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COMPUTER-AIDED PERFORMANCE ANALYSIS OF
ALLISON 250-C30 ENGINES

by

© Vivek Vasudev Mohile, B. Eng.

A thesis submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements for the
Degree of Master of Engineering

Department of Mechanical and Aeronautical Engineering

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Ottawa, Canada

April 1, 1983

The undersigned hereby recommend to the Faculty of Graduate Studies and Research, acceptance of the thesis:

"Computer-aided Performance Analysis of Allison 250-C30 Engines", submitted by Vivek Vasudev Mohile, in partial fulfillment of the requirements for the degree of Master of Engineering.

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ABSTRACT

Allison 250 series engines have been widely used for helicopters and fixed wing light aircraft. Quite often, these aircraft operate in unprepared areas where there are dangers of foreign object damage (FOD) and dust ingestion, which can cause erosion and fouling of the flow passages. Hence more often it is required to keep a close watch on the engine performance parameters, to diagnose the degradation of the engine components using engine health monitoring techniques. Generally, a difficulty is encountered in checking the operating parameters of these engines with that of the recommended manufacturer's values for a healthy engine. Many complicated empirical factors are also involved in the recommended manufacturer's method for performance analysis of these engines. Hence a detailed study was planned to understand the effect of these empirical factors on the engine operation.

In the following thesis report, Allison 250-C30 engines have been chosen for the planned analysis. An empirical method has been developed to calculate the performance parameters of these engines. An interactive software package has been developed for the comparison of the measured performance parameter values with the

expected manufacturer's values. A special attention has been given to use of the software in remote areas or in field. At the end of the report, a simple logical fault detection method is recommended to diagnose the engine health condition.

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NOMENCLATURE

<u>SYMBOLS</u>	<u>ITEM</u>
SHP	Output Shaft Horsepower
N_1	Gas Generator Turbine Speed
N_2	Power Turbine Speed
SFC	Specific Fuel Consumption
P_{am}	Ambient Static Pressure
P_0	Standard Sea Level Pressure, 29.92 in. Hg abs.
P_{t_2}'	Ideal Engine Inlet Total Pressure
P_{t_2}, P_{t_3} , etc.	Total Pressure at Station Indicated
ΔP_{t_2}	$P_{t_2}' - P_{t_2}$
P_{s_7}	Engine Outlet Static Pressure
ΔP_{s_7}	$P_{s_7} - P_{am}$
T_{am}	Ambient Static Temperature
T_0	Standard Sea Level Temperature of Undisturbed Air Mass 59°F, 518.7°R
T_{t_2}, T_{t_3} , etc.	Total Temperature at Station Indicated
T_{t_5}	Gas Generator Turbine Outlet Total Temperature
η_d	Duct Efficiency (P_{t_2}'/P_{t_2})
V_p	Aircraft Speed
W_a	Air Flow Rate
W_{bl}	Amount of Air Flow Bled
W_f	Fuel Flow Rate
θ	T_{t_2}/T_0
δ_{am}	P_{am}/P_0

SYMBOLSITEM

δ'	P_{t_2}'/P_0
δ	P_{t_2}/P_0
RPR'	Ideal Ram Pressure Ratio (P_{t_2}'/P_{s_7})
RPR	Actual Ram Pressure Ratio (P_{t_2}/P_{s_7})
$P_{t_{bl_3}}$	Pad Bleed Total Pressure
$T_{t_{bl_3}}$	Pad Bleed Total Temperature
$W_{a_{3a}}$	Acceleration Bleed Air Flow
$T_{t_{3a}}$	Acceleration Bleed Air Total Temperature
$P_{t_{3a}}$	Acceleration Bleed Air Total Pressure
C_1	Shaft Horsepower Correction Factor
C_2	Gas Generator Turbine Outlet Temperature Correction Factor
C_3	Fuel Flow Correction Factor
HP _{ex(G.G.)} or (P.T.)	Amount of Horsepower Extracted (Gas Generator or Power Turbine)
$C_{d_1}, C_{d_2}, \text{etc.}$	Pressure Loss Correction for Function Indicated
$C_{bl_1}, C_{bl_2}, \text{etc.}$	Bleed Correction for Function Indicated
$C_{hp_1}, C_{hp_2}, \text{etc.}$	Horsepower Correction for Function Indicated

SYMBOLSITEM

$C_{ai1}, C_{ai2}, \text{etc.}$	Anti-icing Correction Factor for Function Indicated
$\left(\frac{\Delta \text{SHP}}{\delta' \sqrt{\theta C_1}} \right)_{\text{RPM}_1}$	Power Turbine Speed Correction for SHP
$\left(\frac{\Delta T_{t5}}{\theta C_2} \right)_{\text{RPM}_2}$	Power Turbine Speed Correction for T_{t5}
$\left(\frac{\Delta W_f}{\delta' \sqrt{\theta C_3}} \right)_{\text{RPM}_3}$	Power Turbine Speed Correction for W_f
$\left(\frac{\Delta \text{SHP}}{\delta' \sqrt{\theta C_1}} \right)_{\text{RPR}_1}$	RPR (Velocity) Correction for SHP
$\left(\frac{\Delta T_{t5}}{\theta C_2} \right)_{\text{RPR}_2}$	RPR (Velocity) Correction for T_{t5}
$\left(\frac{\Delta W_f}{\delta' \sqrt{\theta C_3}} \right)_{\text{RPR}_3}$	RPR (Velocity) Correction for W_f

Note :- Refer to fig. 2 for station numbers

CHAPTER 1

INTRODUCTION

Gas turbines in the range 300 to 700 H.P. have a wide application in helicopter and fixed wing light aircraft market. Both types operate for relatively short flight hours and with many engine starts. In particular, the operating environment of helicopters is hostile as they operate at low altitude, in unprepared areas, and even over the sea. Foreign Object Damage (FOD), dust ingestion, and salt spray can result in serious degradation of the engine performance, and the erosion and fouling of flow passages. These problems can lead to permanent damage of an engine. A frequent assessment of the engine health is recommended to diagnose any serious degradation occurring, before permanent damage is done. This would also help to improve the safety levels and the next mission confidence. Thus, a capability has to be developed to assess the engine health. Obviously the first step is to keep a close watch on engine health parameters and understand their behavior relative to their expected nominal values. It should be noted that the crew cannot discern any changes in the engine health performance by simply monitoring the cockpit instruments as a wide variation in ambient conditions can hide these

changes. The next step towards the assessment of the engine health is to use a fault matrix to locate a problem area.

Detroit Diesel Allison is one of the largest manufacturers of helicopter gas turbines [1]. Since the Sixties, the company has introduced many gas turbine models in 300 to 700 H.P. range. The Allison 250 series engines have been widely used for helicopters and fixed wing light aircraft. Yet the manufacturer's recommended method for calculating the nominal values of the health parameters is complicated, and hence cannot be used in the field as one needs to do the calculation in more than hundred steps and with the use of many complicated figures and formulae. Only a limited amount of calculation work can be done in forward operational areas due to many practical limitations. Thus, such an intensive calculation work is seldom done. There is an urgent need to develop some form of simple method to compare the cockpit instrumentation values with the nominal values, so that consistent periodic health monitoring can be done. In this thesis, an empirical method will be developed to get the basic nominal values for the performance parameters of the Allison 250 engines. A software package will be also presented for the field use and as well as for the use on the advanced computer system.

The approach taken in the presentation of this thesis is as follows. In Chapter 2, a discussion is presented on helicopter operation and the associated major problems. In Chapter 3, the reader is introduced to Allison engines and their basic design capabilities. The performance calculation method recommended by the manufacturer and the physical significance of the empirical factors used in the above method, are discussed in detail in Chapter 4. Chapter 5 discusses the expected performance of these engines at different power settings and at various ambient conditions. This will lead the reader into the development of an empirical method, using the most simplified empirical formulae, for calculating the important performance parameters. The suitability of such a simple empirical method is discussed in Chapter 6. This has resulted in the development of software suitable to be used in remote areas using a pocket computer or on an advanced computer system supporting FORTRAN 77. A brief discussion about the expected limitations of the developed method is also presented in Chapter 6. Finally, future work and application to health monitoring are discussed in Chapter 7. Conclusions are presented on the above research at the end of this report.

CHAPTER 2

HELICOPTER OPERATION AND PROBLEM AREAS

2.1 Applications

Helicopters have a wide range of duties in the modern world. The free-world's helicopter fleet is also growing by more than 10% a year, according to the industrial estimates [1]. Quite often, helicopters are required to operate in unprepared and remote areas. Their operating environment varies from that of a desert to that of a jungle, depending upon the operation zone. Helicopters are being widely used as a transport to off-shore oil platforms. Here they have to face a serious problem of salt spray. Naval and Coast Guard helicopters have to perform search and rescue duties, and have to fly at low altitudes over the sea. This can cause serious salt deposition on and degradation of an engine. Helicopters are also being used for geological research and have to fly to hazardous areas. Even the helicopters operating in urban areas are exposed to dust ingestion and industrial pollution, as they fly at low altitudes. In a well regulated airline operation, most aircraft fly at altitudes above 20,000 feet. The problems faced by helicopters are much more severe and complex than an

airline operation as these helicopters fly at lower altitudes. It should be noted that in many helicopter applications, the reliability is a prime factor. Hence immediate attention has to be given to all critical problems which can cause a permanent damage or lower the safety levels. A systematic diagnostic technique has to be developed to predict the problem area and ensure a smooth reliable service. It is interesting to discuss in detail the effect of the above environmental factors on engine operation.

2.2 Erosion

While operating in remote and unprepared areas, a dense cloud of dust is generated which can cause serious erosion of the compressor. Solid particulates greater than 3 microns, especially those having a high silica content, can erode an axial compressor blade very rapidly [18]. It should be noted that centrifugal compressors are comparatively less vulnerable to a contaminated atmosphere than the axial ones. If the regular operation zone is in a desert, a special filtration system might be needed to minimize the problem of compressor erosion. Compressor erosion results in reduction in power output and increase in fuel flow. This causes the engine to operate at high turbine inlet temperature and may result

in permanent turbine damage or reduction in the blade life. An improved filtration system suitable to the operating environment is the only approach which really gets to the root of this problem, but one has to sacrifice both on intake losses and installation weight. Hence such an extensive filtration system has to be justified by a consistent operation in demanding environment.

2.3 Salt Spray

The problem of salt deposition is a serious and complex one for helicopters operating over the sea. During operation over salt water, there is a significant loss in power with increasing time in service. The salt deposits are sticky and glue to a surface, especially if it is hot. These deposits build up very rapidly and if left for a period of time, they get baked, making them hard to remove. The result is that the axial compressor stator and rotor blade profile gets altered, and their flow areas are decreased. Centrifugal compressors are capable of operating efficiently over a wide range of mass flow at a particular rotational speed [11]. Hence their performance is less affected due to these salt deposits than the axial compressors. For a given gas

2

generator speed, the flow rate passing through the engine will be reduced due to the reduction in flow area, and consequently so will be the output power. Thus to maintain a constant power output, it would be necessary to operate at higher turbine inlet temperature and gas generator (G.G.) speed. If the engine was originally operating near its rated power, any further increase in turbine inlet temperature would be disastrous in terms of turbine blade life. Additionally, the surge line will be lowered as the compressor is forced to operate at off design condition and can lead to a serious problem during starting. In general, gas turbine manufacturers specify the maximum concentration of salt that is permissible in the air entering the engine. Engine wash is one of the easiest ways of combating performance loss, provided the problem is due to engine fouling [9]. But the washing operation is difficult to perform in forward operational areas due to practical limitations. At temperatures below freezing, the washing operation can become almost impossible to be carried out. The washing procedure is classified as motoring wash or running wash, and special cleaning agents are used. The concerns are about the contamination of lubrication system due to the cleaning agents, and redeposition of salt and dirt on hot parts, which are highly undesirable.

2.4 Corrosion

Another important problem caused by salt spray besides compressor fouling is salt corrosion. The corrosive action of salt affects almost every part of the engine, whether external or internal, but it is the hot corrosion of the turbine blades which causes the major problem. It is important to select the turbine material which will have good strength and corrosion resistance at elevated temperatures. The most common alloys used for the turbine blade materials are nickel based but have high chromium content. All the aviation fuels contain sulphur which reacts with sodium to form sodium sulphate and the product gets deposited on the hot surface. This sodium sulphate reacts with the chromium content of the base metal to produce a condition called sulfidation. Then the high temperature corrosion of the nickel rich base metal proceeds without any resistance [17]. Sulfidation is basically a temperature dependent reaction and accelerates rapidly at the surface above 760 degree C [18]. As most turbines operate above this temperature for better efficiency, this reaction is difficult to control. The effect of this reaction is destruction of the blade profiles, especially at the leading edges, and decrease in flow area due to deposits on the stator. As a result the engine has to operate at higher turbine inlet

temperature due to the drop in output power. In some cases the turbine blades even get cemented to the turbine disc because of sulfidation [18]. This may cause fatigue failure of the blades due to change in their vibration frequency. The general approach to the corrosion protection has been to use special protective coatings on all standard components to keep the maintenance cost down.

2.5 Icing

The suction of air into the inlet duct increases with decreasing air speed, and becomes maximum at static conditions, when the G.G. rpm is high [8]. This results in a drop of static pressure of the air passing through the compressor inlet and also a drop in inlet air static temperature. This means that if visible moisture is present when an engine is operating on the ground or at low air speed and high rpm, such as takeoff, ice may form in the compressor inlet even though the ambient temperature is above freezing [8]. Centrifugal compressor engines are relatively free from the danger of ice collecting at compressor inlet, as this is not a limiting factor governing the flight condition of the engines with centrifugal compressors [8]. For a given icing condition, the compressor inlet of smaller engines with

closer guide vane spacing, will be more susceptible to icing than larger engines. The ice restricts the flow of inlet air to the engine. This causes loss of power. The fuel control attempts to correct any loss in power by adding more fuel and running the engine at higher G.G. speed. This results in the increase in turbine inlet temperature, which is undesirable. Anti-icing systems for turboshaft and turboprop engine vary with the size and the design of an engine but the most commonly used is a compressor air inlet anti-icing system. Hot high pressure air is bled from compressor delivery and is ducted through an anti-icing valve to the hollow section of inlet guide vanes. It is recommended to turn on the anti-icing system, when possible, in advance of flying into icing conditions, in order to warm up the engine inlet before ice formation actually commences [8].

2.6 Foreign Object Damage (FOD)

While operating in a hostile environment, engine sucks in some foreign objects, and these objects can cause serious mechanical damage to the compressor. As the basic design of centrifugal compressors is robust, they are less vulnerable to FOD than the axial ones. FOD causes vibrations due to mechanical unbalance of a compressor. The compressor damage results in reduction of

air flow rate, and thus, drop in output power. This causes the engine to operate at higher fuel flow rate, higher turbine inlet temperature and higher G.G. speed at a given power setting. The operating environment of helicopters is very demanding and thus the probability of FOD is higher than a regular airline operation.

2.7 Approach to Solving the Problems

From the above discussion, it is clear that the problems of Foreign Object Damage, erosion and fouling of flow passages is a critical one for helicopters. With the small flow passages common in turboshaft engines in use, performance deterioration can occur much more rapidly than in the well regulated airline operation. As only limited maintenance can be carried out in the forward areas, the following important functions are required to be carried out at a base to ensure a safe flight mission [2].

- 1) Assessment of Engine Health
- 2) Diagnosis and prognosis of malfunction and deterioration, and ability to check their progress in order to permit proposed repair.
- 3) Identification of the area of deterioration

Since the cost of maintaining, inspecting,

repairing, and overhauling engines represents a major portion of their operating expenses, operators are expected to become increasingly aware of the importance of such a maintenance program which reduces operating expenses and in addition improves reliability and safety levels [6].

Now the course of action has to be decided to carry out the above three functions. It is important to note at this point that an engine is a thermodynamic as well as a mechanical device. Hence it is necessary to monitor both the mechanical and thermodynamic health of an engine. Thermodynamic degradation can be equally disastrous from the point of view of safety and economy as a mechanical one. The following are some of the widely used mechanical engine health monitoring (EHM) methods.

Mechanical EHM methods

- 1) Visual inspection via Borescope
- 2) Spectrographic Oil Analysis
- 3) Radiography
- 4) Vibration Analysis

It is difficult to predict or detect incipient failure of certain engine parts. To be more specific, rotating components offer the most critical design and maintenance problems. Turbine discs are subjected to fatigue because of cyclic stresses due to temperature and

centrifugal forces [2]. A rapid bearing failure can still occur. Gear cracking or deterioration can occur and can cause a serious problem. In design, these kind of failures are prevented today by using high factors of safety on the assumption of load cycles being applied in service life. In practice, the above mechanical EHM methods have proven to be the answer to predicting the expected mechanical problems and improved safety levels.

The thermodynamic EHM is generally done using the following two methods.

- 1) Trend Analysis
- 2) Gas Path Analysis

The logic in Trend Analysis is that a healthy gas turbine must follow its unique corrected base line curves under steady state condition. Thus, any specific engine cannot vary extensively from its corrected base line curve unless a malfunction forces it to do so. Certain engine parameters are recorded at scheduled intervals while operating within the useful range, at a steady state condition. Typically for a turboshaft engine, fuel flow, torque meter pressure and exhaust gas or inter turbine temperature are recorded at various gas generator (G.G.) and power turbine (P.T.) speeds. If a malfunction occurs, these performance parameters would show a divergence from their unique base line curves. This

divergence is studied, and a fault diagnosis is done. This method would also help to decide a course of action to be taken, depending upon the severity of the problem.

Gas Path Analysis enables us to compute critical cycle performance parameters of an engine. Such parameters provide information about the health of an engine and its gas path components directly, i.e. these cycle performance parameters are themselves indicative of the engine health. Two of the most important parameters are turbine inlet temperature and mass flow rate, as they have a direct relation with turbine blade life and output power. Unfortunately these cannot be measured directly at the present time. The advantage of Gas Path Analysis is that it provides an indication of both overall engine performance and individual components. To do gas path analysis however, some extra instrumentation might be needed to be installed on the engine.

The above discussion on helicopter operation and problem areas has emphasized the fact that there is an urgent need to develop an EHM method for on helicopters. As the probability of the helicopter engine degradation is higher than a aircraft engine, the engine performance parameters are to be checked with the aid of EHM method more frequently, to ensure the healthy condition of an engine. One should take into account the operating

environment and the field limitations while designing an EHM method. The method has to be simple, and minimum time and skill should be required to use it. It is also to be recognized that an EHM program is most essential as it can improve the operational reliability of helicopters, which is a prime factor in many applications. An EHM program can also help to avoid a major maintenance in forward operational areas and lower the maintenance costs. The approach taken by the author is to consider some of the most widely used engines for the planned research. The proposed EHM scheme is presented in the following chapters.

CHAPTER 3

INTRODUCTION TO ALLISON 250-C30 ENGINES

3.1 General Background

Allison 250 series gas turbines are manufactured by Detroit Diesel Allison, a division of General Motor Corporation, mainly for the helicopter and light executive aircraft market. Early models of 250 series turbines were introduced in the Sixties, and were manufactured to fit in the gas turbine group with the output power below 550 shp [16]. Thus these engines competed more with reciprocating engines than with any other gas turbines then available. Later in the Seventies, more advanced models of the 250 series were introduced with takeoff power up to 650 H.P. Today, Detroit Diesel Allison is one of the largest manufacturer of small turbines and supplies turbines to half of the world's fleet of helicopters under 11,500 lb gross weight [1]. Industrial estimates show that the number of turbine-powered helicopters in this category would increase by 43% over a period of five years, from approximately 21600 in 1980 to 31000 by 1985 [1].

There are two types of design options available on these widely used engines. One is turboprop and another

is turboshaft. The turboshaft version is mainly for helicopters and is used to power a shaft through a gear box. This turbine driven shaft supplies the power to the helicopter rotor through a helicopter mounted reduction gear box. It is interesting to note that the output shaft operates at essentially a constant speed in normal operation [12]. Helicopter lift (engine load) can be varied by changing the G.G. speed, and the angle, or pitch, at which the rotating blade attacks the air. Constant rotor speed, independent of the blade angle of attack, is automatically maintained by the engine fuel control and governor system, and hence simplifies the helicopter operation [12]. The turboprop engine is basically the same engine as the turboshaft option, except that an engine mounted reduction gear box has been added to lower the turbine output shaft speed to a suitable propeller rpm. As for the turboshaft engines, the turboprop engines operate at essentially a constant speed (constant speed of output shaft). Needed variation in the aircraft power is obtained by varying the G.G. speed and the pitch of the propeller blades. Helicopter operation and problem areas are discussed in detail in Chapter 2. The operating environment of helicopters is hostile, and hence, the performance deterioration of an engine can occur more rapidly than the well-regulated airline operation. It has been recognized in Chapter 2

that there is an urgent need to develop an EHM method for helicopters. Thus, the discussion in this report is limited to a turboshaft version only, as this version of the 250 series engines is used for helicopter applications [12]. Fig. 1 shows the typical layout of the Allison Advanced Model 250 turboshaft engine. On the new advanced models, modern single stage centrifugal compressors with a high pressure ratio of about 9 are used, as they are less vulnerable to FOD and ice formation. The Allison 250-C30 model has been chosen for the planned research, thus the details about this engine are furnished below.

3.2 Allison 250-C30 Engine

The Allison 250-C30 engine is one of the new models introduced by Detroit Diesel Allison in the helicopter and light executive aircraft market and has a higher takeoff power capacity than the previous models. The turboshaft version of this model has been chosen for the planned research, and an attempt will be made to develop a simple performance analysis method for use in remote and forward operational areas. As this engine has been chosen for the planned research, it is important to understand its basic design features. The next step will be understanding the details of the performance

calculation procedure, and manufacturer's logic behind the complete performance analysis. Although the discussion below is only about a turboshaft type of an engine, a turboprop engine is also the same except for an additional reduction gear box. It is important to note that the reader is only furnished with some basic information about the engine, which is necessary to understand the logic of the performance calculations and the developed empirical method calculations presented in the next two chapters.

3.2.1 Engine Description

The engine comprises four main modules namely compressor module, gearbox module, turbine module and combustor module [13]. Air enters the engine through the compressor inlet and is compressed by one centrifugal stage (see fig. 1 and 2). A simple single stage fixed geometry impeller is used in the centrifugal compressor, which makes it less vulnerable to FOD. The compressed air is then discharged to the combustion section via two transfer tubes. Here the air enters the single combustion liner, located at the rear of the engine, through the holes in the liner dome and the skin, and is mixed with the fuel sprayed from the nozzle to support combustion [14]. The complete combustor system hardware

can be inspected by removal of the rear combustor module. The turbines are located between the combustion section and the power gear box. A two stage turbine drives the compressor and a two stage power turbine provides the output power through a gear box to the rotor. The first stage turbine is easily accessible by removing the rear combustor module for the inspection and maintenance [14]. The design layout of the Allison 250-C30 engine is a unique one. The combustor is located at the rear of the engine. The power turbine is located in between the compressor and the turbine driving the compressor. Thus, an external gear box has been mounted to get the output power from the P.T. rotor. Necessary mounting pads are provided on the gear box module and the design options of both front and rear drive are available on the module.

3.2.2 Performance and Operation Limits

Design speeds, engine operating speed limits and maximum measured gas temperature limits are presented in Table 1. Refer Table 2 and 3 for the details of the minimum guaranteed engine performance ratings at normal operation as well as at emergency operation. It is important to note from the above information that the design speeds of G.G and P.T. are 51000 and 30650 rpm respectively. During the normal cruise operation, the

G.G. will be running at 48490 rpm which is 95% of its design speed. The estimated output power for the normal cruise operation, at standard sea level static conditions is 557 H.P. [13]. Further, the definition of 90%, 75% and 60% cruise is based on the percent of the output power at the normal cruise. Hence at 90% cruise, the output power is 90% of 557 H.P. at standard sea level static conditions. It should also be noted that the output shaft and the P.T. rotor has a fixed gear ratio of 1:5 and the design speed of the output shaft is 6016 rpm. Guaranteed performance ratings for Ground Idle, Flight Autorotation and Cruise are also presented in Table 2.

3.2.3 Accessories and Mountings

Many accessory mounting pads are furnished on the engine, and the drive is provided by either the power turbine gear train or the gas generator gear train. Some spare drives are also provided to take care of special requirements of a specific customer. These accessories play an important role in the performance calculations as they influence the values of the performance parameters of the engine. Thus, the details about the accessories design layout are presented below.

The power turbine drives a spare pad for aircraft

use, a pad for an aircraft furnished tachometer generator and a pad for engine furnished power turbine governor. The gas generator gear train drives the fuel pump, gas generator fuel control and internally mounted pressure and scavenge pumps. The gas generator also drives a starter generator, a spare pad and a tachometer-generator which are aircraft furnished.

Another important accessory which affects the engine power is the anti-icing system. The anti-icing of the compressor inlet is provided by hot air bled from the compressor discharge. The hot air is metered by an orifice in the air bleed manifold, and is piped forward to the inlet section. On-Off control is provided by an electrically operated valve actuated by a switch in the aircraft. The Allison 250-C30 anti-icing system is capable of anti-icing within 15 seconds if the selection is made within 15 seconds after detection of icing [14].

Typical engine instrumentation gauges are shown in figures 3, 4 and 5. The operating range of an engine is generally shown on these gauges using a standard color code. It is advisable to note the reading accuracy of these gauges, as these values are required to be compared with the nominal values of the engine performance parameters, which are needed to diagnose the engine health. The output power is measured as the percentage

of the maximum continuous torque. The maximum continuous torque limit for the Allison 250-C30 engine is 590 lb-ft. Each division on the torque meter gauge is 2% of 590 lb-ft (figure # 3). The inter-turbine temperature gauge (figure # 5) has a smallest division of 10°C, while on the fuel flow gauge (figure # 5), the smallest division is of 10 lbs/hr. Thus, it is clear that there is a limitation on the reading accuracy of performance parameters from these instrument gauges. This factor has to be taken into account while developing an EHM method.

3.3 Applications and Problem Areas

General applications and the problem areas of helicopters are discussed in detail in Chapter 2. It is known that most of the problems such as FOD, compressor fouling, salt deposition, and hot corrosion are due to the particular operating environment.

Allison 250-C30 engines face the above problems when operating in a hostile environment. The manufacturer has guaranteed the performance of the engine in a dusty atmosphere and tests have shown that if the sand and the dust concentration is about 0.0015 gm per cubic foot then the power loss over a period of 10 hours is not more than 5% and the increase in fuel flow is also about the same

[15]. An electrical signal is also provided to give an indication of metallic particles in the oil system.

A rapid deterioration of an engine can occur in a hostile environment. To diagnose the engine degradation, the thermodynamic performance of an engine has to be closely watched. All deviations in engine parameters, from their unique baseline curves are to be studied. To locate a problem area, an EHM method has to be developed. As the problems faced by helicopters are severe, there is an urgent need for an EHM method. The EHM method has to be simple and suitable for field use, and should function with the standard instruments on the engine.

In the next chapter, the author has presented the manufacturer's method of performance calculation. The requirement for the use of many empirical factors in the manufacturer's performance analysis is also studied in detail.

CHAPTER 4

ENGINE PERFORMANCE

4.1 Performance Calculations

To operate an engine safely, it is necessary to operate it within the design limits. It is also necessary to ensure that each component is operating at the expected efficiency level, and any problem has to be diagnosed and rectified before any serious damage is done. These objectives can be achieved by measuring some prime parameters of an engine, and comparing them with their nominal values. This would help to diagnose the degradation of an engine. The method used by the manufacturer to calculate these nominal values of the engine performance parameters, which are to be compared with the cockpit instrumentation values, is discussed in the next sub-section.

4.1.1 Manufacturer's Method

The manufacturer has recommended an extensive method for the performance calculation of the engine which has been given in detail in Appendix A. The reader should refer to fig. 2 for the station numbering used, and the

nomenclature for the significance of the symbols used in the performance analysis. All the performance calculation figures have been taken from the manufacturer's model specification C868-E (15), and only necessary figures have been included in Appendix A. The logic of the calculation method is discussed below.

The method suggested by the manufacturer is capable of calculating power, inter-turbine temperature, fuel flow rate, air flow rate, compressor delivery temperature and compressor delivery pressure. These parameters can be calculated at various G.G. speeds, altitudes and aircraft velocities. Many empirical factors are incorporated in this analysis to improve the accuracy of the results.

The performance calculations are performed initially knowing the aircraft velocity, altitude and ambient conditions, for the specified engine inlet temperature and pressure. Then for given values of G.G. and P.T. speeds, the calculations are performed for corrected speeds. The manufacturer has provided graphs for corrected power, corrected inter-turbine temperature, corrected fuel flow, corrected air flow, corrected compressor delivery temperature and corrected compressor delivery pressure (Appendix A, figures 59 to 64). These performance parameters are obtained from these graphs for

the calculated value of corrected G.G. speed: The basis of the above graphs is presumably intensive experiments on the engine on fully instrumented test beds. Many correction factors have been applied to these corrected nominal values of the performance parameters. These factors are to be taken from the respective graphs provided by the manufacturer (Appendix A, figures 65 to 82). As a result of these empirical correction factors, various operating effects, such as power extraction from G.G. and P.T., bleed air, or anti-icing are taken into account during the calculation of each parameter. These factors however, complicate the formulae, and many figures have to be considered for the proper selection of these factors. The equations to be used for the performance calculation of each parameter are presented in the next sub-section along with the details about the incorporated empirical factors.

4.1.2 Empirical Factors

Empirical factors are incorporated in the performance calculations to take into account the variation of T_{am} , P_{am} , bleed air effect, power extraction from P.T. and G.G., anti-icing system effect etc. All these factors influence the values of performance parameters, and thus are to be taken into account during

the calculations. Before an attempt is made to develop a simplified method for the performance calculations, the effect of each of these empirical factors on the performance parameters has to be thoroughly understood.

The manufacturer's performance calculation method is capable of calculating six main performance parameters. Information is presented below about the empirical factors incorporated in the calculations of each performance parameter along with the equation to be used. The effect of the ambient conditions on these parameters is also discussed in detail. The reader should refer to the respective equation, to get an overall idea of the mathematical significance of each factor, in the performance evaluation of an engine.

1) Equation and Empirical Factors Used in the SHP Calculations

$$SHP = \left[\delta' \sqrt{\theta} C_1 \left(\frac{SHP}{\delta' \sqrt{\theta} C_1} + \left(\frac{\Delta SHP}{\delta' \sqrt{\theta} C_1} \right)_{RPM_1} + \left(\frac{\Delta SHP}{\delta' \sqrt{\theta} C_1} \right)_{RPR_1} \right) \times \right. \\ \left. \left(1 + C_{d1} \left(\frac{\Delta P_{t2}}{P_{t2}} + \frac{\Delta P_{e7}}{P_{e7}} \right) - \left(\frac{\Delta P_{t2}}{P_{t2}} \right) + C_{u1} \left(\frac{\%W_M}{100} \right) \right) \right. \\ \left. + C_{hp1} (HP_{es(G.G.)} - HP_{es(P.T.)} \right] (C_{di1}) \quad (1)$$

(i)

$$\left(\frac{\Delta SHP}{\delta' \sqrt{\theta} C_1} \right)_{RPM_1}$$

This is a power turbine speed correction increment for the SHP. This factor is equal to 0.0 if the P.T. is

running at the design speed (30650 rpm) (Appendix A, fig.68). If for a constant corrected speed of G.G., the P.T. speed varies from its design speed, then it affects the corrected output power. This correction is made by incorporating the above factor. The value of the correction factor varies with the corrected G.G. speed and corrected P.T. speed. Thus, this factor is not independent of the ambient conditions.

$$(ii) \quad \left(\frac{\Delta SHP}{\delta \sqrt{\theta} C_1} \right)_{RPR}$$

This is an ideal ram pressure ratio (RPR') correction increment for SHP. RPR' is equal to 1.0 at the engine static condition, and varies with T_{am} , and aircraft speed (Appendix A, fig. 81). The value of the above increment is 0.0, at the static condition of an engine (Appendix A, fig. 71). If the RPR' is greater than one, then the RPR' correction increment has a +ve value and the value varies with the corrected G.G. speed.

$$(iii) \quad C_{d_1} \left(\frac{\Delta P_{t_2}}{P_{t_2}} + \frac{\Delta P_{e_2}}{P_{am}} \right)$$

This is a ram pressure loss correction factor for SHP. The intake and exhaust losses tend to lower the ram pressure ratio, and thus the output power, and the above factor is incorporated to take into account this effect.

It is observed that the loss of power due to this factor is high at low corrected G.G. speeds (Appendix A, fig. 74). This factor varies with corrected G.G. speed and ram pressure ratio (RPR'). At a constant G.G. speed, the power loss due to this factor increases with increase in RPR'.

$$(iv) \quad \left(\frac{\Delta P_{t_2}}{P_{t_2}} \right)$$

This factor is a constant for a given aircraft speed and ambient conditions. If the aircraft is static, then the factor is independent of T_{am} . This factor incorporates the intake loss effect on SHP and is dependent on the intake duct efficiency.

$$(v) \quad C_M \left(\frac{\%W_M}{100} \right)$$

This is a bleed correction factor for SHP (Appendix A, fig. 74). Air is bled from the compressor delivery to run the aircraft accessories. As a result of the bleed air, the mass flow rate flowing through the turbine is reduced. Thus the effect of this factor is to reduce the output power. It should be noted that the value of the factor varies with the corrected G.G. speed.

(vi) $C_{hp_1}(HP_{ss}(G.G.))$

This is a G.G. power extraction correction for SHP (Appendix A, fig. 74). Power is extracted from the G.G. to run the accessories. As a result, more fuel is sprayed to compensate for the loss of power, and maintain a constant G.G. speed. The output power is thus increased, as the engine operates at a higher value of ITT due to the increased fuel flow. As the corrected speed of G.G. increases, this correction factor also increases for a constant corrected speed of P.T. The power increase due to this factor depends on the power extracted from G.G. to run the accessories.

(vii) $HP_{ss}(P.T.)$

This is the P.T. power extraction correction factor for SHP. It is a constant for a given value of the power extracted from the P.T. to run the accessories, and reduce the output power of the engine.

(viii) (C_{ai})

This is the anti-icing correction factor for SHP, and is equal to 1.0 if the anti-icing device is off and 0.985 if it is on. The result of turning on the

anti-icing system is to reduce the air flow rate through turbines, thus reducing SHP.

2] Equation and Empirical Factors Used in the ITT Calculations

$$T_{t_2} = \left[\theta C_2 \left(\frac{T_{t_2}}{\theta C_2} + \left(\frac{\Delta T_{t_2}}{\theta C_2} \right)_{RPM_2} + \left(\frac{\Delta T_{t_2}}{\theta C_2} \right)_{RPR_2} \right) \times \right. \\ \left. \left(1 + C_{d_2} \left(\frac{\Delta P_{t_2}}{P_{t_2}} + \frac{\Delta P_{s_2}}{P_{s_2}} \right) + C_{bt_2} \left(\frac{\%W_{bt}}{100} \right) + C_{hp_2} \left(\frac{HP_{s_2}(G.G.)}{\delta \sqrt{\theta}} \right) \right) \right] (C_{at_2}) - 459.67 \quad (2)$$

(i) $\left(\frac{\Delta T_{t_2}}{\theta C_2} \right)_{RPM_2}$

This is a gas generator turbine outlet temperature correction increment, for the effect of P.T. speed (Appendix A, fig. 69). The value of this increment is 0.0 if the P.T. is running at the design speed. If the P.T. speed is higher than the design speed, then the factor reduces the ITT, and if the P.T. speed is lower than the design speed, then the factor increases the ITT. The value of this increment also varies with the corrected G.G. speed.

(ii) $\left(\frac{\Delta T_{t_2}}{\theta C_2} \right)_{RPR_2}$

This is an RPR' correction increment for ITT. For RPR'=1, i.e. at the static condition of an aircraft, this

increment is 0.0 (Appendix A, fig. 72). The value of the increment varies with the aircraft velocity, T_{am} and the corrected G.G. speed. This factor takes into account the variation in the RPR', and its effect on the ITT.

$$(iii) \quad C_{d_1} \left(\frac{\Delta P_{t_1}}{P_{t_1}} + \frac{\Delta P_{e_1}}{P_{am}} \right)$$

This is a ram pressure loss correction for ITT (Appendix A, fig. 76). There are losses in the intake and exhaust ducts and these losses reduce the ram pressure ratio. As a result of this, there is a change in ITT. The factor incorporates this change in the ITT value. The value of this factor varies with the corrected G.G. speed, P_{am} and duct losses.

$$(iv) \quad C_{b_1} \left(\frac{\%W_M}{100} \right)$$

This is a bleed correction for ITT (Appendix A, fig. 76). At low corrected G.G. speeds, this factor has a high value. Bleed air tends to increase the ITT as the loss of air flow rate is compensated by pumping in more fuel.

$$(v) \quad C_{h_p} \left(\frac{HP_{G.G.}}{\delta \sqrt{\theta}} \right)$$

This is a G.G. power extraction factor for ITT (Appendix A, fig. 76). At low corrected G.G. speeds, this

factor has high value. If some power is extracted from the G.G., then more fuel is sprayed to maintain the G.G. speed. This results in higher fuel flow, thus higher ITT. It should be noted from the equation that power extraction from the P.T. does not have any effect on ITT.

(vi)

(C_{ai_2})

This is a anti-icing factor for ITT. If the anti-icing system is on, the air is bled from the compressor discharge. As a result, air flow rate is reduced, and thus the output power. This causes higher fuel flow and higher ITT, to compensate for the power loss.

3] Equation and Empirical Factors Used in the Fuel Flow Calculations

$$W_f = \left[\delta' \sqrt{\theta} C_3 \left(\frac{W_f}{\delta' \sqrt{\theta} C_3} + \left(\frac{\Delta W_f}{\delta' \sqrt{\theta} C_3} \right)_{RPM_s} + \left(\frac{\Delta W_f}{\delta' \sqrt{\theta} C_3} \right)_{RPR_s} \right) \times \right. \\ \left. \left(1 + C_{d_2} \left(\frac{\Delta P_{t_2}}{P_{t_2}} + \frac{\Delta P_{er}}{P_{am}} \right) - \left(\frac{\Delta P_{t_2}}{P_{t_2}} \right) + C_{d_3} \left(\frac{\% W_M}{100} \right) \right. \right. \\ \left. \left. + C_{hp_2} \left(\frac{HP_{ex(G.G.)}}{\delta \sqrt{\theta}} \right) \right) \right] (C_{ai_2}) \quad (3)$$

(i)

$$\left(\frac{\Delta W_f}{\delta' \sqrt{\theta} C_3} \right)_{RPM_s}$$

This is a power turbine speed correction increment for the fuel flow (Appendix A, fig 70). This factor is

0.0 if the P.T. is running at the design speed (30650 rpm). This increment varies with the corrected G.G. and P.T. speeds. If the corrected P.T. speed is lower than the design speed, then the factor increases the fuel flow, and if the P.T. speed is higher than the design speed, then the factor reduces the fuel flow.

$$(ii) \quad \left(\frac{\Delta W_f}{\delta' \sqrt{\theta} C_3} \right)_{RPR}$$

This is an RPR' correction increment for fuel flow (Appendix A, fig. 73). This increment is 0.0 if the engine is at a static condition (i.e. at RPR'=1). As RPR' varies with Tam and aircraft speed, this increment is also dependent on these variables. For the values of RPR' more than one, the increment reduces the fuel flow value as it has a -ve value.

$$(iii) \quad C_d \left(\frac{\Delta P_{t_2}}{P_{t_2}} + \frac{\Delta P_{e_2}}{P_{e_2}} \right)$$

This is a ram pressure loss correction factor for fuel flow (Appendix A, fig. 75). Due to the losses in the intake and exhaust duct, there is a loss in the ram pressure ratio. This effect is taken into consideration by the above factor. This factor also varies with the corrected G.G. speeds, and has a high value at low G.G. speed.

$$(iv) \quad \left(\frac{\Delta P_{t_2}}{P_{t_1}} \right)$$

This is a constant for a given aircraft speed, T_{am} and P_{am} . The intake losses are taken into account by this factor and it is dependent on the intake duct efficiency.

$$(v) \quad C_{M_2} \left(\frac{\%W_M}{100} \right)$$

This is a bleed air correction factor for fuel flow (Appendix A, fig. 75). This varies with % bleed air and corrected G.G. speed. At low G.G. speeds, this factor has a high +ve value. Thus the fuel flow is increased as a result of the bleed air. Of course, this can be explained by the fact that the loss of power due to the bleed air is compensated by increasing the fuel flow.

$$(vi) \quad C_{hp} \left(\frac{HP_{ex(G.G.)}}{\delta \sqrt{\theta}} \right)$$

This is a G.G. power extraction correction for the fuel flow (Appendix A, fig. 75). This factor varies with the power extracted from the G.G. and the corrected G.G. speed. At low G.G. speeds, the value of this factor is high. Overall effect of this factor is to increase the fuel flow.

(vii) (C_{ai})

This is an anti-icing factor for the fuel flow. The value of the factor is equal to 1.0 if the anti-icing system is off, and 1.02 if the system is on. The anti-icing system reduces the air flow rate through the turbine. This causes the drop in the output power. Thus the fuel flow is increased to compensate the loss in the output power.

4) Equation and Empirical Factors Used in the Air Flow Rate Calculations

$$W_a = \left[\frac{\delta'}{\sqrt{\theta}} \left(\frac{W_a}{\delta'} \right) \right] \left(1 + C_{d_i} \left(\frac{\Delta P_{t_2}}{P_{t_2}} + \frac{\Delta P_{t_7}}{P_{a_m}} \right) - \left(\frac{\Delta P_{t_2}}{P_{t_2}} \right) + C_{b_i} \left(\frac{\%W_{bi}}{100} \right) + C_{h_p} \left(\frac{HP_{ex(G.G.)}}{\delta \sqrt{\theta}} \right) \right) \right] (C_{ai}) \quad (4)$$

(i)

$$C_{d_i} \left(\frac{\Delta P_{t_2}}{P_{t_2}} + \frac{\Delta P_{t_7}}{P_{a_m}} \right)$$

This is a factor which takes into account the effect of ram pressure loss on the air flow rate (Appendix A, fig. 77). There is a loss in the ram pressure due to the losses in the intake and exhaust ducts. This loss causes the air flow to decrease by some amount. The amount by which the air flow is decreased, depends upon the corrected G.G. speed.

$$(ii) \quad \left(\frac{\Delta P_{t_2}}{P_{t_2}} \right)$$

This factor remains constant for a given aircraft speed, T_{am} and P_{am} conditions. Knowing the T_{am} and the aircraft speed, RPR' can be determined. The above factor can be calculated from the RPR' if the duct efficiency is known.

$$(iii) \quad C_{M_s} \left(\frac{\%W_M}{100} \right)$$

This is a bleed air correction factor for the air flow rate, and it varies with the corrected G.G. speed and the bleed (Appendix A, fig. 78). This factor increases the air flow rate and this increase varies with the corrected G.G. speed.

$$(iv) \quad C_{hp_s} \left(\frac{HP_{ex(G.G.)}}{\delta \sqrt{\theta}} \right)$$

This is a G.G. power extraction correction factor for the air flow rate (Appendix A, fig. 78). This factor is mainly dependent on the power extracted from G.G. and the corrected G.G. speed. The effect of this factor is to reduce the air flow rate. But the reduction in the air flow is almost negligible, as the value of the factor is very low.

(v) (C_{ai})

This is an anti-icing factor for the air flow rate. If the anti-icing system is on, this factor reduces the air flow rate by about 3%. Thus the amount of air bled for anti-icing is 3% of the total flow rate. The value of this factor is 1.0, if the anti-icing system is off.

5] Equation and Empirical Factors Used in the Compressor Delivery Temperature Calculations

$$T_{t_3} = \left[\theta \left(\frac{T_{t_2}}{\theta} \right) \left(1 + C_{d_1} \left(\frac{\Delta P_{t_2}}{P_{t_2}} + \frac{\Delta P_{s_2}}{P_{am}} \right) + C_{bl_2} \left(\frac{\%W_{bl}}{100} \right) + C_{hps} \left(\frac{HP_{ss}(G.G.)}{\delta \sqrt{\theta}} \right) \right) \right] (C_{ai}) - 459.67 \quad (5)$$

(i)

$$C_{d_1} \left(\frac{\Delta P_{t_2}}{P_{t_2}} + \frac{\Delta P_{s_2}}{P_{am}} \right)$$

This is a ram pressure loss correction factor for the compressor delivery temperature (CDT) (Appendix A, fig. 79). This factor depends on RPR', Pam, inlet duct efficiency and the corrected G.G. speed. The effect of this factor is to increase the CDT, but if the G.G. speed is below 65%, then this factor does not have any effect on CDT.

(ii)

$$C_{bl} \left(\frac{\%W_M}{100} \right)$$

This is a bleed air correction factor for CDT (Appendix A, fig. 79). This factor varies with the corrected G.G. speed and the % bleed air. The effect of this factor is to reduce CDT if the % corrected G.G. speed is above 50% of the design value. Below 50% G.G. speed, this factor does not affect the CDT value.

(iii)

$$C_{hp} \left(\frac{HP_{ex}(G.G.)}{\delta \sqrt{\theta}} \right)$$

This is a G.G. power extraction correction factor for CDT (Appendix A, fig. 79). Its value varies with the corrected G.G. speed and the extracted power from the G.G. This factor increases the CDT only if the corrected G.G. speed is between 55% and 112.5%.

(iv)

$$(C_{ais})$$

This is an anti-icing factor for CDT and is equal to 1.01 if the anti-icing system is on. Thus the CDT is increased by 1% if the anti-icing is on. This factor is equal to 1.0 if the anti-icing system is off. When the anti-icing system is on, the hot air from the compressor delivery is used to heat the intake duct and the guide vanes. This causes the increase in the CDT value.

6] Empirical Factors Used in the Compressor Delivery Pressure Calculations

$$P_{t_2} = \left[\delta \left(\frac{P_{t_2}}{\delta} \right) \left(1 + C_{d_1} \left(\frac{\Delta P_{t_1}}{P_{t_1}} + \frac{\Delta P_{e_1}}{P_{a_1}} \right) - \left(\frac{\Delta P_{t_2}}{P_{t_1}} \right) + C_{M_1} \left(\frac{\%W_M}{100} \right) + C_{A_1} \left(\frac{HP_{a_1}(G.G.)}{\delta \sqrt{\theta}} \right) \right] (C_{a_1}) \quad (6)$$

(i)

$$C_{d_1} \left(\frac{\Delta P_{t_1}}{P_{t_1}} + \frac{\Delta P_{e_1}}{P_{a_1}} \right)$$

This is a ram pressure loss correction factor for the compressor delivery pressure (CDP) (Appendix A, fig. 78). There is a loss in the ram pressure due to the losses in the intake and exhaust ducts. This factor incorporates this effect and as a result, there is an increase in CDP. This increase in CDP, varies with the corrected G.G. speed.

(ii)

$$\left(\frac{\Delta P_{t_1}}{P_{t_1}} \right)$$

This factor is a constant for a given aircraft speed, and Tam and Pam conditions. The duct efficiency has to be known to calculate this factor. The effect of this factor is to reduce the CDP value.

(iii)

$$C_{M_1} \left(\frac{\%W_M}{100} \right)$$

This is a bleed air correction factor for CDP

(Appendix A, fig. 78). This factor varies with the bleed air and the corrected G.G. speed. The effect of this factor is to reduce the CDP.

$$(iv) \quad C_{hp} \left(\frac{HP_{G.G.}}{\delta \sqrt{\theta}} \right)$$

This is a G.G. power extraction factor for CDP (Appendix A, fig. 78). This factor varies with the corrected G.G. speed and the power extracted from the G.G. At low G.G. speed, this factor has a high value. The effect of this factor is to increase the CDP.

$$(v) \quad (C_{ai})$$

This is an anti-icing factor for CDP. It is equal to 1.0 if the anti-icing system is off. If the anti-icing system is on, this factor reduces the CDP by about 2%. Thus the value of the factor is .98 if the system is on.

The above description of the empirical factors used in the performance analysis, has given an idea of their complex nature, and significance in the performance analysis.

4.2 Comments

The method recommended by the manufacturer can evaluate the performance parameters accurately. But it is impractical to expect an operator to do rigorous calculations in forward operating areas or in field due to many practical limitations. Similarly, a computer facility may not be available for these intensive calculations. In particular, it should be realized that the difficulties of reading the gauges to a high degree of accuracy makes the use of many factors rather dubious. Thus it is useful to investigate the actual effect of all the empirical factors incorporated by the manufacturer in the performance calculation, and verify the possibility of developing a simple method for the field use. In the next chapter, the performance parameters will be evaluated at various operating conditions, and an attempt will be made to simplify the analysis procedure.

CHAPTER 5

DEVELOPMENT OF AN EMPIRICAL METHOD

5.1 Engine Performance

The engine performance evaluation method, as suggested by the manufacturer, was discussed in detail in Chapter 4. Helicopters are required to operate over a wide range of ambient conditions. Ambient temperatures can be very high when operating in a desert, whereas these could be well below the freezing point when operating in cold regions such as the Arctic. Similarly, the load on the engine will vary with time, depending upon the nature of the operation. An engine might need to operate from emergency operating conditions to flight autorotation conditions.

It is essential to monitor an engine's health, in order to ensure its operational reliability. Thus, the parameters displayed on the engine instrument gauges must be compared with their nominal values. These nominal values are to be calculated from the manufacturer's method of performance calculations, at the given operating condition of the engine. Before an attempt is made to develop a simple performance calculation method, the manufacturer's performance calculation method at

various operating conditions must be thoroughly understood. Thus, it becomes essential to understand the variation of the empirical factors used by the manufacturer, over a wide range of operating conditions. This would help to explore the numerical significance or, and influence of these empirical factors on the nominal values, at various operating conditions. This would also provide a base for a simple method to be developed for the performance evaluation.

5.1.1 Performance at Various Settings

The most reasonable range of the ambient operating temperatures for helicopters is from 30° C in summer to -20° C in winter. On a very hot or cold day, the ambient temperatures can be out of this temperature range, but this range covers most of the operating period of a helicopter during a year. Thus, it has been decided to perform the performance calculations in the above range. To explore the numerical significance of the empirical factors, the performance calculations are to be done at minimum three ambient temperatures. The chosen temperatures should also represent the complete operating temperature range. Thus, 30° C, 15° C and -20° C are the three chosen temperature conditions, for performance

calculations. At each of the above temperatures, the calculations are performed for three different power settings. The power settings chosen are i) 60% cruise, ii) normal cruise and iii) takeoff power. These chosen power conditions cover a wide range of the operating load conditions of any helicopter operation. To understand the effect of an anti-icing system on engine performance, the calculations are done for both 'ON' and 'OFF' conditions of the anti-icing system. As a result, eighteen conditions are evaluated in order to fully analyze the effect of all the empirical factors on the performance calculations. The calculation procedure is exactly the same as the one explained in Chapter 4. Detailed step by step calculations are not presented along with this report for the eighteen conditions mentioned above, but the final nominal values of the performance calculations are presented in Tables 4 to 9. These tables also present the empirical method program values of the parameters, and the details about this method are discussed later in the Chapter. Figures 6 to 23 show the variation of the performance parameters with T_{amb} , for the chosen power settings. These figures also show the curves for the simplified and the empirical methods. These methods are discussed in detail in the later part of the chapter. The assumptions made in the performance analysis are presented below.

- i) Engine is at a static condition
- ii) P.T. is running at the design speed.
- iii) Intake duct efficiency is 0.98 (manufacturer's value)
- iv) Power extraction from G.G. and P.T. is 3 H.P. and 10 H.P. respectively (manufacturer's assumption).
- v) Ambient pressure is constant for all conditions and is 29.921 in. Hg Abs.
- vi) Bleed air is 1.5% of the engine air flow rate.

These assumptions have helped the author to eliminate the effect of some of the empirical factors, highlighting the significance of the other empirical factors.

5.1.2 Applications of Simple Formulae

The following simple formulae are used to explore the effect of empirical factors on performance analysis. These formulae are obtained by dropping all correction factors in equations 1 to 6. The manufacturer has provided graphs for all corrected health parameters such as $\left(\frac{SHP}{\delta'\sqrt{\theta}C_1}\right)$, $\left(\frac{T_{t_2}}{\theta C_2}\right)$ etc. If the anti-icing system is 'ON', the anti-icing factors recommended by the manufacturer should be used as additional multiplication factors, with the following formulae.

$$SHP = \delta'\sqrt{\theta}C_1 \left(\frac{SHP}{\delta'\sqrt{\theta}C_1} \right) \quad (7)$$

$$T_{1s} = \left[\theta C_2 \left(\frac{T_{1s}}{\theta C_2} \right) - 459.67 \right] \quad (8)$$

$$W_f = \delta' \sqrt{\theta} C_3 \left(\frac{W_f}{\delta' \sqrt{\theta} C_3} \right) \quad (9)$$

$$W_s = \frac{\delta'}{\sqrt{\theta}} \left(\frac{W_s}{\frac{\delta'}{\sqrt{\theta}}} \right) \quad (10)$$

$$T_{1s} = \theta \left(\frac{T_{1s}}{\theta} \right) - 459.67 \quad (11)$$

$$P_{1s} = \delta' \left(\frac{P_{1s}}{\delta'} \right) \quad (12)$$

The values obtained using these simplified formulae, are to be compared with the nominal values obtained from the manufacturer's performance calculations. Figures 6 to 23 show the curves drawn using the above simplified performance formulae values. Thus a comparison can be made with the values obtained from the manufacturer's method. The following observations are made from these curves.

- i) Use of simple formulae results in a shift of the original curve for all parameters except CDT. CDT

remained unchanged, using the simplified formula.

- ii) At any temperature, the amount of shift from the the original curve is almost constant for a particular parameter.
- iii) The amount of shift varies with the power settings of the engine.

Following these observations, an attempt is made to shift these curves back to their original position using an empirical approach. This would then give the performance parameters values close to the values obtained from the manufacturer's method. The procedure adopted is explained below.

5.2 Empirical Approach

To shift the simplified method performance curves shown in figures 6 to 23 back towards the original curves obtained by the manufacturer's method, the percent error observed in the value of each parameter has to be thoroughly studied. An average percent error can be evaluated, knowing the actual error between the two methods at each operating condition. This mean error can be used as an empirical multiplication factor with the proposed simple formulae for the performance evaluation. If these new formulae with the empirical multiplication

factor are used for performance evaluation, the values obtained would certainly be close to the manufacturer's values. As an average error will be taken as a multiplication factor, there will be some difference between the manufacturer's value and the values given by the empirical method. This error has to be studied from the point of view of its actual significance.

5.2.1 Empirical Method

Each performance parameter is evaluated for eighteen different conditions, using both the manufacturer's method and simple formulae method (equations 7 to 12). The error is evaluated in each case between the values obtained from these two methods. This can lead to the evaluation of the mean error for the each performance parameter. This mean error is to be used as a multiplication factor with the simple formulae. The empirical factor evaluation is shown in Tables 10 to 15 for all performance parameters. The following empirical formulae are proposed for performance analysis, based on the above analysis of each parameter. If the anti-icing system is on, another set of formulae with anti-icing empirical factors should be used for performance analysis.

A) Anti-icing Device Off

$$SHP = \delta' \sqrt{\theta} C_1 \left(\frac{SHP}{\delta' \sqrt{\theta} C_1} \right) \times \frac{1}{1.07321} \quad (13)$$

$$T_{i_s} = \left[\theta C_2 \left(\frac{T_{i_s}}{\theta C_2} \right) - 459.67 \right] \times \frac{1}{0.9541} \quad (14)$$

$$W_f = \delta' \sqrt{\theta} C_3 \left(\frac{W_f}{\delta' \sqrt{\theta} C_3} \right) \times \frac{1}{0.97564} \quad (15)$$

$$W_a = \frac{\delta'}{\sqrt{\theta}} \left(\frac{W_a}{\frac{\delta'}{\sqrt{\theta}}} \right) \times \frac{1}{1.02092} \quad (16)$$

$$T_{i_s} = \theta \left(\frac{T_{i_s}}{\theta} \right) - 459.67 \quad (17)$$

$$P_{i_s} = \delta' \left(\frac{P_{i_s}}{\delta'} \right) \times \frac{1}{1.02148} \quad (18)$$

B) Anti-icing Device On

$$SHP = \delta' \sqrt{\theta} C_1 \left(\frac{SHP}{\delta' \sqrt{\theta} C_1} \right) \times \frac{1}{1.07327} \times C_{ai_s} \quad (19)$$

$$T_{i_s} = \left[\theta C_2 \left(\frac{T_{i_s}}{\theta C_2} \right) \times C_{ai_s} - 459.67 \right] \times \frac{1}{0.95314} \quad (20)$$

$$W_f = \delta' \sqrt{\theta} C_3 \left(\frac{W_f}{\delta' \sqrt{\theta} C_3} \right) \times \frac{1}{0.97553} \times C_{ai_s} \quad (21)$$

$$W_a = \frac{\delta'}{\sqrt{\theta}} \left(\frac{W_a}{\frac{\delta'}{\sqrt{\theta}}} \right) \times \frac{1}{1.0287} \times C_{a,i} \quad (22)$$

$$T_{i,2} = \theta \left(\frac{T_{i,2}}{\theta} \right) - 459.67 \quad (23)$$

$$P_{i,2} = \delta' \left(\frac{P_{i,2}}{\delta'} \right) \times \frac{1}{1.02145} \times C_{a,i} \quad (24)$$

The results obtained from the above empirical formulae are presented in Tables 4 to 9. The results from the empirical method are also shown graphically in figures 6 to 23.

The following observations are made from these figures. The percent error between the values given by the empirical method and the manufacturer's methods, is maximum 1.12% at normal cruise condition. The error at takeoff and 60% cruise power is of about the same order. The scatter of the values obtained from the empirical method has to be studied from the point of view of its actual physical significance in health monitoring analysis, which is discussed below.

5.2.2 Error Significance

The nominal values obtained from performance

calculations are to be compared with the engine instrumentation values. The error between each manufacturer's method parameter value and the empirical method parameter value can be easily evaluated. The significance of this error on the engine instrument gauge is to be studied. It is observed that, for all the cases mentioned in Table 4 to 9, the error between these two methods is almost insignificant on instrument gauges. For example, the fuel flow at takeoff power, on a cold day ($T_{amb} = -20^{\circ}\text{C}$), is 414.2 lb/hr, according to the manufacturer's calculations. The empirical method gives a value of 418 lb/hr at the same conditions. Thus, a % error of 0.917 is introduced according to the empirical approach. Now refer to figure 5 to read off both values from the flow meter. One can immediately realize that this error is insignificant on the instrument gauge. Similar observations are made for all parameters, and the error is found to be insignificant on the instrument gauges. Finally, the comparison is shown between the two ~~methods~~ in figures 24 to 29, for each performance parameter. Both methods are in very good agreement at all chosen operating conditions. Thus, the proposed method is suitable for carrying out performance analysis of Allison 250-C30 engines in the field with quite acceptable accuracy.

CHAPTER 6

APPLICATION OF THE EMPIRICAL METHOD

6.1 Suitability of the Method

The empirical method has many advantages over the manufacturer's method of performance analysis for use in the field. All performance parameters can be easily evaluated using the empirical method, and because of its simplicity, it is suitable for use in forward operational areas. The calculation work and the time factor associated with it is greatly reduced. Thus, more frequent comparisons of the engine dial gauge values with their nominal values are possible. This would help to keep a close watch on engine health. As a result, reliability of engine operation can be improved. Maintenance costs can be kept low, as preventive maintenance action could be taken before serious damage is done to an engine. The major maintenance problems in critical areas can be avoided by effective implementation of a health monitoring scheme. More frequent health monitoring would also explore the effects of a particular operating environment on engine performance. The empirical method can be used to evaluate the deviation of an overhauled engine from its baseline curves. As the

empirical method is very simple, an interactive software package could be developed on a pocket computer for use in field. Details of the developed software are presented in the next sub-section.

6.2 Software Development

After the empirical method was thoroughly tested for suitability and accuracy, it was decided to develop a software package. First, a software package has been developed on the Honeywell 66 system, using FORTRAN 77 as a programming language. As an advanced computer facility will not be available in forward operational areas, a program is also developed on the Radio Shack TRS-80 PC-2 pocket computer, using Basic programming language. This computer, being very compact in size, can be carried to forward operational zones, for computations using the empirical method. Simple interactive software packages are generally recommended, as these are easy to use. The details of the software design, and the instructions for using the program are discussed in the following sub-section.

6.2.1 Software Design

The main aim, while designing the software package, has been to keep it as simple as possible. An interactive type of software package is very easy to use, as very little information is required concerning the program structure. In an interactive software package, the data is entered by answering simple questions asked by the computer. Thus, a person having no knowledge of computers can run an interactive program.

The first interactive software was developed on the Honeywell 66 system. This package can be adopted by any system supporting FORTRAN 77 language. The logic of complete software is presented in the flow chart (Appendix B). The hard copy of the program is presented in Appendix C, along with a sample run file. While using this package, the user is required to chose appropriate values of C1, C2, and C3 from the figures provided by the manufacturer, with the model specifications C868-E(15). The second package is mainly developed for use in field, where an advanced computer facility is not available. This package has a subroutine to evaluate C1, C2 and C3 at the given running condition. Thus, no aid of any figures is required to run this program. The software is compatible with the Radio Shack TRS-80 model PC-2 pocket

computer. Figure 30 shows the computer unit with the printer and cassette interface. The program can be stored on a C-20 cassette, and can be loaded back to the computer through a cassette interface. The complete software and output file is presented in Appendix C. The program is capable of evaluating all the six performance parameters, but only three are printed on the output file, as the others are not generally measured on an engine. To run the program, the software has to be loaded into the Pocket Computer through the cassette interface. This operation can be done at the main base. The 'RUN' mode has to be chosen on the computer to execute the program. The next step is to give a 'RUN' instruction to the computer, and answer all the questions. The total time required to feed in the data and get an output on PC-2 printer is about 4 to 5 minutes. The hard copy of the output data can be very useful for engine performance record keeping and this could help in analyzing the engine behaviour at base. There is an option of choosing 'ON' or 'OFF' condition of anti-icing system on both software packages.

6.2.2 Computer Requirements

The following accessories are required with the

basic computer unit:

- i) Radio Shack TRS-80 pocket computer model PC-2,
- ii) 8K memory module,
- iii) PC-2 Printer cum cassette interface,
- iv) Plotter pens and printer paper,
- v) Tape recorder (for program loading only), and
- vi) C-20 computer cassette (for software storage only)

The total cost of the above unit with accessories is about \$ 1100. The unit is very compact, and weighs about 2.5 kg with a carrying case about the size of a small brief case. Thus, it can be easily carried to forward operational areas, and used in_flight if required.

The software developed in FORTRAN 77 is compatible with the Honeywell 66 system. Both packages can be modified to suit the requirements of a particular customer.

6.2.3 Limitations of the Empirical Method

There are some limitations to the empirical method approach suggested by the author. The user is expected to understand the assumptions made in the development of the method. The empirical method has to be applied after these assumptions are satisfied. The two main

assumptions are;

- i) Engine should be at static conditions
- ii) Power turbine should be running at the design speed.

Thus, this method can evaluate the engine performance at static condition on the ground only. At steady state running condition, the power turbine speed is automatically maintained at the design value by the governor system. Hence the user should ensure that the engine is running at steady state, before performance parameters are read off instrument gauges. Other assumptions are;

- i) Percent bleed air for accessories is 1.5%
- ii) Power extracted from G.G. and P.T. is 3 H.P. and 10 H.P. respectively.
- iii) Intake duct efficiency is 0.98

If the above three assumptions do not hold good for a particular application of an engine, the empirical factors are to be recalculated as explained in chapter 5. Once the new empirical factors are known, the respective changes should be made in the software, and then the program could be used in field.

At ambient temperatures below 15°C and G.G. speed below 88%, the acceleration bleed is automatically turned 'ON'. As a result, the values of the performance

parameters are changed. At present, the software does not have capability to evaluate the performance if the acceleration bleed is on, but with more research in that area, one can easily develop the capability to take into account the acceleration bleed, and modify the software accordingly. It is important to note that at a G.G. speed below 88%, the power setting is lower than 60% cruise. It is not desirable to check the engine performance at power settings below 60% cruise, as the data would show high scatter if recorded over a wide range of power settings [21]. It should also be noted that the manufacturer's method has to be used to evaluate engine performance after an overhaul operation. If the empirical method has to be used to analyze the engine performance at 100 Knots forward speed, 1000 ft altitude and at normal cruise condition, the errors observed in the health parameters are not significant. As the operating speed and altitude of helicopters is low in comparison with air-line operation, the ram pressure effect does not have a significant effect on health parameters. The results obtained at 100 Knots speed are presented in tables 17 and 18. The values of ITT and fuel flow do not change significantly, and the main effect is on SHP but is still not really significant. Thus, the empirical method would be certainly adequate for use at cruise conditions.

CHAPTER 7

APPLICATION TO HEALTH MONITORING

7.1 Discussion

Some basic constraints are to be considered in the development of an EHM scheme for helicopters. The first constraint is that the EHM method must be able to function with existing instrumentation on an engine. The second constraint is that the EHM method must be simple to use. The following engine parameters are measured on Allison 250-C30 engines;

- i) Gas generator speed,
- ii) Output power,
- iii) Inter-turbine temperature,
- iv) Fuel flow, and
- v) Power turbine speed.

With the limited instrumentation installed, a Gas Path Analysis technique cannot be developed. Therefore, Trend Analysis has to be used for EHM. The Trend Analysis is a simple method, and can provide sufficient information or early warning about the deterioration of engine health. The logic of Trend Analysis is that healthy gas turbine engines must follow their unique

corrected baseline curves under steady state conditions. Thus, any specific engine cannot vary extensively from its baseline curves, unless a malfunction forces it to do so. A comparison can be made between the instrument gauge values and the nominal values for each performance parameter. Whenever such a comparison is to be made, the nominal values are to be evaluated at that particular running condition. Now, the nominal values can be easily evaluated using the developed empirical method, but this requires doing some calculations and going through a group of performance curves. This is a cumbersome process, especially in forward operational zones, and is not acceptable to the user. Thus, the developed computer program can be used for evaluating the nominal values. As the Radio Shack PC-2 computer is portable and compact, it is suitable for use in remote areas, and this simplifies Trend Analysis to a great extent.

The data collection procedure simply requires that all engine parameters, ambient pressure, and ambient temperature be recorded once after each flight mission. It is also required that all engine parameters be recorded with G.G. speed above 88%, to ensure that the acceleration bleed port is closed as it would falsely give an indication of poor engine performance when it is open. The engine should be at static conditions, and P.T. speed should be at design value, at the time of data

recording. This data can then be used with the nominal values to get trend plots of each performance parameters. These trend plots indicate the difference between the nominal values and the engine instrument values over a period of time. Experience by Coast Guard on Air Cushion Vehicles has shown that EHM of gas turbines can be done satisfactorily with the aid of standard gauge readings.[5] Finally, with the aid of a fault diagnosis matrix, the gross overall thermodynamic health of an engine can be determined using a simple logical approach.

7.2 Logical Fault Detection

After Trend Analysis is done, the next important step is to take a decision about the engine's health. Thus, the results obtained from Trend Analysis are to be analyzed with the aid of a fault matrix. The percent deviation of each performance parameter has to be taken into account while applying the fault matrix. If there is a vibration problem with an engine, it should be considered during the analysis. Table #16 presents a typical fault matrix to be used for fault diagnosis of turboshaft engines (10). The fault matrix gives a list of probable faults in a gas turbine and the behaviour of each performance parameter relative to its nominal values. Thus, the comparison of the results obtained from Trend Analysis with the fault matrix could help the

user to diagnose the problem area of a degraded engine.

In the case of Allison 250-C30 engines, only three performance parameters could be used for Trend Analysis; these are power, inter-turbine temperature, and fuel flow. Thus, the fault diagnosis has to be based on the deviation analysis of these three parameters only. Appendix D presents a typical flow chart to diagnose the problem area. The EHM method presented by the author is very simple to use, and an easy acceptance of the method in the field is expected. The user can get many direct and indirect advantages by implementing such an EHM method. These advantages are listed in the next sub-section.

7.3 Advantages of EHM

The developed software package for performance evaluation of Allison C-30 engines simplifies the implementation of an EHM method. The following advantages can be obtained, if the EHM is done using the recommended software package.

- 1) As EHM becomes simple with the aid of the software package, frequent data analysis is possible.
- 2) Calculation work is totally eliminated with the aid of a pocket computer.

- 3) The computer unit being compact and portable, allows EHM to be done in remote locations.
- 4) Time and skill required for EHM is greatly reduced. Both are very important factors in forward operational zones.
- 5) Operational reliability of an engine can be improved
- 6) Safety levels can be improved.
- 7) Fault diagnosis can be done before any serious damage is done.
- 8) The maintenance cost can be kept low.
- 9) Major maintenance problems in forward areas can be avoided.
- 10) The effect of a particular environment can be explored and studied.
- 11) A course of action can be taken to eliminate or reduce particular environmental problems.
- 12) Past data can be easily analyzed.

7.4 Future Work

(i) Using the empirical method program package, further investigation should be carried out to analyze field data. This would help to decide the acceptable deviation limits of each performance parameter from its baseline value.

(ii) Once the acceptable deviation limits from the baseline values are evaluated for each performance parameter, the complete logic of the fault matrix should be programmed in a pocket computer. This would then be a very useful software, as it would not only evaluate the deviations of performance parameters, but also give an indication about fault areas.

(iii) The empirical method program should be used to compare the performance of overhauled engines with nominal values. Further investigation should be carried out to develop a method which could diagnose problems with overhauled engines which deviate from their nominal curves.

(iv) Similar empirical methods should be developed for other models of Allison 250 series engines. The method should also be applied to the turboprop versions with further investigations in that direction.

CHAPTER 8

CONCLUSIONS

1. A review of helicopter applications showed that the problems faced by helicopters are much more severe and complex than an airline operation.

2. It was shown that a real need exists for some form of Engine Health Monitoring on helicopters.

3. Allison 250 series engines are the most widely used engines for helicopters, and it was shown that the manufacturer's method of performance analysis for Allison 250-C30 engines is very complicated, and is not suitable for use in the field.

4. A simple empirical method has been developed for performance analysis of Allison 250-C30 engines.

5. The results obtained from the empirical method, at various power settings and ambient conditions, are in good agreement with the results obtained from the manufacturer's method.

6. Computer-aided performance evaluation capability has been developed, using the empirical method. An interactive software package has been developed on the

Radio Shack TRS-80 PC-2 pocket computer for the field use.

7. The Trend Analysis technique is recommended for Engine Health Monitoring of engines.

8. The proposed Engine Health Monitoring, being simple to use, would be widely accepted by both helicopter crew and maintenance personnel.

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FIGURES

Figure # 1

ADVANCED MODEL 250
TURBOSHAFT ENGINE

Figure # 2

GAS FLOW DIAGRAM

- 2. ENGINE INLET
- 3. COMPRESSOR DISCHARGE
- 4. GAS GENERATOR TURBINE INLET
- 5. GAS GENERATOR TURBINE OUTLET
- 6. POWER TURBINE DISCHARGE
- 7. ENGINE OUTLET

Figure # 3
INSTRUMENT GAUGES I

TRIPLE TACHOMETER

H_r TACHOMETER (ROTOR)

- 115% - MAXIMUM POWER OFF
- 107% TO 115% - PRECAUTIONARY RANGE
- 107% - MAXIMUM POWER ON
- 100% TO 107% - NORMAL RANGE
- 87 TO 100% - PRECAUTIONARY RANGE
- 87% - MINIMUM

H₂ TACHOMETER (ENGINE ONLY)

- 114% - MAXIMUM
- 107% TO 114% - PRECAUTIONARY RANGE
- 95% TO 107% - NORMAL RANGE

N1 TACHOMETER

- 105% - MAXIMUM
- 59% TO 105% - NORMAL RANGE
- 59% - MINIMUM

TORQUEMETER

- 111.2% - 2-1/2 MINUTE LIMIT - SINGLE ENGINE
- 104% TO 111.2% PRECAUTIONARY RANGE
- 104% - 30 MINUTE LIMIT - SINGLE ENGINE
- 100% TO 104% - PRECAUTIONARY RANGE
- 100% - TAKEOFF 5 MINUTE LIMIT DUAL ENGINE AND MAXIMUM CONTINUOUS LIMIT
- 85.3% TO 100% - ADVISORY AREA*
- 0% TO 100% - NORMAL OPERATION

* NOTE:

THE GREEN AND WHITE ARC ON THE TORQUEMETER REPRESENTS RECOMMENDATIONS OF THE ENGINE MANUFACTURER. SEE PART 2, SECTION I FOR DETAILS.

Figure # 4
INSTRUMENT GAUGES II

ENGINE OIL
TEMPERATURE/PRESSURE

- 107°C - MAXIMUM
- 0°C TO 107°C - NORMAL RANGE
- 0°C - MINIMUM FOR FLIGHT
- 130 PSI - MAXIMUM
- 90 TO 130 PSI - NORMAL RANGE
- 50 TO 90 PSI - PRECAUTIONARY RANGE
- 50 PSI - MINIMUM

TRANSMISSION OIL
TEMPERATURE/PRESSURE

- 120°C - MAXIMUM
- 105° TO 120°C - PRECAUTIONARY RANGE
- 15° TO 105°C - NORMAL RANGE
- 20° TO 15°C - PRECAUTIONARY RANGE
- 20°C - MINIMUM
- 120 PSI - MAXIMUM
- 70 TO 120 PSI - PRECAUTIONARY RANGE
- 30 TO 70 PSI - NORMAL RANGE
- 20 TO 30 PSI - PRECAUTIONARY RANGE
- 20 PSI - MINIMUM

FUEL PRESSURE

- 5 TO 50 PSI - NORMAL RANGE
- 5 PSI - MINIMUM

AIRSPED INDICATOR

- 0 TO 30 KIAS - PRECAUTIONARY RANGE-INDICATIONS INCONSISTENT
- 30 TO 155 KIAS - NORMAL RANGE
- 155 KIAS - MAXIMUM

HYDRAULIC PRESSURE

- 3300 PSI - MAXIMUM
- 2800 TO 3200 PSI - NORMAL RANGE
- 2700 PSI - MINIMUM

Figure # 5
INSTRUMENT GAUGES III

T5 INDICATOR

- 826°C - 2-1/2 MINUTE LIMIT - SINGLE ENGINE
- 798° TO 826°C - PRECAUTIONARY RANGE
- 798°C - 30 MINUTE LIMIT - SINGLE ENGINE
- 768° TO 798°C - PRECAUTIONARY RANGE
- 768°C - TAKEOFF 5 MINUTE LIMIT DUAL ENGINE AND MAXIMUM CONTINUOUS LIMIT
- 694° TO 768°C - ADVISORY AREA
- 350° TO 768°C-NORMAL OPERATION

DIGITAL T5 REPEATER

LIGHT INDICATIONS

- 350°C AND ABOVE
- 695°C AND ABOVE
- 769°C AND ABOVE
- 799°C AND ABOVE
- 827°C AND ABOVE

NOTE

THE GREEN AND WHITE ARC ON THE T5 INDICATOR AND GREEN AND WHITE LIGHT ON THE T5 REPEATER INDICATOR REPRESENTS RECOMMENDATIONS OF THE ENGINE MANUFACTURER. SEE PART 2 SECTION 1 FOR DETAILS.

FUEL FLOWMETER

- 412 LB/HR-MAXIMUM
- 75 TO 412 LB/HR-NORMAL RANGE
- 75 LB/HR - MINIMUM

SHP AT TAKEOFF POWER

Figure # 6

SHP AT NØRML CRUISE

Figure # 7

SHP AT 60 PERCENT CRUISE

Figure # 8

ITT AT NORMAL CRUISE

Figure # 10

OF / DE

FUEL FLOW AT NORMAL CRUISE

Figure # 13

AIR FLOW AT 60 PERCENT CRUISE

Figure # 17

COMP. DEL. PRESS. AT 60 PERCENT POWER

Figure # 23

Figure # 24

Figure # 25

Figure # 26

Figure 27

Figure # 28

Figure # 29

Figure # 30 Pocket Computer TRS-80 Model PC-2

TABLES

Allison 250-C30 General Specifications

Table # 1

1. DESIGN SPEEDS

i) Gas Producer rotor	100% (51000 rpm)
ii) Power Turbine rotor	100% (30650 rpm)
iii) Power output Shaft	100% (6016 rpm)

2. ENGINE OPERATING SPEED LIMITS

i) Gas Producer (N1)	
Maximum continuous	105% (53550 rpm)
Maximum overspeed (10 sec.)	106% (54060 rpm)
ii) Output Shaft (N2)	
Maximum continuous	varies from 114% at autorotation to 107.1% at 2-1/2 minute power.
Maximum 15 sec	varies from 119% at autorotation to 109% at 2-1/2 minute power.

3. ENGINE PERFORMANCE RATINGS

Refere Table # 2 and # 3 for the details.

4. MAXIMUM MEASURED GAS TEMPERATURE

Condition	Temperature Deg F (Deg C)
2-1/2 minute power *	1518 (826)
30 minute power *	1468 (798)
Takeoff (5 minute)	1414 (768)
Maximum continuous **	1414 (768)
Normal Cruise ***	1282 (694)
Starting	1700 (927)

* Apply to one-engine-inoperative (O.E.I.) of multi-engine aircraft

** FAA approved for continuous operation.

*** Highest power authorized by manufacturer for continuous operation

Table #2

Performance Ratings for Normal Operation									
Rating	Shaft Power hp (kW)	Jet Thrust (est) lb (N)	Gas Generator rpm (est)	Output Shaft rpm	Specific Fuel Cons. (max) lb/SHP-hr (mg/kW·h)	Measured Rated Gas Temp (est) °F (°C)	Maximum Allowable Output Shaft Torque		
							Ft lb (N·m)	Torque	
Guaranteed Performance Ratings - Standard Sea Level Static Conditions									
Takeoff (5 min)	650 (485)	77 (343)	50340	6016	0.592 (360)	1368 (742)	590 (800)		
Normal Cruise	557 (415)	67 (298)	48490	6016	0.607 (369)	1282 (694)	487 (660)		
Cruise A (90%)	501 (374)	62 (276)	47595	6016	0.624 (380)	----	---		
Cruise B (75%)	418 (312)	54 (240)	46365	6016	0.657 (400)	----	---		
Cruise C (60%)	334 (249)	45 (200)	44950	6016	0.705 (429)	----	---		
Ground Idle	40° (30) max 170 lb-ft (230 N·m) (max torque)	--	30000-33000	Zero and 3000-6300	75 lb/hr (34.02 Kg/hr)	750 ±100 (398 ±56)	---		
Flight Auto- rotation	0	--	33000	5900-6858	75 lb/hr (34.02 Kg/hr)	725 ±100 (305 ±56)	---		
Guaranteed Performance Ratings - 3000 Ft Altitude, Standard Ambient Conditions, 125 KTS True Airspeed									
Cruise	325 (242)	16 (71)	44915	6016	0.681 (414)	----	487 (660)		

Specific Fuel Consumption = Fuel Flow/SHP

Cruise A, Cruise B, and Cruise C ratings are at power levels that are 90%, 75%, and 60%, respectively, of rated Normal Cruise Power at standard sea level static conditions.

Table #3

Performance Ratings for One-Engine-Inoperative Operation and/or Emergency Two-Engine Operation

Rating	Pressure Altitude Ft (M)	Ambient Temp		Shaft Power hp (kW)	Jet Thrust lb (N)	Gas Generator put		Specific Fuel Cons. (max) lb/shp-hr (mg/KW-h)	Measured Rated Gas		Maximum Allowable Output Shaft Torque ft/lb (N.m)				
		°F	(°C)			rpm	shaft (est)		Temp (est)	°F		(°C)			
Guaranteed Performance Ratings – Static Conditions															
2½ Minute Power	S.L.	59	(15)	700	(522)	82	(365)	51550	6016	0.588	(358)	1424	(773)	627	(850)
2½ Minute Power	S.L.	90	(32)	700	(522)	80	(356)	52545	6016	0.598	(364)	1518	(826)	627	(850)
30-Minute Power	S.L.	59	(15)	650	(485)	77	(343)	50340	6016	0.592	(360)	1368	(742)	590	(800)
30-Minute Power	1000 (305)	90	(32)	630	(470)	73	(325)	51450	6016	0.604	(367)	1468	(798)	590	(800)
Max. Cont. *	S.L.	59	(15)	650	(485)	77	(343)	50340	6016	0.592	(360)	1368	(742)	590	(800)
Max. Cont. *	1000 (305)	90	(32)	575	(429)	73	(325)	50307	6016	0.612	(372)	1414	(768)	590	(800)

*Max continuous is FAA approved for continuous operation; but is authorized by the engine manufacturer only during one-engine-inoperative (O.E.I.) operation of multi-engine aircraft and emergency two-engine operation.

Comparison of the Empirical Method Program results with
the manufacturer's values of the Performance Parameters

Table # 4

Engine running condition :- Takeoff Power, Anti-icing
device OFF.

Performance Parameter	Hot Day 30 °C	Normal Day 15 °C	Cold Day -20 °C
Shaft Power H.P.	559 (562.3)	600 (607.6)	659 (665.4)
Inter Turbine Temp. °C	795 (791.6)	774 (770.5)	723 (714.4)
Fuel Flow Rate lb/hr	373 (372.1)	391 (389.6)	418 (414.2)
Air Flow Rate lb/sec	5.13 (5.14)	5.43 (5.42)	5.96 (5.96)
Comp. Deliv. Temp. °C	332 (332.2)	313 (313.4)	269 (269.2)
Comp. Deliv. Press. Psig	99.6 (99.4)	105.2 (104.6)	114.1 (113.6)

Note :-

Values in parentheses are the manufacturer's
values for the engine performance parameters.
Values without parentheses are calculated using
the Empirical Method Program.

Table # 5

Engine running condition :- Takeoff Power, Anti-icing device ON.

Performance Parameter	Hot Day 30 °C	Normal Day 15 °C	Cold Day -20 °C
Shaft Power H.P.	551 (553.9)	591 (598.5)	649 (655.4)
Inter Turbine Temp. °C	810 (805.0)	789 (784.1)	737 (745.4)
Fuel Flow Rate lb/hr	380 (379.5)	398 (397.4)	426 (422.5)
Air Flow Rate lb/sec	4.98 (4.99)	5.26 (5.26)	5.78 (5.79)
Comp. Deliv. Temp. °C	338 (338.4)	319 (319.3)	275 (274.6)
Comp. Deliv. Press. Psig	97.3 (97.1)	102.8 (102.3)	111.5 (111.1)

Note :-

Values in parentheses are the manufacturer's values for the engine performance parameters. Values without parentheses are calculated using the Empirical Method Program.

Table # 6

Engine running condition :- Normal Cruise Power,
Anti-icing device OFF.

Performance Parameter	Hot Day 30 °C	Normal Day 15 °C	Cold Day -20 °C
Shaft Power H.P.	458 (458.7)	514 (518.6)	605 (611.9)
Inter Turbine Temp. °C	736 (739.9)	722 (724.0)	672 (669.3)
Fuel Flow Rate lb/hr	322 (323.6)	343 (344.9)	382 (381.3)
Air Flow Rate lb/sec	4.82 (4.83)	5.18 (5.19)	5.91 (5.92)
Comp. Deliv. Temp. °C	312 (313.7)	296 (297.4)	252 (252.5)
Comp. Deliv. Press. Psig	89.9 (89.4)	96.8 (97.0)	109.9 (109.4)

Note :-

Values in parentheses are the manufacturer's values for the engine performance parameters. Values without parentheses are calculated using the Empirical Method Program.

Table # 7

Engine running condition :- Normal Cruise Power,
Anti-icing device ON.

Performance Parameter	Hot Day 30 °C	Normal Day 15 °C	Cold Day -20 °C
Shaft Power H.P.	451 (451.8)	507 (510.8)	596 (602.7)
Inter Turbine Temp. °C	750 (751.3)	736 (737.0)	686 (681.5)
Fuel Flow Rate lb/hr	329 (330.0)	350 (351.8)	390 (388.9)
Air Flow Rate lb/sec	4.68 (4.69)	5.02 (5.03)	5.74 (5.74)
Comp. Deliv. Temp. °C	318 (319.5)	302 (303.1)	258 (257.8)
Comp. Deliv. Press. Psig	87.8 (87.3)	94.6 (94.8)	107.4 (106.9)

Note :-

Values in parentheses are the manufacturer's values for the engine performance parameters. Values without parentheses are calculated using the Empirical Method Program.

Table # 8

Engine running condition :- 60% Cruise Power, Anti-icing device OFF.

Performance Parameter	Hot Day 30 °C	Normal Day 15 °C	Cold Day -20 °C
Shaft Power H.P.	263 (260.6)	311 (306.4)	452 (455.6)
Inter Turbine Temp. °C	619 (627.6)	607 (612.5)	581 (584.3)
Fuel Flow Rate lb/hr	225 (231.0)	246 (248.4)	298 (299.4)
Air Flow Rate lb/sec	4.11 (4.11)	4.45 (4.46)	5.43 (5.44)
Comp. Deliv. Temp. °C	270 (270.5)	256 (257.5)	223 (223.5)
Comp. Deliv. Press. Psig	69.0 (68.9)	75.6 (75.6)	94.2 (94.2)

Note :-

Values in parentheses are the manufacturer's values for the engine performance parameters. Values without parentheses are calculated using the Empirical Method Program.

Table # 9

Engine running condition :- 60% Cruise Power, Anti-icing device ON.

Performance Parameter	Hot Day 30 °C	Normal Day 15 °C	Cold Day -20 °C
Shaft Power H.P.	259 (256.7)	306 (301.8)	446 (448.8)
Inter Turbine Temp. °C	631 (639.4)	619 (624.0)	593 (595.0)
Fuel Flow Rate lb/hr	230 (235.6)	251 (253.3)	304 (305.4)
Air Flow Rate lb/sec	3.99 (3.99)	4.31 (4.32)	5.27 (5.28)
Comp. Deliv. Temp. °C	275 (275.9)	261 (262.8)	228 (228.4)
Comp. Deliv. Press. Psig	67.3 (67.3)	73.8 (73.8)	92.0 (92.0)

Note :-

Values in parentheses are the manufacturer's values for the engine performance parameters. Values without parentheses are calculated using the Empirical Method Program.

Empirical Factor Evaluation for SHP

Table # 10

Note:- Anti-icing system condition OFF. SHP in H.P.

	! Manufacturer's ! ! Method	! Simple Formulae ! ! Method	! %Difference !
1] 60% Cruise Power			
i) Tam 30°C!	260.6	! 285.39	! +9.51
ii) 15°C!	306.39	! 333.	! +8.6
iii) -20°C!	455.59	! 488.63	! +7.25
2] Normal Cruise Power			
i) Tam 30°C!	458.65	! 492.24	! +7.32
ii) 15°C!	518.57	! 555.	! +7.02
iii) -20°C!	611.88	! 651.89	! +6.54
3] Takeoff Power			
i) Tam 30°C!	562.3	! 600.66	! +6.82
ii) 15°C!	607.57	! 648.	! +6.65
iii) -20°C!	665.39	! 706.52	! +6.18

Thus the empirical factor for SHP is 1.073211, as the mean % difference is +7.3211%.

Empirical Factor Evaluation for ITT

Table # 11

Note:- Anti-icing system condition OFF. ITT in °F.

	Manufacturer's Method		Simple Formulae Method		%Difference
1] 60% Cruise Power					
i) Tam 30°C	1161.83	!	1095.90	!	-5.6
ii) 15°C	1134.50	!	1074.33	!	-5.3
iii) -20°C	1083.71	!	1030.90	!	-4.87
2] Normal Cruise Power					
i) Tam 30°C	1363.90	!	1299.45	!	-4.70
ii) 15°C	1335.26	!	1275.33	!	-4.48
iii) -20°C	1236.68	!	1185.40	!	-4.15
3] Takeoff Power					
i) Tam 30°C	1456.9	!	1394.36	!	-4.29
ii) 15°C	1418.90	!	1360.33	!	-4.12
iii) -20°C	1318.56	!	1268.27	!	-3.80

Thus the empirical factor for ITT is 0.9541, as the mean % difference is 4.59%.

Empirical Factor Evaluation for Fuel Flow

Table # 12

Note:- Anti-icing system condition OFF. Fuel Flow in lb/hr.

	Manufacturer's Method	Simple Formulae Method	%Difference
1) 60% Cruise Power			
i) Tam 30°C	230.96	222.41	-3.7
ii) 15°C	248.35	240.	-3.36
iii) -20°C	299.42	292.05	-2.46
2) Normal Cruise Power			
i) Tam 30°C	323.57	314.90	-2.67
ii) 15°C	344.94	337.	-2.30
iii) -20°C	381.29	374.34	-1.80
3) Takeoff Power			
i) Tam 30°C	372.05	363.755	-2.20
ii) 15°C	389.56	382.	-1.90
iii) -20°C	414.16	407.79	-1.54

Thus the empirical factor for fuel flow is 0.97564, as the mean % difference is 2.436%.

Empirical Factor Evaluation for Air Flow

Table # 13

Note:- (Anti-icing system condition OFF. Air flow in lb/sec.

	Manufacturer's Method	Simple Formulae Method	%Difference
1) 60% Cruise Power			
i) Tam 30°C	4.1134	4.2	+2.118
ii) 15°C	4.456	4.55	+2.109
iii) -20°C	5.443	5.56	+2.151
2) Normal Cruise Power			
i) Tam 30°C	4.834	4.93	+1.99
ii) 15°C	5.1927	5.3	+2.06
iii) -20°C	5.9175	6.04	+2.07
3) Takeoff Power			
i) Tam 30°C	5.146	5.253	+2.08
ii) 15°C	5.4226	5.54	+2.165
iii) -20°C	5.969	6.057	+2.089

Thus the empirical factor for air flow is 1.02092, as the mean % difference is 2.092%.

Empirical Factor Evaluation for Comp. Del. Temp.

Table # 14

Note:- Anti-icing system condition OFF. Compressor Del.Temp. in °F.

	Manufacturer's Method	Simple Formulae Method	%Difference
1] 60% Cruise Power			
i) Tam 30°C	518.98	518.69	0.0
ii) 15°C	495.57	495.33	0.0
iii) -20°C	434.21	434.13	0.0
2] Normal Cruise Power			
i) Tam 30°C	596.63	596.53	0.0
ii) 15°C	567.35	567.33	0.0
iii) -20°C	486.656	486.814	0.0
3] Takeoff Power			
i) Tam 30°C	630.15	630.20	0.0
ii) 15°C	596.19	596.33	0.0
iii) -20°C	516.51	516.66	0.0

Thus the empirical factor for Compressor Del. Temp. is 1.0, as the mean % difference is 0.0%.

Empirical Factor Evaluation for Comp. Del. Press.

Table # 15

Note:- Anti-icing system condition OFF. Compressor Del. Press. in Inches Hg Abs.

	Manufacturer's Method	Simple Formulae Method	%Difference
1] 60% Cruise Power			
i) Tam 30°C	170.74	174	+1.91
ii) 15°C	184.34	188.	+1.98
iii) -20°C	222.29	227.	+2.11
2] Normal Cruise Power			
i) Tam 30°C	212.5	217.	+2.12
ii) 15°C	228.06	233.	+2.17
iii) -20°C	253.24	233.	+2.27
3] Takeoff Power			
i) Tam 30°C	232.89	238.	+2.19
ii) 15°C	243.55	249.	+2.23
iii) -20°C	261.88	268.	+2.33

Thus the empirical factor for Compressor Del. Press. is 1.02146, as the mean % difference is 2.146%.

Table # 16

Engine Fault Matrix
(at constant gas generator speed)

Fault		TIT	SHP	m_f	CPR	Vibration	LEAP Indication
Gas Generator Turbine	1. Rotor damage	↑	↑	↑	↑	Yes	η_t low
	2. Nozzle erosion	↑	↑	↑	↓	No	$m\sqrt{T_3/P_3}$ high
	3. Nozzle coking	↓	↓	↓	↑	No	$m\sqrt{T_3/P_3}$ low
Power Turbine	1. Rotor damage	0	↓	0	0	Yes	η_t low, EGT high
	2. Nozzle erosion	↓	↓	↓	↓	No	$m\sqrt{T_4/P_4}$ high
	3. Nozzle coking	↑	↑	↑	↑	No	$m\sqrt{T_4/P_4}$ low
Compressor	1. F.O.D.	↑	↓	↑	↓	Yes	η_c low, m_1 low
	2. Dirty	↓	↓	↓	↓	No	η_c low, m_1 normal or slightly reduced

Table # 17

Engine running condition :- Helicopter Speed 100 Knots,
Altitude 1000 feet, Normal Cruise Power Setting, and
Anti-icing device OFF.

Performance Parameter	Hot Day 30 °C	Normal Day 15 °C	Cold Day -20 °C
Shaft Power H.P.	458 (451.66)	514 (522.2)	605 (627.7)
Inter Turbine Temp. °C	736 (742.4)	722 (720.5)	672 (668.1)
Fuel Flow Rate lb/hr	322 (324.04)	343 (345.8)	382 (388.9)

Note :-

Values in parentheses are the manufacturer's values for the engine performance parameters. Values without parentheses are calculated using the Empirical Method Program. Refer to the Table# 18 for the %Error observed in above health parameters.

Table # 18

%Error observed at 100 Knots speed and at 1000 ft altitude (Normal cruise power condition)

Performance Parameter	% Error observed at 100 Knots speed and at 1000 ft altitude using the empirical method
SHP	+1.4 to -3.6
ITT	+0.58 to -0.8
Fuel flow	-1.7 to -0.63

Note :- Refer to the Table# 17 for the parameter values.

APPENDIX A

MANUFACTURER'S PERFORMANCE CALCULATION METHOD

MANUFACTURER'S PERFORMANCE CALCULATION METHOD

MODEL SPECIFICATION C868-E

SAMPLE PERFORMANCE CALCULATION

STEP	QUANTITY	OBTAINED	VALUE
1	Altitude (feet)	Assume	9000
2	T_{am} , °F	Assume	35
3	V_p (knots)	Assume	200
4	Duct Efficiency (η_d)	Assume	0.98
5	P_{s7} (In. Hg Abs.)	Assume	22.000
6	Z Air Flow Bled	Assume	1.5
7	HP_{ex} (Gas Generator)	Assume	3
8	HP_{ex} (Power Turbine)	Assume	10
9	Anti-icing Control Setting	Assume	on
10	P_{am} (In. Hg Abs)	Tables (U.S. Std. Atms., 1962)	21.388
11	δ_{am}	(10) / 29.921	0.7148
12	θ	Figure No. 80	0.9720
13	$\sqrt{\theta}$	Figure No. 80	0.9853
14	T_{t2} , °R	(12) x 518.67	504.1
15*	T_{t2} , °F	(14) - 459.7	44.4
16	RPR'	Figure No. 81	1.0685
17	P_{t2}	(10) x (16)	22.855
18	P_{t2}	(17) x (4)	22.398
19	δ'	(17) / 29.921	0.7633
20	δ	(18) / 29.921	0.7456
21	RPR	(18) / (5)	1.0181
22	$HP_{ex(G.G.)} / \delta \sqrt{\theta}$	(7) / ((20) x (13))	4.065
23	N_1	Assume	44570
24	N_2	Assume	31640

*See Paragraph 7.3.

MODEL SPECIFICATION C868-E
SAMPLE PERFORMANCE CALCULATION CONTINUED

STEP	QUANTITY	OBTAINED	VALUE
25	ZN_1	$(\textcircled{23} / 51000) \times 100$	87.39
26	ZN_2	$(\textcircled{24} / 30650) \times 100$	103.23
27*	$N_1 / \sqrt{\theta}$	$\textcircled{23} / \textcircled{13}$	45212
28	$N_2 / \sqrt{\theta}$	$\textcircled{24} / \textcircled{13}$	32096
29	$SHP / \delta' \sqrt{\theta} C_1$	Figure No. 59	350.0
30	$T_{t_5} / \theta C_2, ^\circ R$	Figure No. 61	1550.0
31	$W_f / \delta' \sqrt{\theta} C_3$	Figure No. 60	244.0
32	$W_a \sqrt{\theta} / \delta'$	Figure No. 62	4.610
33	$T_{t_3} / \theta, ^\circ R$	Figure No. 64	960.0
34	P_{t_3} / δ'	Figure No. 63	191.5
35	C_1	Figure No. 65	1.00655
36	C_2	Figure No. 66	1.0150
37	C_3	Figure No. 67	1.0230
38	$(\Delta SHP / \delta' \sqrt{\theta} C_1)_{RPM_1}$	Figure No. 68	-3.5
39	$(\Delta T_{t_5} / \theta C_2)_{RPM_2}$	Figure No. 69	-4.0
40	$(\Delta W_f / \delta' \sqrt{\theta} C_3)_{RPM_3}$	Figure No. 70	-0.50
41	$(\Delta SHP / \delta' \sqrt{\theta} C_1)_{RPR_1}$	Figure No. 71	17.1
42	$(\Delta T_{t_5} / \theta C_2)_{RPR_2}$	Figure No. 72	-18.0
43	$(\Delta W_f / \delta' \sqrt{\theta} C_3)_{RPR_3}$	Figure No. 73	-3.4
44	$ZN_1 / \sqrt{\theta}$	$\textcircled{25} / \textcircled{13}$	88.65
45	$ZN_2 / \sqrt{\theta}$	$\textcircled{26} / \textcircled{13}$	104.72
46	$\Delta P_{t_2} / P_{t_2}$	$(\textcircled{17} - \textcircled{18}) / \textcircled{17}$	0.0200

MODEL SPECIFICATION C868-E
SAMPLE PERFORMANCE CALCULATION CONTINUED

STEP	QUANTITY	OBTAINED	VALUE
47	$\Delta P_{s7} / P_{am}$	$(5) - (10) / (10)$	0.0286
48	$(\Delta P_{t2} / P_{t2}') + (\Delta P_{s7} / P_{am})$	$(46) + (47)$	0.0486
49	$ZW_{b1} / 100$	$(6) / 100$	0.015
50	C_{d1}	Figure No. 74	-0.88
51	C_{bl1}	Figure No. 74	-0.15
52	C_{hp1}	Figure No. 74	0.966
53	$C_{d1} \left[\frac{\Delta P_{t2}}{P_{t2}} + \frac{\Delta P_{s7}}{P_{am}} \right]$	$(50) \times (48)$	-0.0428
54	$C_{bl1} (ZW_{b1} / 100)$	$(51) \times (49)$	-0.00225
55	$C_{hp1} (HP_{ex(G.G.)})$	$(52) \times (7)$	2.898
56	C_{ai1} (Anti-icing correction factor)	Figure No. 74	0.985
57	$\delta' \sqrt{\theta} C_1$	$(19) \times (13) \times (35)$	0.75789
58	SHP	$(57) \times (29) + (38) + (41) \times (1 + (53) - (46) + (54) + (55) - (8)) \times (56)$	246.8
59	C_{d2}	Figure No. 76	0.204
60	C_{bl2}	Figure No. 76	1.632
61	C_{hp2}	Figure No. 76	0.002

MODEL SPECIFICATION C868-E
SAMPLE PERFORMANCE CALCULATION CONTINUED

STEP	QUANTITY	OBTAINED	VALUE
62	$C_{d2} \left[\frac{\Delta P_{t2}}{P_{t2}} + \frac{\Delta P_{s7}}{P_{am}} \right]$	(59) x (48)	0.0099
63	$C_{b12} (\%W_{b1}/100)$	(60) x (49)	0.0245
64	$C_{hp2} (HP_{ex(G.G.)} / \delta \sqrt{\theta})$	(61) x (22)	0.00813
65	C_{a12}	Figure No. 76	1.013
66	θC_2	(12) x (36)	0.98658
67	$T_{t5}, ^\circ F$	$[(66) x (30) + (39) + (42) x (1 + (62) + (63) + (64))] x (65) - 459.67$	1132.4
68	C_{d3}	Figure No. 75	0.30
69	C_{b13}	Figure No. 75	4.07
70	C_{hp3}	Figure No. 75	0.00422
71	$C_{d3} \left[\frac{\Delta P_{t2}}{P_{t2}} + \frac{\Delta P_{s7}}{P_{am}} \right]$	(68) x (48)	0.01458
72	$C_{b13} (\%W_{b1}/100)$	(69) x (49)	0.0611
73	$C_{hp3} (HP_{ex(G.G.)} / \delta \sqrt{\theta})$	(70) x (22)	0.01715
74	C_{a13}	Figure No. 75	1.020
75	$\delta \sqrt{\theta} C_3$	(19) x (13) x (37)	0.77027
76	W_f	$[(75) x (31) + (40) + (43) x (1 + (71) - (46) + (72) + (73))] x (74)$	202.4

MODEL SPECIFICATION C868-E
SAMPLE PERFORMANCE CALCULATION CONTINUED

STEP	QUANTITY	OBTAINED	VALUE
77	C_{d5}	Figure No. 77	-0.0225
78	C_{b15}	Figure No. 77	0.0758
79	C_{hp5}	Figure No. 77	-0.000209
80	$C_{d5} \left[\frac{\Delta P_{t2}}{P_{t2}} + \frac{\Delta P_{s7}}{P_{am}} \right]$	(77) x (48)	-0.00011
81	$C_{b15} (\%W_{b1}/100)$	(78) x (49)	0.00114
82	$C_{hp5} (HP_{ex(G.G.)} / \delta \sqrt{\theta})$	(79) x (22)	-0.00085
83	C_{a15}	Figure No. 77	0.970
84	$\delta' / \sqrt{\theta}$	(19) / (13)	0.77480
85	W_a	$[(84) \times (32) \times (1 + (80) - (46) + (81) + (82))] \times (83)$	3.396
86	C_{d6}	Figure No. 79	0.01338
87	C_{b16}	Figure No. 79	-0.0416
88	C_{hp6}	Figure No. 79	0.000108
89	$C_{d6} \left[\frac{\Delta P_{t2}}{P_{t2}} + \frac{\Delta P_{s7}}{P_{am}} \right]$	(86) x (48)	0.00065
90	$C_{b16} (\%W_{b1}/100)$	(87) x (49)	-0.00062
91	$C_{hp6} (HP_{ex(G.G.)} / \delta \sqrt{\theta})$	(88) x (22)	0.00044

MODEL SPECIFICATION C868-E
SAMPLE PERFORMANCE CALCULATION CONTINUED

STEP	QUANTITY	OBTAINED	VALUE
92	C_{a16}	Figure No. 79	1.010
93	T_{t3} , °F	$\left[\frac{(12) \times (33) \times (1 + (89) + (90) + (91))}{(92) - 459.67} \right]$	483.2
94	C_{d7}	Figure No. 78	0.0836
95	C_{b17}	Figure No. 78	-0.3995
96	C_{hp7}	Figure No. 78	0.00102
97	$C_{d7} \left[\frac{\Delta P_{t2}}{P_{t2}} + \frac{\Delta P_{s7}}{P_{am}} \right]$	$(94) \times (48)$	0.00406
98	$C_{b17} (\%W_{b1}/100)$	$(95) \times (49)$	-0.00599
99	$C_{hp7} (HP_{ex(G.G.)}/\delta \sqrt{\theta})$	$(96) \times (22)$	0.00415
100	C_{a17}	Figure No. 78	0.98
101	P_{t3}	$\left[\frac{(19) \times (34) \times (1 + (97) - (46) + (98) + (99))}{(93) + 459.67} \right] \times (100)$	140.8
102	$\sqrt{T_{t3}}$ (°R)	$\sqrt{(93) + 459.67}$	30.706
103	$W_a \sqrt{T_{t3}} / P_{t3}$	$((85) \times (102)) / (101)$	0.7406
104	P_{t3} / P_{tb13}	Figure No. 82	1.0758
105	P_{tb13}	$(101) / (104)$	130.9
106	T_{tb13} , °F	Figure No. 82 (Same as (93))	483.2

MODEL SPECIFICATION C868-E

SAMPLE PERFORMANCE CALCULATION CONTINUED

STEP	QUANTITY	OBTAINED	VALUE
107	SFC	(76) / (58)	0.820
108	W_{b1}	((6) x (85)) / 100	0.05094

7.3 Performance With Acceleration Bleed If the value of $N_1/\sqrt{\theta}$ in Step No. (27) is less than 44800 rpm, and the value in Step No. (15) is less than 60°F, an additional correction to the engine performance parameters must be included for the effect of Acceleration Bleed. This is accomplished as follows:

1. Obtain W_a (Step (85)) for the initial parameter.
 2. From Figure No. 83 obtain $W_{a3a} \sqrt{\theta/\theta'}$ and by using the values in Steps (13) and (20) obtain W_{a3a} .
 3. Divide W_{a3a} by W_a to obtain % Bleed/100.
 4. Read C_{b1_1} , C_{b1_2} , etc. from Figures 74 through 79.
 5. Multiply the values obtained in (4) above by the value shown in (3).
 6. Subtract the values in (5) from 1.000. These then are the final factors to be applied to Steps (58), (67)*, (76), (85), (93)*, and (101) to correct for acceleration bleed.
- * Add 459.67 (converting to °R) before applying factor.
7. NOTE: If the value in Step No. (15) is 60°F or greater, the Acceleration Bleeds are automatically closed and Steps (1) through (6) above are unnecessary.

Note :- All figures in the above performance specification are included in this Appendix

FIGURE NO. 59

FIGURE NO. 60

 N_1/θ CORRECTED GAS GENERATOR SPEED, rpm

FIGURE NO. 61

FIGURE NO. 62

FIGURE NO. 63

FIGURE NO. 64

 $N_1 / \%$, CORRECTED GAS GENERATOR SPEED, rpm

FIGURE NO.65

FIGURE NO.66

ESTIMATED PERFORMANCE
ALLISON MODEL 250-C30

FUEL FLOW CORRECTION FACTOR
FOR THE EFFECTS OF INLET TEMPERATURE AND PRESSURE

C_3 , FUEL FLOW CORRECTION FACTOR

FIGURE NO.67

FIGURE NO. 69

$$\left(\frac{\Delta W_f}{W_f} \right) \left(\frac{8.1163}{\text{RPM}_3} \right) \cdot \text{POWER TURBINE SPEED CORRECTION INCREMENT FOR } W_f, 1b/hr$$

ESTIMATED PERFORMANCE
ALLISON MODEL 250-C30

SHAFT HORSEPOWER CORRECTION INCREMENT
FOR THE EFFECT OF RPR'

FIGURE NO. 71

FIGURE NO.72

FIGURE NO.73

FIGURE NO. 74

FIGURE NO. 75

FIGURE NO. 76

 $N_1/\sqrt{\theta}$, PERCENT GAS GENERATOR SPEED

FIGURE NO. 77

SPEC. NO. C868-E

ESTIMATED PERFORMANCE
ALLISON MODEL 250-C30

FIGURE NO. 78

FIGURE NO. 79

FIGURE NO. 81

FIGURE NO. 82

Appendix B

Flow Chart for The Empirical Method Program

Appendix C
Software for the Performance Evaluation
of Allison 250-C30 Engines

Software for the Performance Analysis of Allison 250-C30
Engines

(To be used on a Computer System supporting FORTRAN 77)

C Allison 250- C30 engine performance calculation program using the
C Empirical Method.

C
C The program is to be used to calculate the performance parameters
C of Allison 250-C30 engine at the sea level static condition and at
C power turbine speed of 30650 rpm (Design speed). Method used is an
C empirical method and gives the best results at normal power
C condition i.e. at gas generator speed of 48490 rpm. Please refer
C to the theoretical document for the accuracy and the limitations
C of the Empirical Method.
C

```

      INTEGER J,J2
      REAL SHP(21),T5(21),WF(21),WA(21),RATIO,T3(21),P3(21)
      DATA SHP/ -35.0, -33.0, -30.0, -26.0, -21.0, -14.0, -3.0, 11.5,
+34.0, 72.0, 126.0, 196.0, 282.0, 392.0, 527.0, 631.0, 712.0, 772.0
+ , 830.0, 882.0, 935.0/
      DATA T5/ 1084.0, 1091.0, 1100.0, 1112.0, 1123.0, 1138.0, 1157.0,
+1181.0, 1214.0, 1262.0, 1320.0, 1387.0, 1482.0, 1590.0, 1707.0,
+1805.0, 1897.0, 2000.0, 2130.0, 2250.0, 2372.0/
      DATA WF/32.0,35.0, 39.0, 44.0, 50.0, 57.0, 67.0, 81.0, 98.0, 118.0
+ , 142.0, 172.0, 216.0, 268.0, 323.0, 374.0, 419.0, 457.0, 498.0,
+542.0, 588.0/
      DATA WA/1.72, 1.77, 1.84, 1.92, 2.04, 2.18, 2.38, 2.63, 2.9, 3.2,
+3.55, 3.93, 4.34, 4.76, 5.21, 5.51, 5.68, 5.71, 5.71, 5.71, 5.71/
      DATA T3/636.0, 651.0,668.0,685.0,714.0,726.0,751.0,777.0,805.0,
+834.0,864.0,896.0,933.0,975.0,1018.0,1051.0,1082.0,1118.0,1156.0,
+1175.0,1234.0/
      DATA P3/42.5,47.0,52.0,58.0,64.5,72.5,82.5,94.0,106.5,120.0,135.5,
+154.0,176.0,201.0,227.0,247.0,261.0,269.0,276.0,282.5,288.0/
      ALT=0
      VP=0
      WRITE(6,201) ALT,VP
      EFFDUCT=.98
      WBL=1.5
      HPEXGC=3
      HPEXPT=10
      PO=29.921
      TO=59
      RAN=459.67
      PRINT 401
401 FORMAT (' What is the ambient temperature in Degree C ?')
      READ(5,101) ATAM
      TAM=9.0*ATAM/5.0+32
      PRINT 402
402 FORMAT (' What is the ambient pressure in In. Hg Abs ?')
```



```

      READ(5,901) PAM
901  FORMAT (G)
      THETA=(TAM+RAN)/(TO+RAN)
      ROOTTH=SQRT(THETA)
      T2=TAM+RAN
      T2LIMIT=60
      PS7=PAM+.612
      RPR1=1
      P21=RPR1*PAM
      P2=P21*EFFDUCT
      DELTA1=P21/PO
      DELTA=P2/PO
      RPR=P2/PS7
      PRINT 403
403  FORMAT ( ' What is the speed of Gas Generator in % rpm ? ')
      READ(5,102)BN1
      AN1= BN1*51000./100.
      PRINT 404
404  FORMAT ( ' Please note that power turbine speed is assumed to be
+ 30650 rpm ',/)
      AN2=30650
      WRITE(6,202) ATAM,PAM
      WRITE(6,203) AN1,AN2
      PERN1=AN1*100/51000
      PERN2=AN2*100/30650
      AN1TH=AN1/ROOTTH
      AN2TH=AN2/ROOTTH
      AN1THL=44800
      IF (T2.LT.T2LIMIT.AND.AN1.LT.AN1THL) GO TO 500
      PRINT 405
405  FORMAT ( ' Please feed the value of C1 from fig. No 65 of the
+ ',/' sample performance calculations.')
      READ(5,103) C1
      PRINT 406
406  FORMAT (/' Please feed the value of C2 from fig. No 66 of the
+ ',/' sample performance calculations.')
      READ(5,801) C2
      PRINT 407
801  FORMAT(G)
407  FORMAT (/' Please feed the value of C3 from fig. No 67 of the
+ ',/' sample performance calculations.')
      READ(5,802) C3
802  FORMAT(G)
      PRINT 408
408  FORMAT ( ' Feed 0 if anti-icing device is off and 1 if it is on
+ .')
      READ(5,104) ANIICE
      PRINT 8888
8888  FORMAT ( ' What is the measured %torque?')
      READ (5,8889) TORQUE
8889  FORMAT(G)
      PRINT 8810
8810  FORMAT ( ' What is the measured inter turbine temperature in DegC')

```

```

      READ (5,8811) ATIT
8811 FORMAT(G)
      PRINT 8812
8812 FORMAT (' What is the measured fuel flow in lb/hr?')
      READ (5,8815) FUEL
8815 FORMAT (G)
      J=(ANLTH-20000.)/2000.
      RATIO=(ANLTH-(J*2000+20000))/2000.0
      J=J+1
      J2=J+1
      IF (J.LT.21) THEN
        ASHP=SHP(J)+(SHP(J2)-SHP(J))*RATIO
        AT5=T5(J)+(T5(J2)-T5(J))*RATIO
        AWF=WF(J)+(WF(J2)-WF(J))*RATIO
        AWA=WA(J)+(WA(J2)-WA(J))*RATIO
        AT3=T3(J)+(T3(J2)-T3(J))*RATIO
        AP3=P3(J)+(P3(J2)-P3(J))*RATIO
      ELSE
        ASHP=SHP(21)
        AT5=T5(21)
        AWF=WF(21)
        AWA=WA(21)
        AT3=T3(21)
        AP3=P3(21)
      ENDIF
      IF (ANTIICE) 10,10,20
10  BSHP=DELTA1*ROOTTH*C1*ASHP/1.07321
      BT5=(THETA*C2*AT5-459.67)/.9541
      BWF=DELTA1*ROOTTH*C3*AWF/.97564
      BWA=DELTA1/ROOTTH*AWA/1.02092
      BT3=AT3*THETA-459.67
      BP3=AP3*DELTA1/1.02146
      GO TO 501
20  CAI1=.985
      BSHP=DELTA1*ROOTTH*C1*ASHP*CAI1/1.07327
      CAI2=1.013
      BT5=(THETA*C2*AT5*CAI2-459.67)/.95314
      CAI3=1.02
      BWF=DELTA1*ROOTTH*C3*AWF*CAI3/.97558
      CAI5=.97
      BWA=DELTA1/ROOTTH*AWA*CAI5/1.02087
      CAI6=1.01
      BT3=AT3*THETA*CAI6-459.67
      CAI7=.98
      BP3=AP3*DELTA1*CAI7/1.02145
501 CT5=5.*(BT5-32.)/9.
      CT3=5.*(BT3-32.)/9.
      CP3=14.696*(BP3/29.921)-14.696
      TOR=BSHP*5252./6016.0
      TORHP=TOR/590.*100.
      ERHP=(TORQUE-TORHP)/TORHP*100.
      ERITT=(ATIT-CT5)/CT5*100.
      ERFUEL=(FUEL-BWF)/BWF*100.

```

```

WRITE(6,204),BSHP,CT5,BWF,BWA,CT3,CP3,TORHP
201 FORMAT(///// ' INPUT DATA : '///// ' ALTITUDE ASSUMED= ',I1,' ft',//
+ ' AIRCRAFT SPEED= ',I1,' Knots',//)
202 FORMAT(' AMBIENT TEMPERATURE= ',I3,' Deg C',//
+ ' AMBIENT PRESSURE= ',F6.2,' In Hg Abs.',//)
203 FORMAT(' G.G.SPEED IN RPM= ',I5,/// ' P.T. SPEED IN RPM= ',I5,///)
101 FORMAT(G)
102 FORMAT(G)
103 FORMAT(G)
104 FORMAT(G)
204 FORMAT (// ' NOMINAL DATA: '///// ' SHAFT HORSE POWER= ',I4,' H.P.'
+//, ' INTER TURBINE TEMPERATURE= ',I5,' Deg C',/// ' FUEL FLOW= ',
+I4,' lb/hr',/// ' AIR FLOW RATE= ',F6.2,' lb/sec',/// ' COMPRESSOR
+DELIVERY TEMPERATURE= ',I5,' Deg C',/// ' COMPRESSOR DELIVERY'
+ ' PRESS.= ',F6.1,' Psig',/// ' TORQUE METER READING= ',F4.1,' %',/
+/)
WRITE (6,209) TORQUE,ATIT,FUEL

209 FORMAT (/// ' MEASURED DATA: '///// ' TORQUE METER READING IN %= '
+ ,F8.1,/// ' INTER TURBINE TEMPERATURE IN DEG C= ',I8,/// ' FUEL FLOW
+ IN LB/HR= ', I8,///)
WRITE (6,220) ERHP,ERITT,ERFUEL
220 FORMAT (/// ' %ERROR: '///// ' %ERROR IN POWER= ',F8.1,/// ' %ERROR IN
+ INTER TURBINE TEMP= ', F8.1,/// ' %ERROR IN FUEL FLOW= ',F8.1,///)
GO TO 505
500 WRITE (6,205)
205 FORMAT ('AS THE ENGINE INLET TEMPERATURE AND THE GAS GENERATOR
+SPEED IS LOW, REFERE TO THE PARAGRAPH 7.3 OF THE SAMPLE
+PERFORMANCE CALCULATIONS')
505 STOP
END

```

Note :- This program has been created in the CP6 account No. PN043196,MOHILE and is stored on a tape using STOW command. The name of the file is 'ALLISON_STOW'.

Output from the Computer System Supporting FORTRAN 77

RUN_ALLISON_C30

INPUT DATA :

ALTITUDE ASSUMED= 0 ft

AIRCRAFT SPEED= 0 Knots

What is the ambient temperature in Degree C ?

730

What is the ambient pressure in In. Hg Abs ?

729.921

What is the speed of Gas Generator in % rpm ?

798.7

Please note that power turbine speed is assumed to be 30650 rpm

AMBIENT TEMPERATURE= 30 Deg C

AMBIENT PRESSURE= 29.92 In Hg Abs.

G.G.SPEED IN RPM= 50337

P.T. SPEED IN RPM= 30650

Please feed the value of C1 from fig. No 65 of the
sample performance calculations.

?1.0042

Please feed the value of C2 from fig. No 66 of the
sample performance calculations.

?1.0025

? Please feed the value of C3 from fig. No 67 of the
sample performance calculations:

71.013

Feed 0 if anti-icing device is off and 1 if it is on.

70

What is the measured torque?

782

What is the measured inter turbine temperature in DegC

7790

What is the measured fuel flow in lb/hr?

7370

NOMINAL DATA:

SHAFT HORSE POWER= 559 H.P.

INTER TURBINE TEMPERATURE= 795 Deg C

FUEL FLOW= 373 lb/hr

AIR FLOW RATE= 5.13 lb/sec

COMPRESSOR DELIVERY TEMPERATURE= 332 Deg C

COMPRESSOR DELIVERY PRESS.= 99.6 Psig

TORQUE METER READING= 82.8 %

MEASURED DATA:

TORQUE METER READING IN %= 82.0

INTER TURBINE TEMPERATURE IN DEG C= 790

FUEL FLOW IN LB/HR= 370

%ERROR:

%ERROR IN POWER= -.9

%ERROR IN INTER TURBINE TEMP= -.7

%ERROR IN FUEL FLOW= -.9

STOP

Sample Output Data from Radio Shack Pocket Computer PC-2

ALLISON C30

*DATE AND TIME=

m d h m s

30 11 3.0509

*ENGINE NO=

A327

INPUT DATA

1) Ambient Temp.
in deg C=

30

2) Ambient press.
in HG=

29.921

3) G.G. % Speed=
98.74) Rotor Speed
Assumed rpm=

6016

5) Anti-Icing
Device=

Off

NOMINAL DATA

1) Shaft horse
Power in H.P.=

559.

2) Inter Turbine
Temp. in deg C=

795.

3) Fuel Flow
in Lb/Hr=

373.

MEASURED DATA

Shaft Power H.P.=

559.

Inter turbine
Temp. in C=

790.

Fuel flow in lb/hr

370.0

ERROR

1) % Error in
Power=

0.0

2) % Error in ITT=

-0.6

3) % Error in Fuel
flow=

-0.8

Software for Allison 250-C30 Engine Performance Analysis

(To be used on Radio Shack Pocket Computer Model PC-2)

1:"ALLISONC30"	403:W(3)=39
2:TEXT	404:W(4)=44
3:CLEAR	405:W(5)=50
4:GOSUB 8000	406:W(6)=57
5:GOTO 1020	407:W(7)=67
100:"X"	408:W(8)=81
101:COLOR 1	409:W(9)=98
201:S(1)=-35	410:W(10)=118
202:S(2)=-33	411:W(11)=142
203:S(3)=-30	412:W(12)=172
204:S(4)=-26	413:W(13)=216
205:S(5)=-21	414:W(14)=268
206:S(6)=-14	415:W(15)=323
207:S(7)=-3	416:W(16)=374
208:S(8)=11.5	417:W(17)=419
209:S(9)=34	418:W(18)=457
210:S(10)=72	419:W(19)=498
211:S(11)=126	420:W(20)=542
212:S(12)=196	421:W(21)=588
213:S(13)=282	501:A(1)=1.72
214:S(14)=392	502:A(2)=1.77
215:S(15)=527	503:A(3)=1.84
216:S(16)=631	504:A(4)=1.92
217:S(17)=712	505:A(5)=2.04
218:S(18)=772	506:A(6)=2.18
219:S(19)=830	507:A(7)=2.38
220:S(20)=882	508:A(8)=2.63
221:S(21)=935	509:A(9)=2.90
301:T(1)=1084	510:A(10)=3.20
302:T(2)=1091	511:A(11)=3.55
303:T(3)=1100	512:A(12)=3.93
304:T(4)=1112	513:A(13)=4.34
305:T(5)=1123	514:A(14)=4.76
306:T(6)=1138	515:A(15)=5.21
307:T(7)=1157	516:A(16)=5.51
308:T(8)=1181	517:A(17)=5.68
309:T(9)=1214	518:A(18)=5.71
310:T(10)=1262	519:A(19)=5.71
311:T(11)=1320	520:A(20)=5.71
312:T(12)=1387	521:A(21)=5.71
313:T(13)=1482	601:R(1)=636
314:T(14)=1590	602:R(2)=651
315:T(15)=1707	603:R(3)=668
316:T(16)=1805	604:R(4)=685
317:T(17)=1897	605:R(5)=714
318:T(18)=2000	606:R(6)=726
319:T(19)=2130	607:R(7)=751
320:T(20)=2250	608:R(8)=777
321:T(21)=2372	609:R(9)=805
401:W(1)=32	610:R(10)=834
402:W(2)=35	611:R(11)=864
	612:R(12)=896


```

613:R(13)=933
614:R(14)=975
615:R(15)=1018
616:R(16)=1051
617:R(17)=1082
618:R(18)=1118
619:R(19)=1156
620:R(20)=1175
621:R(21)=1234
800:GOTO 1300
1020:B=.98
1030:C=29.921
1040:D=59
1050:E=459.67
1055:BEEP 1,100,3
      00
1056:INPUT "Feed
      Engine Numbe
      r --<",A$
1060:BEEP 1,100,3
      00
1070:INPUT "Feed
      Ambi. Temp.
      in C --<",FA
1080:F=9*FA/5+32
1085:BEEP 1,100,3
      00
1090:INPUT "Feed
      Ambi. Press.
      in Hg--<",PA
1100:TH=(F+E)/(D+
      E)
1110:TR=JTH
1120:T1=F+E
1130:TL=60
1140:PS=PA+.612
1150:PN=PA*B
1160:DL=PA/C
1170:BEEP 1,100,3
      00
1180:INPUT "Feed
      % G.G. Speed
      --<",PP
1190:NG=PP*5000/
      100
1200:NR=6016
1082:NL=44800
1220:NT=NG/TR
1230:IF F>TLGOTO
      1270
1240:IF NG<NLGOTO
      2999

```

```

1270:BEEP 1,100,3
      00
1275:INPUT "Anti-
      icing On=1 0
      ff=0",Y
1277:BEEP 1,100,3
      00
1278:INPUT "Feed
      measured ITT
      TEMP C",MT
1279:BEEP 1,100,3
      00
1280:INPUT "Feed
      measured fue
      l lb/hr",MF
1281:BEEP 1,100,3
      00
1282:INPUT "Feed
      measured % t
      orque-<",MP
1287:BEEP 1,100,3
      00
1288:PRINT "Pleas
      e wait for 0
      utput"
1289:GOTO 6010
1290:GOTO 100
1300:COLOR 3
1304:CSIZE 3
1306:LPRINT " ALL
      ISON C30"
1307:CSIZE 2
1308:LPRINT "----
      ----"
1310:LPRINT "*DAT
      E AND TIME="
      LPRINT "
      m d h
      m s",TIME
1311:LPRINT "*ENG
      INE NO="
1312:LCURSOR 7:
      LPRINT A$
1313:LPRINT "----
      ----"
1318:COLOR 0
1320:LPRINT " IN
      PUT DATA"
1341:LPRINT "1) A
      mbient Temp.
      ", " in deg C
      ="
1342:LCURSOR 10

```

```

1343:LPRINT FA
1350:LPRINT "2) A
      mbient Press
      ", " in HG="
1351:LCURSOR 10
1352:LPRINT PA
1361:LPRINT "3) G
      .G. % Speed="
1362:LCURSOR 10
1363:LPRINT PP
1371:LPRINT "4) R
      otor Speed",
      "Assumed rpm
      ="
1372:LCURSOR 10
1373:LPRINT NR
1375:LPRINT "5) A
      nti-Icing ",
      "Device="
1376:LCURSOR 10:
      IF Y=1GOTO 1
      379
1378:LPRINT "Off"
      :GOTO 1391
1379:LPRINT "On"
1391:LPRINT "-----
      ----"
1394:COLOR 1
1400:J=INT ((NT-2
      0000)/2000)
1410:K=(NT-(J*200
      0+20000))/20
      00
1420:J=J+1
1430:L=INT (J+1)
1450:IF J<21THEN
      1700
1460: SX=S(21)
1470: TX=T(21)
1480: WX=W(21)
1490: AX=A(21)
1500: RX=R(21)
1510: PX=P(21)
1520:GOTO 2000
1700: SX=S(J)+(S(L
      )-S(J))*K
1710: TX=T(J)+(T(L
      )-T(J))*K
1720: WX=W(J)+(W(L
      )-W(J))*K
1730: AX=A(J)+(A(L
      )-A(J))*K
1740: RX=R(J)+(R(L
      )-R(J))*K
1750: PX=P(J)+(P(L
      )-P(J))*K
2000: IF Y=1THEN 2
      410
2010: SU=DL*TR*ZA*
      SX/1.07321
2020: TU=(TH*ZB*TX
      -459.67)/.95
      41
2030: WU=DL*TR*ZC*
      WX/.97564
2040: AU=DL*AX/1.0
      2092/TR
2050: RU=TH*RX-E
2060: PU=PX*DL/1.0
      2146
2070:GOTO 2600
2410: SU=DL*TR*ZA*
      SX*.917816
2430: TU=(TH*1.013
      *TX*ZB-459.6
      7)/.95314
2450: WU=DL*TR*ZC*
      WX*1.04551
2470: AU=DL*AX*0.9
      42937/TR
2490: RU=RX*TH*1.0
      1-459.671
2510: PU=PX*DL*.95
      94204
2600: TU=5*(TU-32)
      /9
2610: RU=5*(RU-32)
      /9
2630: PU=14.696*(P
      U/29.921)-14
      .696
2800:GOTO 5000
2999:COLOR 3
3000:LPRINT "G.G.
      Speed and",
      "Ambient Tem
      p. LOW"
3001:LPRINT "for
      the program"
3002:BEEP 5,100,3
      00
3005:PRINT "ERROR
      "
3010:GOTO 6000
5000:LPRINT " NO
      MINAL DATA"

```

```

5020:LPRINT "1)Sh
      gft horse", "
      Power in H.P
      ="
5030:LCURSOR 10
5040:LPRINT USING
      "####.";SU
5060:LPRINT "2)In
      ter Turbine"
      , "Temp. in d
      eg C="
5070:LCURSOR 10
5080:LPRINT USING
      "#####.";TU
5100:LPRINT "3) F
      uel Flow", "i
      n Lb/Hr="
5110:LCURSOR 10
5120:LPRINT USING
      "####.";WU
5200:LPRINT "----
      ----"
5210:MQ=(MP*590*6
      016)/(5200*1
      00)
5300:LPRINT " ME
      ASURED DATA"
5310:LPRINT USING
      "####."; "Sha
      ft Power H.P
      .=", MQ
5320:LPRINT USING
      "#####."; In
      ter turbine
      , "Temp. in
      C="
5340:LPRINT MT
5350:LPRINT USING
      "####.#"; "Fu
      el flow in l
      b/hr=", MF
5360:LPRINT "----
      ----"
5375:ZP=((MQ-SU)/
      SU)*100
5380:ZT=((MT-TU)/
      TU)*100
5385:ZF=((MF-WU)/
      WU)*100
5400:COLOR 2
5405:LPRINT " %E
      RROR"

5410:LPRINT "1) %
      Error in", '
      Power="
5412:CURSOR 10
5414:LPRINT USING
      "####.#";ZP
5420:LPRINT "2) %
      Error in IT
      T="
5422:CURSOR 10
5424:LPRINT USING
      "####.#";ZT
5430:LPRINT "3) %
      Error in Fu
      el"; "flow="
5432:CURSOR 10
5434:LPRINT USING
      "####.#";ZF
5440:LPRINT "----
      ----"
5500:END
6000:"CCONS"
6001:GG=99
6005:INPUT "AMBI
      TEMP IN C", F
      A
6006:INPUT "PRESS
      ", PA
6010:DIM PD(14)
6011:DIM S(21)
6012:DIM T(21)
6013:DIM W(21)
6014:DIM A(21)
6015:DIM R(21)
6016:DIM P(21)
6017:DIM S4(14)
6018:DIM T4(14)
6030:PD(1)=36.
6031:PD(2)=34.
6032:PD(3)=32.
6033:PD(4)=29.92
6034:PD(5)=28.
6035:PD(6)=26.
6036:PD(7)=24.
6037:PD(8)=22.
6038:PD(9)=20.
6039:PD(10)=18.
6040:PD(11)=16.
6041:PD(12)=13.75
6042:PD(13)=12.
6043:PD(14)=10.

```

6044: S(1)=.97425
 6045: S(2)=.976
 6046: S(3)=.97775
 6047: S(4)=.98025
 6048: S(5)=.98275
 6049: S(6)=.98475
 6050: S(7)=.98725
 6051: S(8)=.99
 6052: S(9)=.9925
 6053: S(10)=.99525
 6054: S(11)=.99825
 6055: S(12)=1.0022
 5
 6056: S(13)=1.0055
 6057: S(14)=1.0085
 6058: T(1)=1.6477E
 -4
 6059: T(2)=1.6364E
 -4
 6060: T(3)=1.6477E
 -4
 6061: T(4)=1.6477E
 -4
 6062: T(5)=1.6477E
 -4
 6063: T(6)=1.6477E
 -4
 6064: T(7)=1.6477E
 -4
 6065: T(8)=1.6477E
 -4
 6066: T(9)=1.6590E
 -4
 6067: T(10)=1.6705
 E-4
 6068: T(11)=1.6477
 E-4
 6069: T(12)=1.6477
 E-4
 6070: T(13)=1.6477
 E-4
 6071: T(14)=1.6136
 E-4
 6072: W(1)=.97625
 6073: W(2)=.97975
 6074: W(3)=.984
 6075: W(4)=.98825
 6076: W(5)=.993
 6077: W(6)=.99925
 6078: W(7)=1.0045
 6079: W(8)=1.01075
 6080: W(9)=1.017
 6081: W(10)=1.024

6082: W(11)=1.0312
 5
 6083: W(12)=1.039
 6084: W(13)=1.0452
 5
 6085: W(14)=1.0525
 6086: A(1)=1.36364
 E-4
 6087: A(2)=1.25E-4
 6088: A(3)=1.0909E
 -4
 6089: A(4)=9.6591E
 -5
 6090: A(5)=8.6364E
 -5
 6091: A(6)=6.3636E
 -5
 6092: A(7)=5.6818E
 -5
 6093: A(8)=5.2273E
 -5
 6094: A(9)=5.0E-5
 6095: A(10)=5.0E-5
 6096: A(11)=5.0E-5
 6097: A(12)=5.2273
 E-5
 6098: A(13)=5.3409
 E-5
 6099: A(14)=5.4545
 E-5
 6100: R(1)=.908
 6101: R(2)=.915
 6102: R(3)=.925
 6103: R(4)=.931
 6104: R(5)=.938
 6105: R(6)=.946
 6106: R(7)=.954
 6107: R(8)=.963
 6108: R(9)=.975
 6109: R(10)=.989
 6110: R(11)=1.004
 6111: R(12)=1.025
 6112: R(13)=1.042
 6113: R(14)=1.062
 6114: P(1)=5.636E-
 4
 6115: P(2)=5.5E-4
 6116: P(3)=5.2272E
 -4
 6117: P(4)=5.0909E
 -4
 6118: P(5)=4.9545E
 -4
 6119: P(6)=5.6435E
 -4
 6120: P(7)=5.5714E
 -4

6121: P(8)=5.5714E-4	6230: TT=0.
6122: P(9)=5.2857E-4	6235: IF TP<-60.
6123: P(10)=4.9286E-4	THEN 6245
6124: P(11)=4.5E-4	6240: TT=TP+60.
6125: P(12)=3.8571E-4	6245: FOR I=1 TO 14
6126: P(13)=3.5714E-4	6250: IF PR>=PD(1)
6127: P(14)=3.2857E-4	THEN 6265
6128: S4(6)=1.025	6255: NEXT I
6129: S4(7)=1.032	6260: I=14
6130: S4(8)=1.041	6265: NX=I-1
6131: S4(9)=1.049	6270: NP=I
6132: S4(10)=1.058	6280: CY=S(NP)+T(NP)*TT
6133: S4(11)=1.067	6290: CZ=W(NP)+A(NP)*TT
6134: S4(12)=1.08	6300: CU=R(NP)+P(NP)*TT
6135: S4(13)=1.092	6310: IF NP>1 THEN
6136: S4(14)=1.108	6320
6137: T4(6)=3.125E-4	6315: ZA=CY, ZB=CZ,
6138: T4(7)=2.75E-4	ZC=CU: GOTO 6370
6139: T4(8)=2.25E-4	6320: IF NP>=14
6140: T4(9)=2.125E-4	THEN 6315
6141: T4(10)=1.625E-4	6321: CX=S(NX)+T(NX)*TT
6142: T4(11)=1.375E-4	6322: CW=W(NX)+A(NX)*TT
6143: T4(12)=1.1125E-4	6323: CU=R(NX)+P(NX)*TT
6144: T4(13)=.0001	6350: RR=(PD(NX)-P(R))/(PD(NX)-P(D(NP)))
6145: T4(14)=.0001	6355: ZA=CX-(CX-CY)*RR
6150: T4(1)=5.25E-4	6360: ZB=CW-(CW-CZ)*RR
6152: T4(2)=5.0E-4	6365: ZC=CU-(CU-CU)*RR
6154: T4(3)=4.5E-4	6370: IF TP<=80
6156: T4(4)=4.125E-4	GOTO 6500
6158: T4(5)=3.5E-4	6375: TT=TP-80.
6170: S4(1)=.99	6380: CU=S4(NP)+T4(NP)*TT
6172: S4(2)=.996	6385: IF NP>1 THEN
6174: S4(3)=1.004	6391
6176: S4(4)=1.01	6386: ZC=CU: GOTO 6500
6178: S4(5)=1.018	6390: IF NP>=9 THEN
6200: NX=1, NP=1	6386
6210: TP=FA	6391: CU=S4(NX)+T4(NX)*TT
6215: PR=PA	6400: ZC=CU-(CU-CU)*FR
6216: TP=9/5*TP+32	6500: P=5/9*(TP-32)
6220: TT=220.	
6225: IF TP>160.	
THEN 6245	

```

6710: IF GG=99GOTO
7007
7000: GOTO 1290
7007: IF U=1 THEN
GOTO 7009
7008: GOTO 7010
7009: LPRINT "YP T
P " ; YP; TP
7010: LPRINT "PR C
1 " ; PR; ZA
7015: LPRINT "C2 C
3 " ; ZB; ZC
7016: LF 1
7050: END
8000: "GP"
8010: WAIT 0
8020: GCURSOR 44.
GPRINT 127
8030: GCURSOR 109.
GPRINT 127
8050: FOR I=25 TO 3
5: WAIT 0: K=1
-5
8060: GCURSOR K
8070: GPRINT 0; 8; 2
8; 60; 62; 120;
127; 126; 126;
127; 120; 62; 6
0; 28; 8
8080: NEXT I
8090: WAIT 2.
GCURSOR K
8100: GPRINT 0; 8; 2
8; 60; 62; 120;
127; 126; 126;
127; 120; 62; 6
0; 28; 8
8110: FOR I=12 TO
110 STEP -1
8120: WAIT 0: K=1-1
8130: GCURSOR K
8140: GPRINT 8; 28;
60; 62; 120; 12
7; 126; 126; 12
7; 120; 62; 60;
28; 8; 0
8150: NEXT I
8160: WAIT 2.
GCURSOR K
8170: GPRINT 8; 28;
60; 62; 120; 12
7; 126; 126; 12
7; 120; 62; 60;
28; 8; 0
8180: GCURSOR 49.
WAIT 0

```

```

8190: PRINT "ALL IS
ONC30"
8200: WAIT 0:
GCURSOR 1
8210: GPRINT 113; 5
0; 116; 2; 113;
80; 119; 0; 113
330; 116; 2; 11
3; 0; 119; 71; 6
9; 0; 119; 114;
85
8215: WAIT 50
8220: GCURSOR 135
8230: GPRINT 127; 1
27; 127; 127; 1
27; 127; 127;
WAIT 50
8231: GCURSOR 135
8235: GPRINT 127; 1
27; 127; 119; 1
27; 127; 127;
WAIT 50
8236: GCURSOR 135
8240: GPRINT 127; 1
27; 99; 99; 99;
127; 127; WAIT
50
8241: GCURSOR 135
8245: GPRINT 127; 6
5; 65; 65; 65; 6
5; 127; WAIT 9
0
8249: CLEAR
8250: RETURN

```

Appendix D

Typical Flow Chart for Fault Diagnosis

* This additional measurement is required for detailed fault diagnosis, only after the engine has been decided as faulty.

END

06109H84

FIN