuel flow is to be read from the flowmeter and corrected for specific gravity.

a. Using the measured compressor inlet temperature and pressure enter the Performance Data Correction Factors chart [14] and obtain the fuel flow correction factor (WF).
b. Multiply the corrected flowmeter value obtained for fuel flow by the correction factor (WF). This product is the fuel flow corrected for the effects of compressor inlet temperature, pressure, fuel specific gravity and speed.
c. Multiply the value obtained in sub-paragraph b by the ratio of the lower heating value of the specification fuel (18400 BTU/lb.) as found on the Table 3.4 fuel lower heating value (LHV) correction chart. This product is the fuel flow corrected for specific gravity, engine inlet pressure and temperature and lower heating value.
d. The correction for the effect of ram pressure ratio is obtained from Figure 3.3, add this value to the value obtained in subparagraph c. above. This sum is the fuel flow corrected to sea level, static, (unity ram) standard day conditions and 18400 BTU LHV. Record the corrected fuel flow on the log sheet.

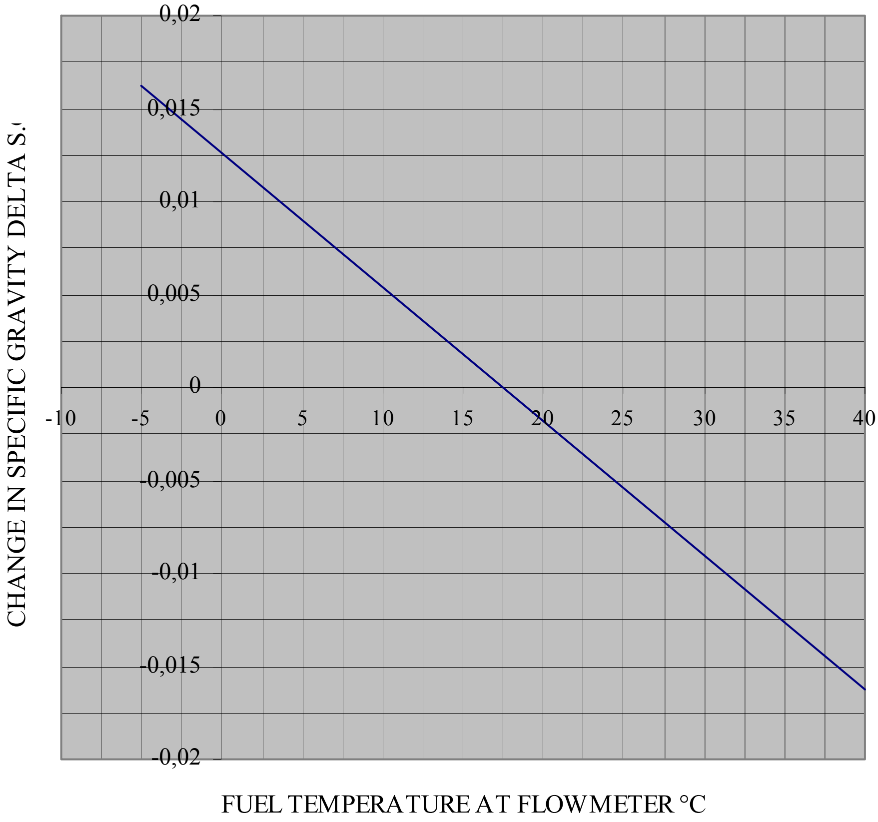


Figure 3.4 Fuel Specific Gravity Change With Fuel Temp**.**

Fuel flow is measured as 106 kg/hr (233 lb/hr) at takeoff power, and fuel temperature on flowmeter is 25 ˚C (77 ˚F). Air inlet pressure PT2 = 93 kPa (27.5 in.Hg), air inlet temperature TT2 = 24˚C (75 ˚F). From Figure 3.4, ΔSG = -0.005, WF Correction factor (WFCF) is obtained as 1.0691. Lower Heating Value for Grade JP-8 is 18600 and C = 18400, from Table 3.4 LHV/C= 1.01087, PS7 = 93 kPa (27.5 in.Hg), RPRWF (Ram pressure ratio effect on fuel flow) is 1 from Figure 3.3.

$$CWF = \frac{WF * SG}{(SG + \Delta SG)} \frac{WFCF * LHV}{C_{24}} + RPRWF$$ From equation (3.12),

Table 3.4 Fuel Lower Heating Value (LHV) Correction

LHV of Test Fuel kCal/kg (BTU/lb)	LHV of Test Fuel/10212 (18400) kCal/kg (BTU/lb)	LHV of Test Fuel kCal/kg (BTU/lb)	LHV of Test Fuel/10212(18400) kCal/kg (BTU/lb)
10422.9 (18780)	1.02065	10278.6 (18520)	1.00652
10411.8 (18760)	1.01957	10267.5 (18500)	1.00543
10400.7 (18740)	1.01848	10256.4 (18480)	1.00435
10389.6 (18720)	1.01739	10245.3 (18460)	1.00326
10378.5 (18700)	1.01630	10234.2 (18440)	1.00217
10367.4 (18680)	1.01522	10223.1 (18420)	1.00109
10356.3 (18660)	1.01413	10212 (18400)	1.00000
10345.2 (18640)	1.01304	10200.9 18380	0.99891
10334.1 (18620)	1.01196	10189.8 (18360)	0.99783
10323 (18600)	1.01087	10178.7 (18340)	0.99674
10311.9 (18580)	1.00978	10167.6 (18320)	0.99565
10300.8 (18560)	1.00870	10156.5 (18300)	0.99457
10289.7 (18540)	1.00761		

Corrected fuel flow = {106* 0.77/[0.77+ (-0.005)]* 1.0691*1.01087}+ 1

Corrected fuel flow = 115.305 kg/hr (254 lb/hr)

Corrected fuel flow obtained for sea level, standard day conditions and heating value is 18400 BTU.

T_{T5} Gas Producer Turbine Outlet Temperature (GPTOT):

a. Gas producer turbine outlet temperature is read in ˚F on the gage. Convert to ˚R by adding 460, then correct as indicated below;

b. Using the measured compressor inlet temperature, enter the Performance Data Correction Factors chart and obtain the value for T_{T5} [14].

c. Multiply the value for the gas producer turbine outlet temperature converted to ˚R ,or by the value for T_{T5} to obtain a gas producer turbine outlet temperature (˚R) corrected for engine inlet temperature.

d. Obtain the value for the correction due to the effect of ram pressure ratio from Figure 3.3 and record this value on the log sheet. Algebraically add this value to the gas producer outlet temperature (˚R) corrected for engine inlet temperature.

e. Subtract 460 from the value of the gas producer turbine outlet temperature obtained in subparagraph c. above to obtain the gas producer turbine outlet temperature corrected to sea level, static (unity ram), standard day conditions. Record the corrected temperature on the log sheet.

Gas producer turbine outlet temperature is measured as T_{T5} = 1482 ˚F (805.5 ˚C) at takeoff power. T_{T5} Correction factor (T_{T5}CF) is obtained as 0.9701. PS7 = 93 kPa (27.5 inHg), RPRT$_{T5}$ (Ram pressure ratio effect on gas producer turbine outlet temperature) is 1 from Figure 3.3.

From equation 3.11

$$CT_{T5} = \left(T_{T5} + 460\right) * T_{T5}CF + RPRT_{T5} - 460$$

Corrected GPTOT = (1482 + 460)*0.9701 + 1 - 460
Corrected GPTOT = 1425 ˚F (774 ˚C)
Corrected gas producer turbine outlet temperature obtained for sea level, static (unity ram), standard day conditions.

Corrected Gas Producer Speed (N1):

a. The gas producer speed (N1) is read from the tachometer to the nearest 100 rpm fault and corrected for tachometer calibration error at each of the five data points,
b. Using the measured compressor inlet temperature at each of the five data points and obtain a value for $1/\theta^{1/2}$ [14].
c. Multiply the value of the gas producer speed obtained in step a by the value of $1/\theta^{1/2}$ to arrive at a value of corrected (N1) speed. ($N1/\theta^{1/2}$)

Gas producer turbine speed N1 is measured as 51600 rpm at takeoff power. Air inlet temperature TT2 = 24˚C (75 ˚F).$1/\theta^{1/2}$ value is 0.98492.

Corrected (N1) = 51600*0.98492
Corrected (N1) = 50822 rpm

Plotting Horsepower, Fuel Flow And Speed:

Plot the recorded value obtained for corrected horsepower and the recorded value obtained for corrected fuel flow versus the recorded value obtained for corrected gas producer turbine outlet temperature on Sea Level Calibration plot.(Figure 3.5)

a. Draw the best straight line that can be drawn through the fuel flow points and extend this line to include the range of gas producer turbine outlet temperature from 1148 to 1380ºF.

b. Draw the best straight line that can be drawn through the horsepower points, in the range where the compressor bleed is closed, taking cognizance of the corresponding points that were passed through or missed with the fuel flow line. Extend this line to include the range of gas producer turbine temperature from 1148 to 1380ºF.

c. Plot the corrected gas producer speed (N1) versus the corrected SHP. (See Figure 3.5) This is the same corrected SHP that was plotted against corrected GPTOT in the performance plot.

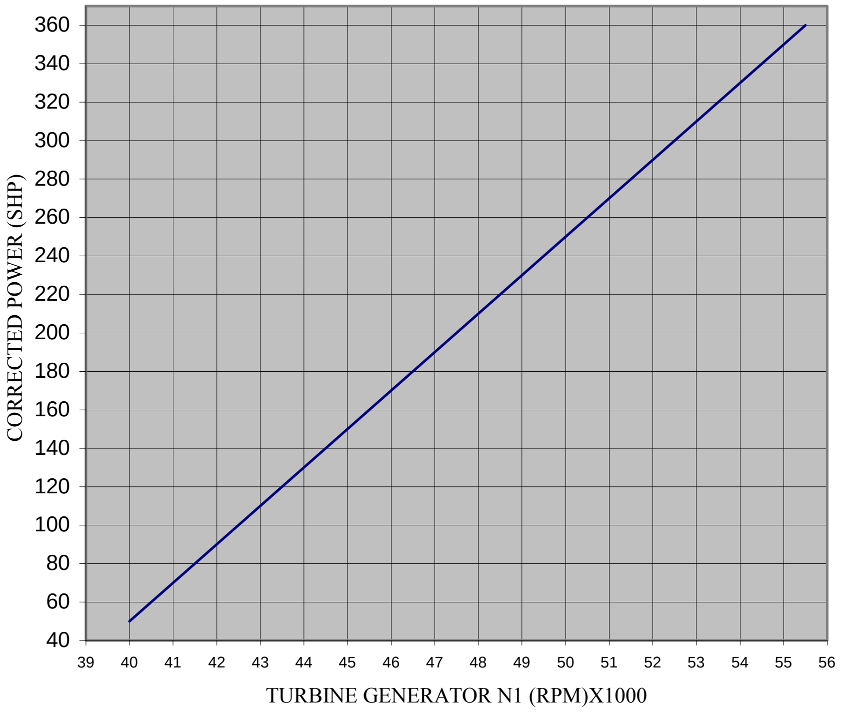


Figure 3.5 Corrected N1 Versus Corrected SHP

d. Enter the corrected SHP versus corrected gas producer speed (N1) plot at 317 SHP and determine the gas producer speed (N1). This speed must be no greater than 53165 rpm.

Corrected Horsepower :

a. Torque (ft.lb) is read on the dynamometer forcemeter.
b. Multiply the horsepower by the correction factor from Ref. 14 to obtain a horsepower (SHP) that is corrected for effects of inlet pressure, temperature and speed.
c. Obtain the correction for ram pressure ratio effects. (See Figure 3.3)
d. The corrected sea level, static (unity ram), standard day horsepower is the algebraic sum of subparagraphs b. and c.
e. If desired, the values of horsepower may be plotted at the appropriate gas producer turbine outlet temperatures on the corrected horsepower section of the Sea Level Calibration plot (similar to Figure 3.6.a).

Record the corrected horsepower on the log sheet.

Corrected Specific Fuel Consumption :

a. From the Sea Level Calibration plot.(Figure 3.6), obtain values from the horsepower line and the fuel flow line at gas producer turbine outlet temperatures 1148, 1280, and 1380ºF [16].
b. Divide the fuel flow value at these points by the horsepower for each of the gas producer turbine outlet temperatures to obtain a corrected specific fuel consumption (SFC) value. Record the corrected SFC values in the spaces provided on the log sheet.
c. If desired, the values of specific fuel consumption may be plotted at the appropriate gas producer turbine outlet temperatures on the specific fuel consumption section of the Sea Level Calibration plot (similar to Figure 3.6.b).

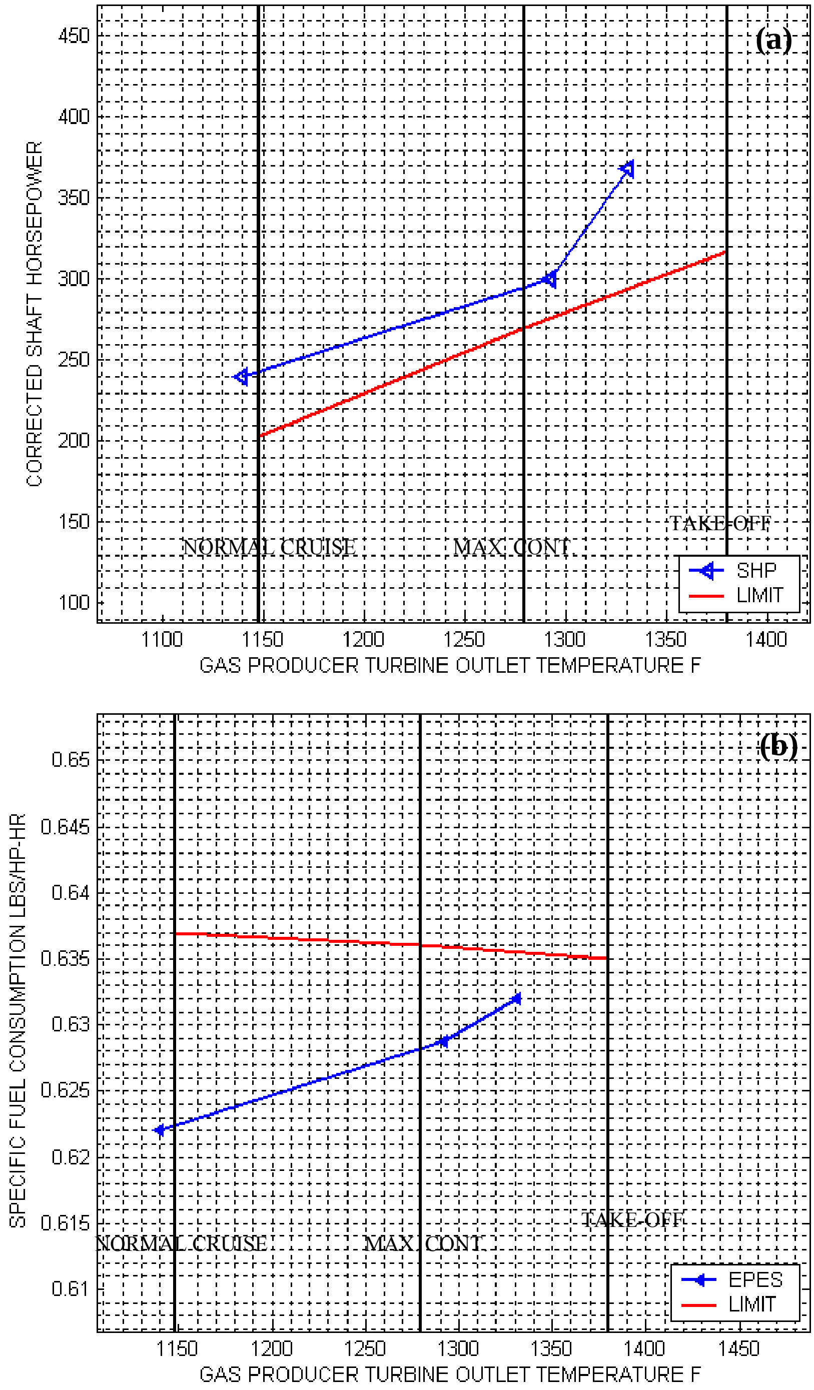


Figure 3.6.a,b Sea Level Calibration Plot

Determination Of An Acceptable Engine :

If the plotted horsepower line on the Sea Level Calibration plot is above the specification horsepower line, the engine is considered to be better than specification requirements on power. If the plotted specific fuel consumption points on the Sea Level Calibration plot are below the specification specific fuel line, the engine is considered to be better than specification requirements for specific fuel consumption. The corrected N1 speed at 317 corrected horsepower shall not exceed 53165 rpm.

Determination Of Percent Variance From Specification Values :

Corrected horsepower and corrected specific fuel consumption values at gas producer turbine outlet temperatures of 1148°F (Cruise B), 1280°F (Max Cont), and 1380°F (Takeoff) are recorded. The variance is calculated from specification values in Table 3.5 for each gas producer turbine outlet temperature.

Table 3.5 Specific Values for use in the calculation

SETTING	TOT (°F)	HP	SFC
Cruise B	1148	203	0.762
Max Cont	1280	270	0.706
Takeoff	1380	317	0.697

Torquemeter Calibration:

On the Torquemeter Calibration curve (Figure 3.7), plot torquemeter oil pressure in psig versus indicated horsepower in hp (value of forcemeter x applicable conversion factor) for each data point that required the reading of the engine torquemeter and the dynamometer forcemeter. Draw the best straight line that can be drawn through these points and the 0-0 point of the chart. This shall constitute torquemeter calibration. All calibration points must fall within the limits shown on Figure 3.7. The spec Torquemeter calibration limits are as follows (Table 3.6):

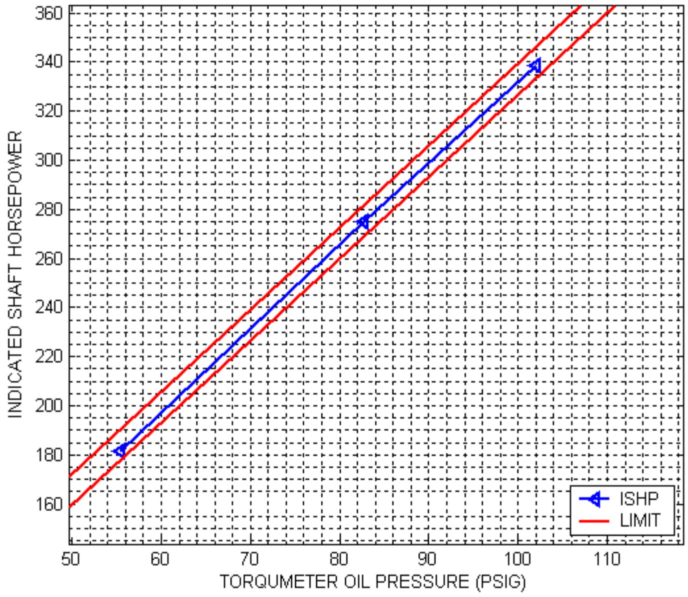


Figure 3.7 Torquemeter Calibration Curve

Corrected Airflow :

Engine airflow can be determined using compressor air inlet bell and the corrected engine inlet airflow curve. (Corrected airflow lb/sec versus inlet bell pressure ΔP inches H_2O) (See Figure 3.8.a,b)

Table 3.6 Torquemeter Calibration Limits

SETTING	HP	TORQUEMETER PRESSURE (psig)
Cruise B	203	61.0 ± 1.6
Max Cont	270	81.0 ± 1.6
Takeoff	317	95.0 ± 1.6

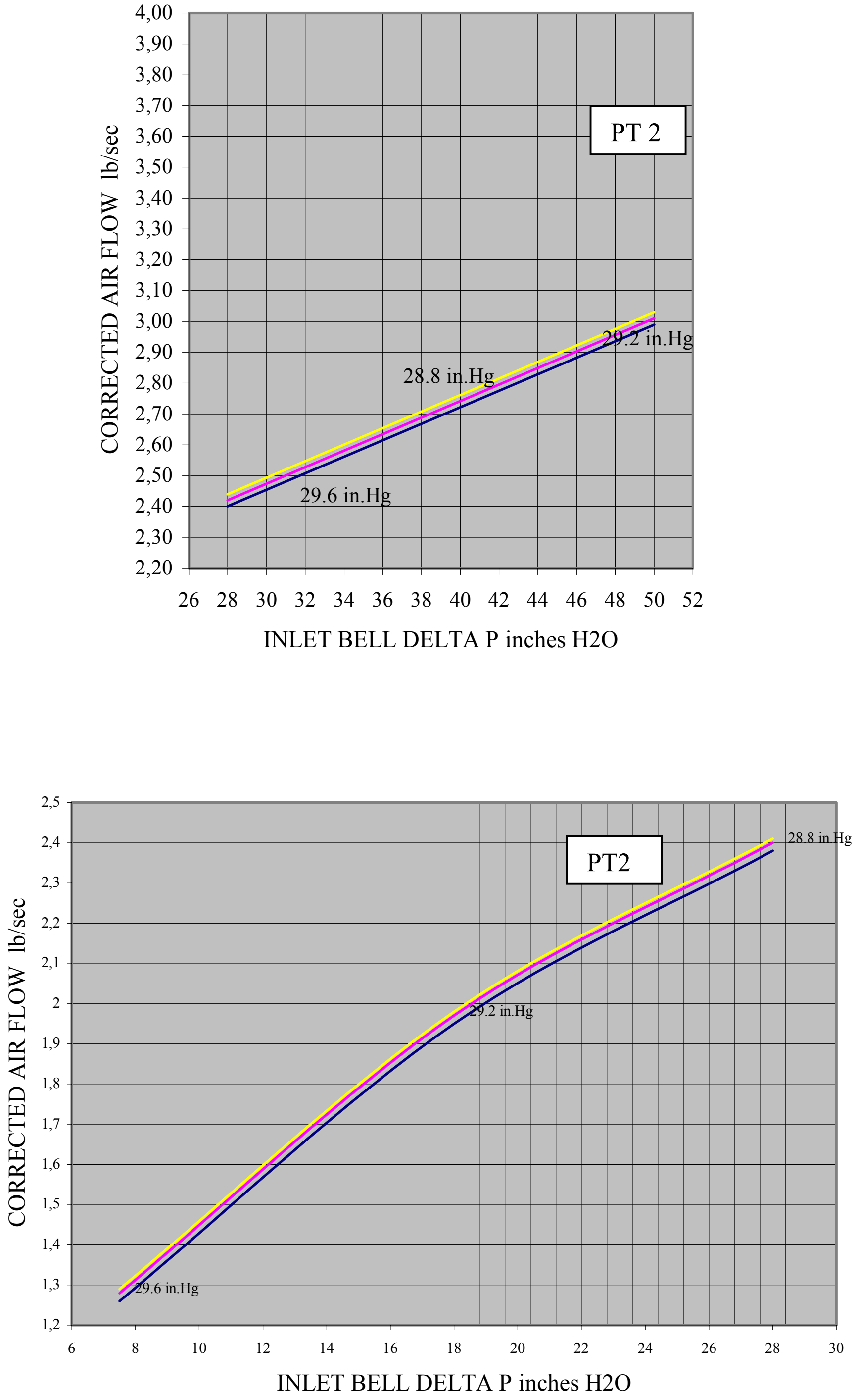


Figure 3.8.a,b Corrected Engine Inlet Airflow

3.5 EPES (Engine Performance Evaluation Software)

In this section, software is developed in order to evaluate the engine performance. The software gives the results obtained from the performance test on the graphics by visual.

CORRECTION FACTORS [17]

Corrected SHP

Inputs

P_{T2} = Compressor inlet pressure (in. Hg)

T_0 = Compressor inlet temperature (^{o}F)

$$SHPCF = C_0 + C_1 * P_{T2} + C_2 * T_0 + C_3 * P_{T2}^2 + C_4 * P_{T2} * T_0 + C_5 * T_0^2 \qquad (3.1)$$

Where:

C_1= 3.0977

C_2= -0.10214122

C_3= -0.00193956

C_4= 0.00113491

C_5= 0.0000322217

C_6= -0.000000127371

Corrected WF

Inputs

P_{T2} = Compressor inlet pressure (in. Hg)

T_0 = Compressor inlet temperature (^{o}F)

$$WFCF = C_6 + C_7 * P_{T2} + C_8 * T_0 + C_9 * P_{T2}^2 + C_{10} * P_{T2} * T_0 + C_{11} * T_0^2 \qquad (3.2)$$

Where:

C_6 = 3.0084

C_7 = -0.09517293

C_8 = -0.00312041

C_9 = 0.00104744

C_{10} = 0.00004204458

C_{11} = 0.00000318555

Corrected T_{T5}

Inputs

P_{T2} = Compressor inlet pressure (in. Hg)

T_0 = Compressor inlet temperature (°F)

$$T_{T5}CF = C_{12} + C_{13} * P_{T2} + C_{14} * T_0 + C_{15} * P_{T2}^2 + C_{16} * P_{T2} * T_0 + C_{17} * T_0^2 \quad (3.3)$$

Where:

C_{12} = 1.0332

C_{13} = 0.00462705

C_{14} = -0.0021974

C_{15} = -0.0000410391

C_{16} = -0.000011755

C_{17} = 0.00000433182

RAM PRESSURE RATIO

$$RPR = \frac{P_{T2}}{P_{S7}} \quad (3.4)$$

RPR WF (RAM)

$$RPRWF = C_{18} * RPR - C_{18} \quad (3.5)$$

Where:

C_{18} = 107.1429

RPR TT5 (RAM)

$$RPRT_{T5} = C_{19} * RPR - C_{19} \quad (3.6)$$

Where:

C_{19} = 500

RPR SHP (RAM)

$$RPRSHP = C_{20} - C_{20} * RPR \quad (3.7)$$

Where:

$C_{20} = 170$

ΔSG SPEC. GRAVITY CHANGE

$$\Delta SG = C_{21} - C_{22} * TWFI \tag{3.8}$$

Where:

$C_{21} = 0.0253676$

$C_{22} = 0.0004193$

READING SHP

$$READSHP = \frac{TORQ_1}{C_{23}} \tag{3.9}$$

Where:

$C_{23} = 10.48$

MIN SFC EPES

MIN SFC EPES (Take-Off) = 0.697

MIN SFC EPES (Max. Cont.) = 0.706

MIN SFC EPES (Normal Cruise) = 0.762;

CORRECTED VALUES

CSHP

$$CSHP = READSHP * SHPCF * RPRSHP \tag{3.10}$$

GPTOT TAKE_OFF

$$CT_{T5} = \left(T_{T5} + 460\right) * T_{T5}CF + RPRT_{T5} - 460 \tag{3.11}$$

WF TAKE_OFF

$$CWF = \frac{WF * SG}{\left(SG + \Delta SG\right)} \frac{WFCF * LHV}{C_{24}} + RPRWF \tag{3.12}$$

Where:

$C_{24} = 18400$

SHP CURVE SLOPE

$$SHP\,CURVE = \frac{CSHP_{(Take-off)} - CSHP_{(NormalCruise)}}{CT_{T5(Take-off)} - CT_{T5(NormalCruise)}} \tag{3.13}$$

SHP CONST. VALUE,

$$SHP\,CONST\ VAL = CSHP - SHP\,CURVE * CT_{T5} \tag{3.14}$$

SHP TAKE OFF

$$SHP\ T/O = \frac{CSHP_{(Take-off)} - CSHP_{(NormalCruise)}}{CT_{T5(Take-off)} - CT_{T5(NormalCruise)}} T_{T5} + SHP\,CONST\,VAL \tag{3.15}$$

WF CURVE FUEL FLOW CURVE SLOPE

$$WF\ CURVE = \frac{CWF_{(Take-off)} - CWF_{(NormalCruise)}}{CT_{T5(Take-off)} - CT_{T5(NormalCruise)}} \tag{3.16}$$

WF CT FUEL FLOW CONST. VALUE

$$WF\,CT = CWF - WF\,CURVE * CT_{T5} \tag{3.17}$$

WF FUEL FLOW AT TAKE-OFF

$$WF\ T/O = \frac{CWF_{(Take-off)} - CWF_{(NormalCruise)}}{CT_{T5(Take-off)} - CT_{T5(NormalCruise)}} T_{T5} + WF\,CT \tag{3.18}$$

TORQUEMETER LIMIT

$TORQ_{LIMIT\ (Take\text{-}Off)} = 61$

$TORQ_{LIMIT\ (Max.\ Cont.)} = 81$

$TORQ_{LIMIT\ (Normal\ Cruise)} = 95$

SFCEPES

$$\text{SFC EPES} = \frac{\left(WF\,CURVE * CONSTVAL\ T_{T5} + WF\,CT\right)}{\left(SHP\,CURVE * CONSTVAL\ T_{T5} + SHP\,CONST\,VAL\right)} \tag{3.19}$$

CONSTVAL $T_{T5\ (\text{Take-Off})}$ =1380

CONSTVAL $T_{T5\ (\text{Max. Cont.})}$ =1280

CONSTVAL $T_{T5\ (\text{Normal Cruise})}$ =1153

SPEC.SFC EPES CONST.

CSPEC.SFC EPES $_{(\text{Take-Off})}$ = 0.697

SPEC.SFCEPES $_{(\text{Max. Cont.})}$ = 0.706

CSPEC.SFC EPES $_{(\text{Normal Cruise})}$ = 0.762

SFCEPES Variance

$$\text{SFC EPES}_{\text{Variance}} = \frac{\left(\text{SFCEPES - CSPEC.}SFC\text{EPES}\right)}{\text{CSPEC.}SFC\text{EPES}}100 \tag{3.20}$$

Plotted SHP

$$PSHP = SHP\,CURVE * CONSTVAL\ T_{T5} + SHP\,CONST\ VAL \tag{3.21}$$

SPEC. SHP CONST

CSPEC. SHP$_{(\text{Take-Off})}$ = 317

CSPEC. SHP$_{(\text{Max. Cont.})}$ = 270

CSPEC. SHP$_{(\text{Normal Cruise})}$ = 203

HP VARIANCE

$$HP_{VARIANCE} = \frac{\left(PSHP - CSPEC.SHP\right)}{CSPEC.SHP} \tag{3.22}$$

EPES is a kind of Graphical User Interface (GUI) created using MATLAB 6.5 [18] (Figure 3.9). EPES software requires three set of input values. The actual values are entered the input windows by means of three different buttons in the 'INPUTS' section. (Figure 3.10, Figure 3.11, Figure 3.12)

EPES software runs when 'RUN' button is pressed. A required performance graphic is chosen from the list box in the 'GRAPHS' section, then it is plotted when 'PLOT' button is pressed. (Figure 3.13.a, b, c). 'ZOOM' button is used to see in detail the desired value on the graphics. (Figure 3.14). As a result, EPES software makes possible preliminary evaluation of the test results for 250C-18 model engine. EPES software may be used after getting the approved test cell results and compared with the real evaluations.

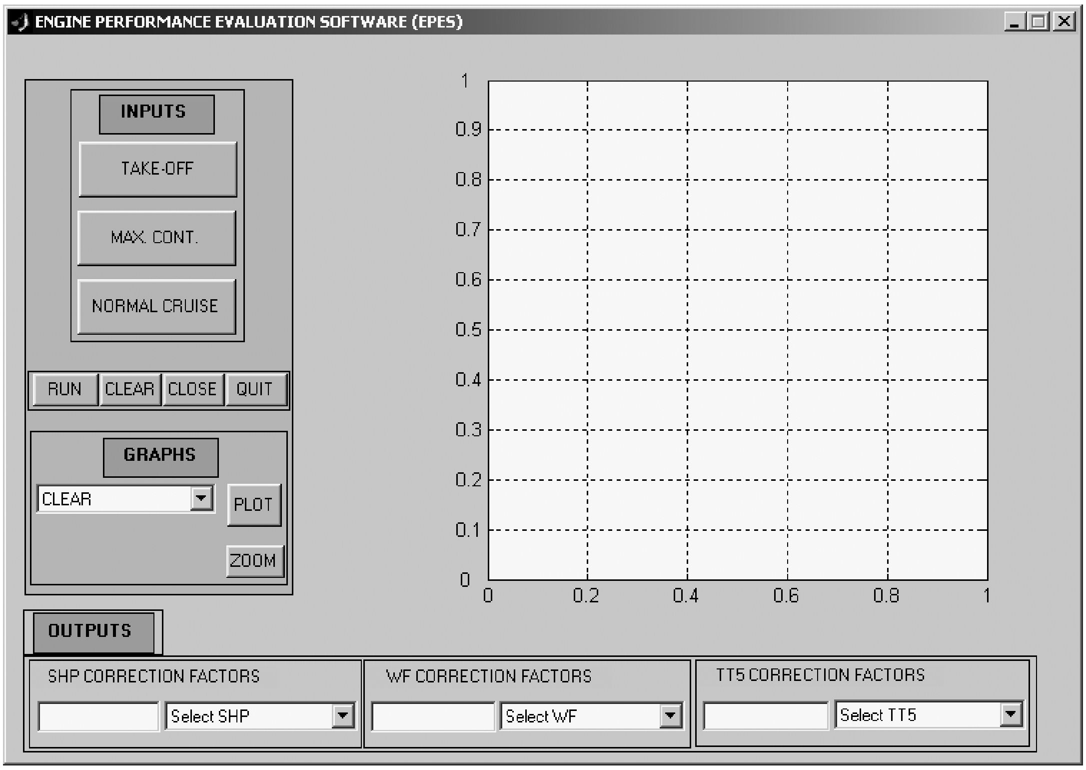
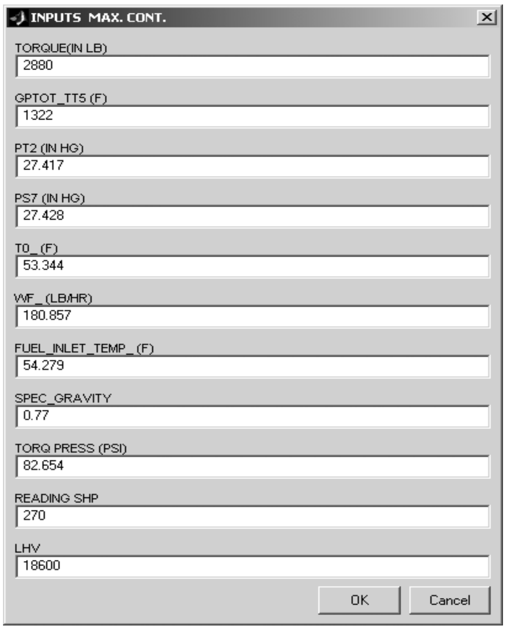


Figure 3.9 Main Menu



TORQUE(IN LB)
2880

GPTOT_TT5 (F)
1322

PT2 (IN HG)
27.417

PS7 (IN HG)
27.428

T0_ (F)
53.344

WF_ (LB/HR)
180.857

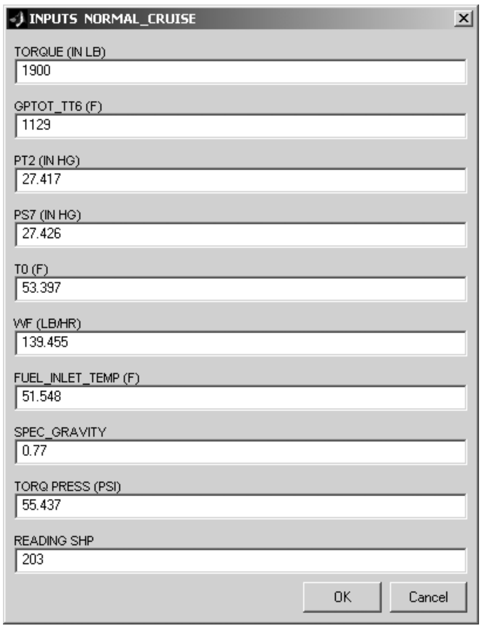
FUEL_INLET_TEMP_ (F)
54.279

SPEC_GRAVITY
0.77

TORQ PRESS (PSI)
82.654

READING SHP
270

LHV
18600



TORQUE (IN LB)
1900

GPTOT_TT6 (F)
1129

PT2 (IN HG)
27.417

PS7 (IN HG)
27.426

T0 (F)
53.397

WF (LB/HR)
139.455

FUEL_INLET_TEMP (F)
51.548

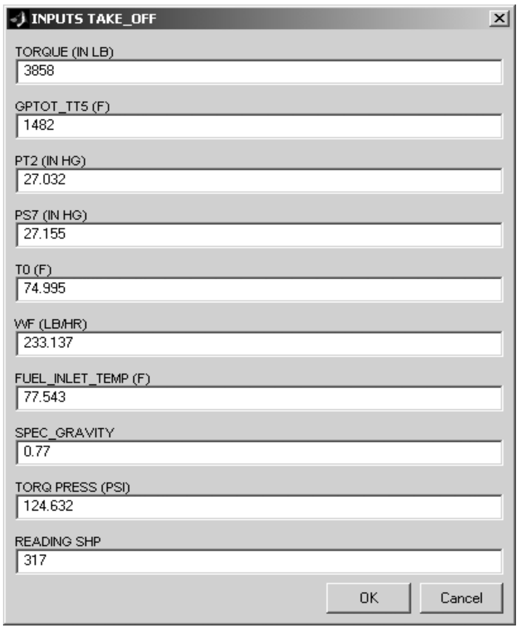
SPEC_GRAVITY
0.77

TORQ PRESS (PSI)
55.437

READING SHP
203

Figure 3.10 Input Menu-1

Figure 3.11 Input Menu-2



TORQUE (IN LB)
3858

GPTOT_TT5 (F)
1482

PT2 (IN HG)
27.032

PS7 (IN HG)
27.155

T0 (F)
74.995

WF (LB/HR)
233.137

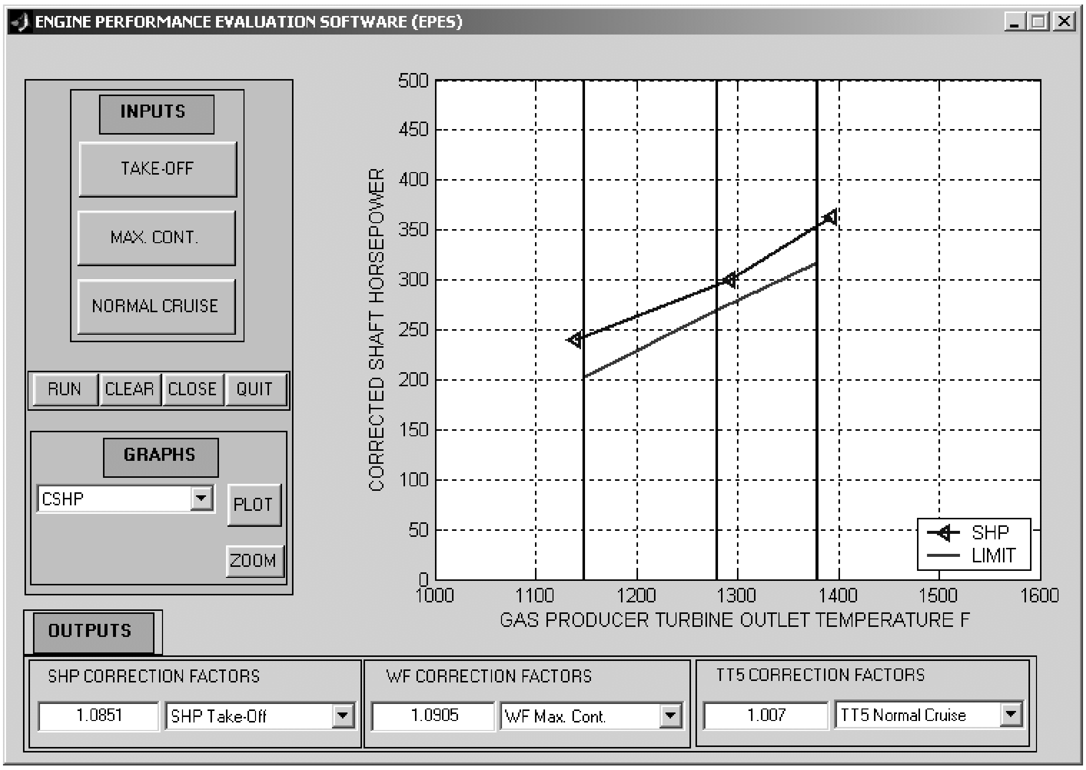
FUEL_INLET_TEMP (F)
77.543

SPEC_GRAVITY
0.77

TORQ PRESS (PSI)
124.632

READING SHP
317

Figure 3.12 Input Menu-3



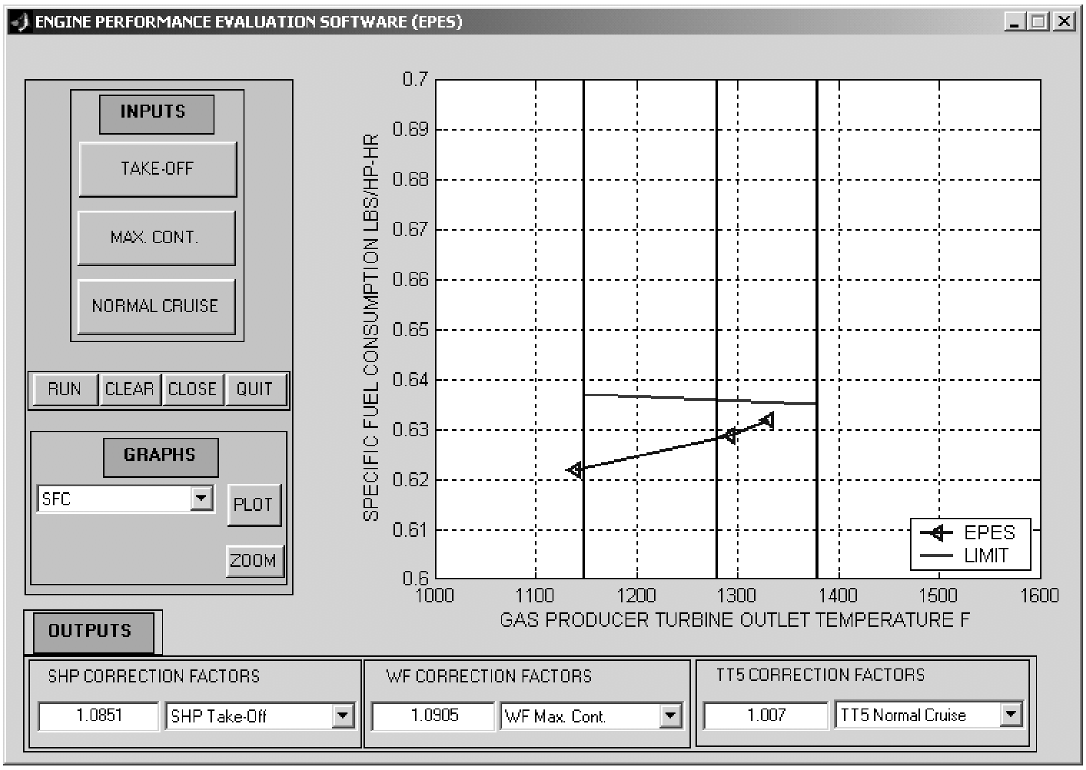
GRAPHS: CSHP

SHP CORRECTION FACTORS: 1.0851 SHP Take-Off

WF CORRECTION FACTORS: 1.0905 WF Max. Cont.

TT5 CORRECTION FACTORS: 1.007 TT5 Normal Cruise

Figure 3.13.a Plot Menu CSHP



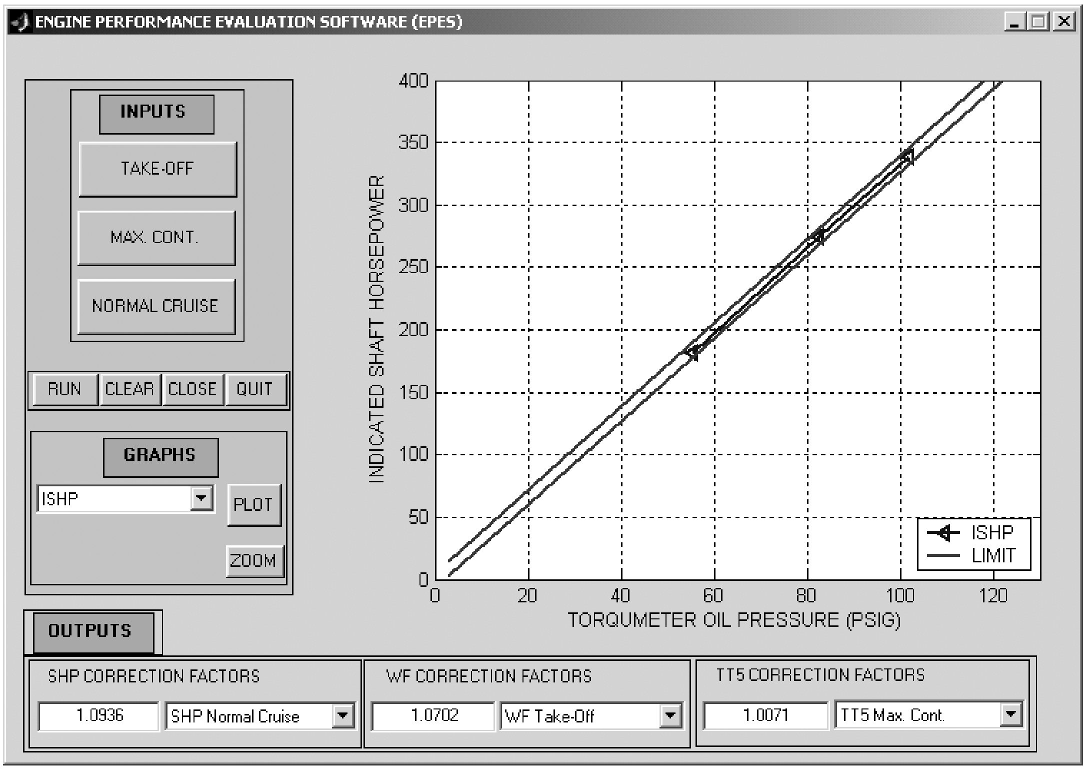
GRAPHS: SFC

SHP CORRECTION FACTORS: 1.0851 SHP Take-Off

WF CORRECTION FACTORS: 1.0905 WF Max. Cont.

TT5 CORRECTION FACTORS: 1.007 TT5 Normal Cruise

Figure 3.13.b Plot Menu SFC



ENGINE PERFORMANCE EVALUATION SOFTWARE (EPES)

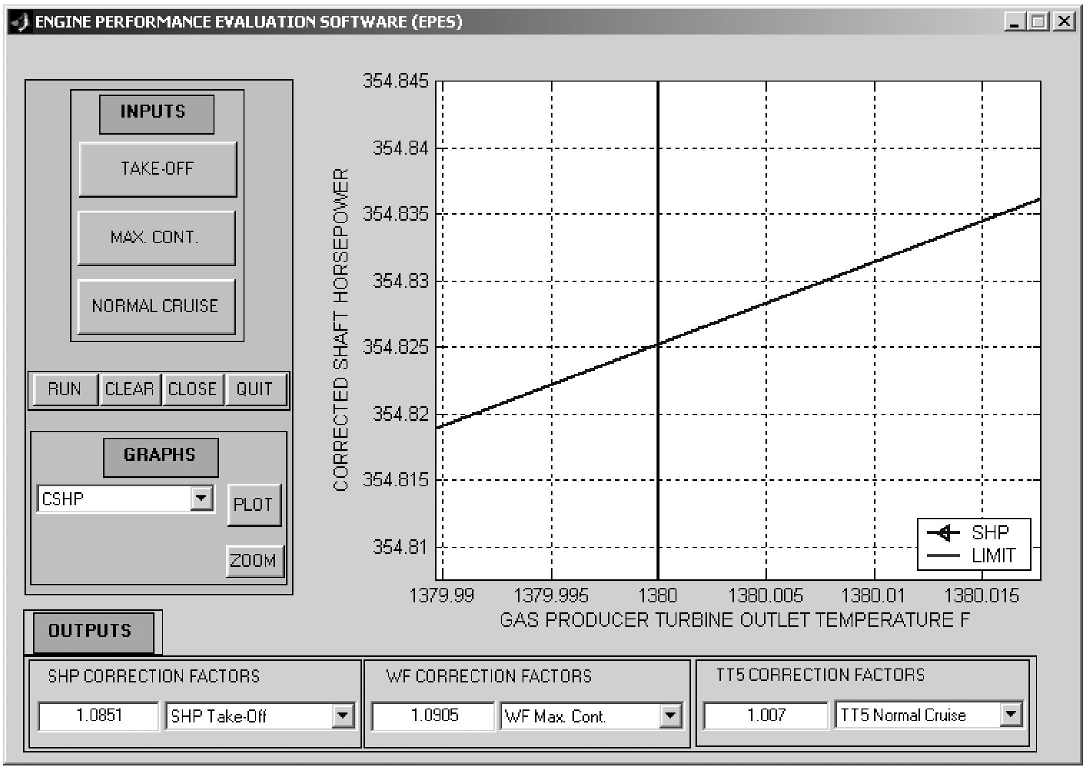
GRAPHS: ISHP

SHP CORRECTION FACTORS: 1.0936 SHP Normal Cruise

WF CORRECTION FACTORS: 1.0702 WF Take-Off

TT5 CORRECTION FACTORS: 1.0071 TT5 Max. Cont.

Figure 3.13.c Plot Menu ISHP



GRAPHS: CSHP

SHP CORRECTION FACTORS: 1.0851 SHP Take-Off

WF CORRECTION FACTORS: 1.0905 WF Max. Cont.

TT5 CORRECTION FACTORS: 1.007 TT5 Normal Cruise

Figure 3.14 Zoom Menu

CHAPTER 4

4. CONCLUSION

Establishment of a test system requires very detail work. First, technical characteristics of a gas turbine must be known. Not only to study the engine power and speed values from the manuals, but also to obtain the values pertaining to related sections of the engine. It is necessary to find out which port of the engine suitable for taking the pressure, temperature, and speed values. In order to run the engine and to determine the values which are taken from the engine are also important.

Any works with a gas turbine must be performed by experienced personnel. It is extremely important to understand that the warnings and cautions given by the manufacturer manuals [11, 14].

Most of all test cells are equipped with viewing windows that allow the test cell operator to visually monitor the engine during the run cycle as with all gas turbine engines. Test cell operators should not be located in the plane of any rotating parts while the engine is in the start, run or shutdown cycle even when located behind an explosion-proof viewing window [14]. It is mandatory that the gas turbine test stand must be run after taken the precautions and warnings mentioned in all related technical manuals. The gas turbine test stand operator should be behind an explosion-proof viewing window and protect himself from any rotating parts while the engine is in the start, run or shutdown cycle.

It is possible to create the evaluation software after obtaining the required values for the evaluation. EPES software is not fully applicable on the 250C-18 engine performance evaluation. It needs improvement. EPES software may be used after getting the approved test cell results and comparing these with real evaluations.

I determined the engine normal run position and the mounting places before starting the design process. I installed the engine with the mounting parts which could be adjustable in vertical and horizontal planes. This was the first requirement for running of the engine smoothly. The engine distance from the ground was ergonomically determined. The test frame may be manufactured differently, but I preferred to make each side of the engine test frame like a triangular shape.

The oil system was installed on the engine test frame because I did not want to use the oil hoses longer than required. Oil pressure is not required for the engine oil inlet section. There is an oil pump inside the engine. No need to use an extra oil pump. The level between the oil tank and the engine oil inlet section must be taken into account. The oil tank level must be higher than the engine oil inlet section level. I understood after the first run that only one input and output were not enough for the oil system. The other oil vent lines were added from the engine to the oil tank. I placed an oil cooling system on the engine test frame consisting of an oil cooler and a fan pumped air from under the oil cooler. I installed thermocouples on the oil cooler input and oil tank output. Because the engine oil inlet and oil outlet temperature must be observed during the engine run cycle. I put a pressure gage to measure main oil pressure of the engine.

I placed a fuel system on the engine test frame consisting of a low pressure fuel pump, fuel pipes and a fuel tank. Obtained fuel inlet pressure was suitable for the requirements of the engine as an extra fuel pump was used. To run an engine running without a loading system was dangerous as engine may overspeed. In fact, the loading system was not required for the start and the ground idle cycles according to the technical manuals. The idea of controlling the speed through with push-pull rods was adequate. In addition to that, I fixed the position of the fuel control pointer so that the pointer moved between minimum and ground idle position.

The control of the gas producer turbine speed and power turbine speed was enough. The observed speed values on the control panel must be constantly observed. This is important because the engine might enter the dangerous overspeed area. In addition to the speed indicators, I placed two pressure gages for the main oil pressure and torquemeter pressure and two temperature indicators for the gas producer turbine outlet temperature and oil inlet/outlet temperatures. After I completed the sub-system design of the gas turbine test stand, I checked the system’s functions step by step. For example, I activated the starter on/off switch and observed if the start and ignition occurred at the same time. It was very exiting for me to first run the engine.

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