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Performance Analysis and Diagnostics of a Small Gas Turbine

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ABSTRACT

In this paper, the performance of Auxiliary Power Unit (APU) - GTCP30-92 was investigated. The aim is to provide a test facility for students to run the engine and develop their abilities in gas turbine performance analysis. To prepare for this, the engine has been provided with measurement instruments; in order to measure the performance of the engine; and to simulate and compare the engine performance with the measurements. The measurements and predictions are presented in this paper.

NOMENCLATURE

A	Area
CW	Compressor work
FAR	Fuel-to-Air ratio
Mach	Mach number
P	Total Pressure
PR	Pressure ratio
T	Total temperature
TET	Turbine Entry Temperature
T5	Turbine Exhaust Temperature
TW	Turbine work
V	Velocity
η	Efficiency

INTRODUCTION

The Auxiliary Power Unit investigated, (APU) GTCP30-92 (Garrett/Honeywell, 1951), is an old gas turbine system with several main functions as follows:

- Main engine starting.
- Supply of cooling air for aircraft secondary systems, particularly when at ground idle in hot climates.
- Supply of electrical power when main engines are shut down, including for ground checkout of aircraft systems.

The functions give an aircraft self-sufficiency when on the ground. In addition the GTPC30-92 can be required to fire up at altitude in case of main engine flame out, to power electrical systems- vital for fly by wire aircraft – and if at low flight Mach number to provide crank assistance to help restart the engines.

Gas turbine performance measurement and fault determination are very important for gas turbine operation (Cohen, Rogers and Saravanamuttoo, 1996, Hünecke, 1997, Walsh, and Fletcher, 1998). The APU engine in the School of Engineering can be a platform for student teaching in this field. The aim of this study is to measure the small gas turbine thermodynamic parameters such as temperature, pressure, mass flow, fuel flow and shaft speed. The small gas turbine clean and deteriorated performance has then been investigated. The component faults were determined by using Gas Path Analysis. In this paper, measured gas turbine thermal properties are presented. A suite of computer programs has been implemented to analyse clean and deteriorated performance as well as to determine engine fault. A computer acquisition was developed in the measurement. An important objective is for students to measure gas turbine performance and determine faults.

DESCRIPTION OF GTCP30-92 APU

The gas turbine GTCP30-92 consists of a gear drive assembly, a centrifugal compressor and turbine rotating assembly, combustion chamber components, enclosing plenum and housing, a lubrication system, a fuel system and an electrical system.

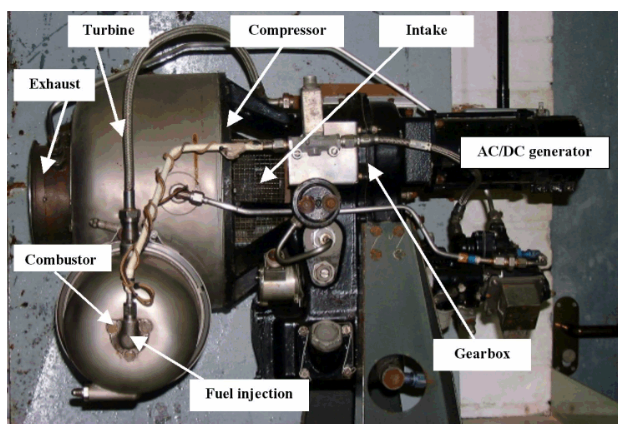

Figure 1 Main components

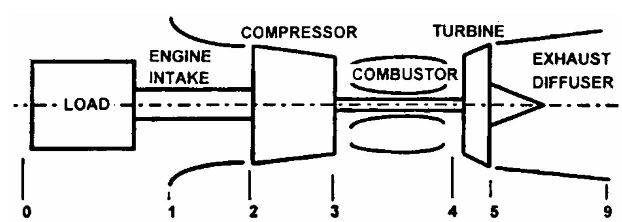

Figure 2: Engine Diagram

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The gear drive assembly consists of a reduction gear train with output and accessory drives of required RPM. There is an intake and an inlet screen before the centrifugal compressor. A single combustion tube is used in the engine chamber.

During operation of the engine at normal speed, the flyweight-type governor in the engine-fuel-control assembly controls the fuel flow. The control system also consists of an over temperature thermostat mounted in the engine tailpipe.

EXPERIMENT SETUP AND MEASUREMENT INSTRUMENTATION

The engine layout can be simplified as shown in figure 2.

Exhaust condition and mass flow

An extra exhaust duct was installed to set up the instrumention to determinate the exhaust conditions and the engine mass flow rate.

There are 3 wall pressures, 3 thermocouple probes to measure total temperatures and 3 Pitot probes to measure total pressures shown in figure 3.

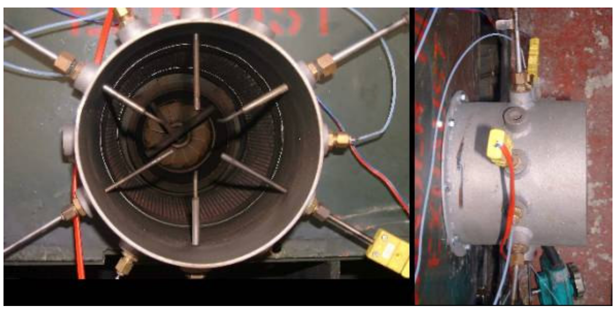

Figure 3: Exhaust Instrumentations

In order to achieve a precise value for the mass flow of the engine, the measurements of the parameters are carried out in different points on the exhaust tube radius. Referring to the British standard (British Standards Institution, 1981), Methods of Measurement of Fluid Flow in Closed Conduits, the instruments were positioned along the different radius ratios as: 0.3586, 0.7303 and 0.9358.

The mass flow can be calculated from the mean values of static, total pressure and total temperature measured in the intersection between the three circumferences and instruments radius

Measurement of temperature and pressure

The three static pressure tubes are connected together to obtain directly the average value. However this value is very close to zero since it is near the exit.

Another wall pressure and thermocouple were installed on a nut on the pneumatic control line at the exit of the compressor in order to obtain the compressor discharge pressure and temperature. These enable the compressor pressure ratio and efficiency to be determined.

The DPI101 digital pressure indicator was used to measure pressure in four different scales. The accuracy is 0.04% of the full scale.

K-type Chromel (chromium-nickel alloy) - alumel (aluminium-nickel alloy) thermocouples were used to measure temperature range between -200°C / 1370°C, with an accuracy of +/-2.2°C or 0.75% of the measurement.

Fuel flow meter

A ball flow meter has been installed on the fuel line before the injection in the combustion chamber. This flow meter was calibrated with an accuracy of 1% of the full scale.

A computer acquisition system was developed to analyse the test data by Huang.

Table 2. Performance Data

Compressor	Combustion	Turbine	Exhaust
PR = 2.26	η = 0.869	PR = 2.07	T9 =527(K)
η = 0.681	TET = 620(K)	η = 0.928	P9 = 101967(Pa)
CW = 67.5(KW)	FAR= 0.0064	TW = 67.5(KW)	$\dot{m} = 0.627(kg/s)$
P3 = 229082	P4=211555	P5=101967	Mach9 = 0.0975
T3= 399(K)	T4 = 620(K)	T5 = 527(K)	V9 = 43.71(m/s)
			A9 = 0.0217(m^2)

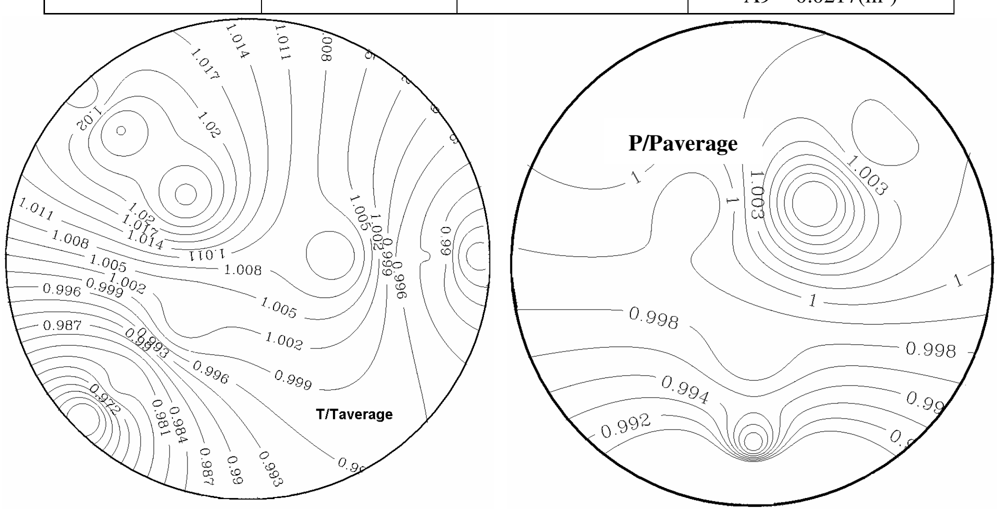

Figure 4.Exhaust temperature and pressure contour

MEASUREMENT RESULTS

Table 2 presents the measured performance data. The engine has a typical single-stage centrifugal compressor. Its efficiency is 68.1% and it is close to the manufacturer's design data (Garrett/Honeywell, 1951). The turbine efficiency is too high.

Figure 4 presents the measured exhaust temperature and pressure contours. Both of the temperature and pressure plots indicate non-uniform distributions. The measured temperature difference is over 39 degrees and about 7.3% of the exhaust average temperature. The exhaust temperature difference is about 0.61% of the exhaust average pressure. The temperature difference is larger than the pressure difference.

SIMULATION

The engine's design and behaviour have been explored using TURBOMATCH, a gas-turbine performance simulation program used in the Cranfield School of Engineering [Palmer, 1983].

Table 3

	Simulation	Experiment	Difference (%)
A5	0.0217	0.0214	-1.29%
T4(K)	628	622.8	-0.83%
T5(K)	523	527.0	0.77%
V5(m/s)	42.8	43.7	2.13%
P5(kPa)	101.923	101.968	0.04%
CW(W)	69479	69521	0.06%

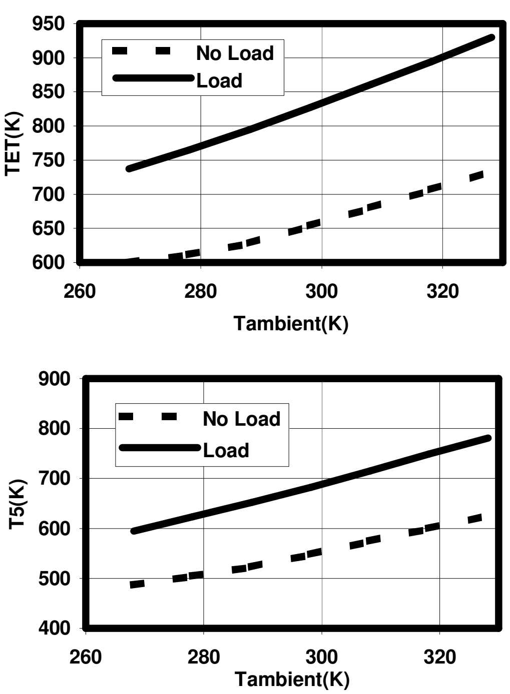

Figure 5. Turbine entry-TET and exhaust temperature T5 variation with ambient temperature

Design Point simulation.

Table 3 presents the comparison between the simulation and experiment. The simulation is in agreement with the experiment. The relative difference is less than 2.2% in order to match the exhaust jet speed and the compressor work. The turbine entry temperature is a bit higher than the experiment.

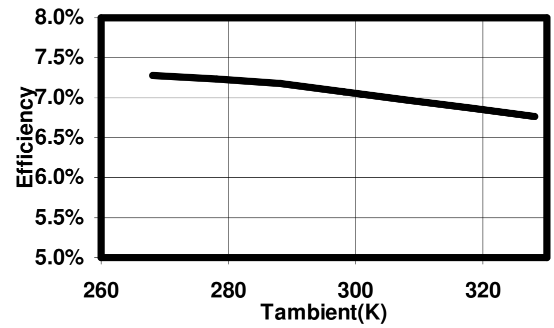

Figure 6. Cycle thermal efficiency with load against ambient temperature

Off-design performance with and without load

In the off-design simulation, the shaft speed remains constant (97.5% of design speed). In the case without load, the load of 20KW to drive the generator was disconnected.

Figures 5 and 6 present the influence of ambient temperature on the turbine entry and exhaust temperature as well as the cycle efficiency with load. In order to maintain the constant shaft speed, the turbine entry temperature increases with the ambient temperature. The cycle efficiency decreases with ambient temperature.

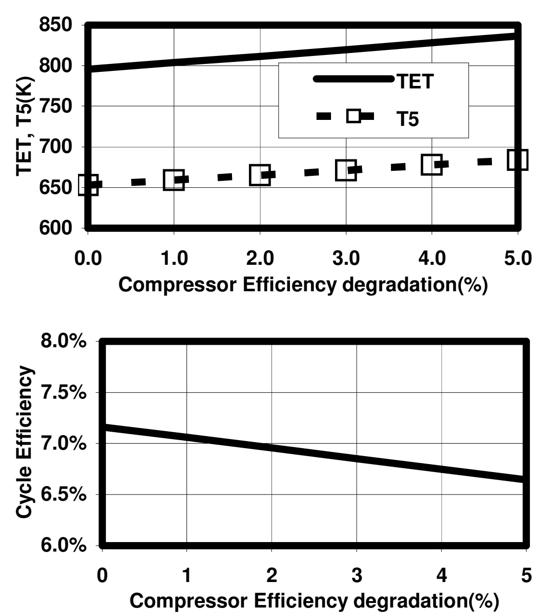

Figure 7. Influence of degradation in compressor efficiency

Degradation

The degraded engine performance was simulated with load by degrading compressor and turbine efficiency and mass flow capacity.

Figures 7 and 8 present the influence of degradation in compressor and turbine efficiency on the engine performance. In order to maintain the constant shaft speed, the TET and exhaust temperature rise with the increase in compressor and turbine efficiency drop. The cycle efficiency drops as well. At 5% efficiency drop, there is over 30-degree increase in TET and T5; there is over 5% drop in the cycle efficiency.

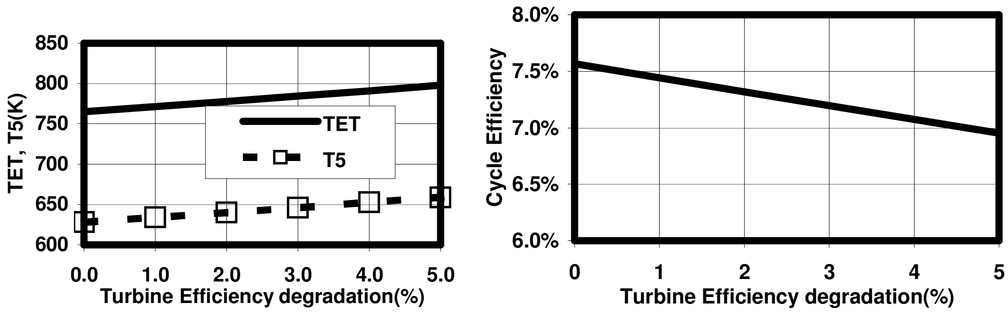

Figure 8. Influence of degradation in turbine efficiency

Table 4. Results of Gas Path Analysis

	Power Output	20KW		Linear GPA	Non-Linear GPA
Monitored parameters		Degraded Component	Implanted Faults:	Observed Faults:	Observed Faults:
P3	0.863	Compressor Mass Flow	-1.0	-1.085	-0.990
T3	1.194	Compressor Efficiency	-2.0	-2.105	-1.981
T5	4.307	Turbine Efficiency	-1.5	-1.560	-1.485
			RMS error:	0.086	0.015
P3	0.863	Compressor Mass Flow	-1.0	-1.078	-0.990
T5	4.307	Compressor Efficiency	-2.0	-1.880	-1.972
Fuel Flow	6.091	Turbine Efficiency	-1.5	-1.711	-1.492
			RMS error:	0.147	0.018
T5	4.307	Compressor Mass Flow	-1.0	-1.075	-0.991
Fuel Flow	6.091	Compressor Efficiency	-2.0	-2.092	-1.980
T3	1.194	Turbine Efficiency	-1.5	-1.572	-1.483
			RMS error:	0.080	0.016

Gas Path Analysis (GPA)

Linear and non-linear gas path analysis techniques were used to determine component faults in compressor and turbine. The Gas Path Analysis program – Pythia, has been applied to study instrumentation and monitoring (Escher, 1995). In the compressor, the efficiency drops by 2.0% and non-dimensional mass flow drops by 1.0%. The turbine efficiency drops by 1.5%. Three different sets of monitored parameters were investigated and the results are presented in table 4.

Non-linear GPA's results are better than linear GPA. The three sets of monitored parameters in non-linear GPA, all present good prediction of compressor and turbine fault. For linear GPA, monitored parameters are compressor discharge pressure, exhaust temperature and fuel flow; they give the biggest error in the prediction.

CONCLUSION

In this paper, the performance of the Auxiliary Power Unit (APU) – GTCP30-92 was measured and predicted by using TURBOMATCH. The aims of this study are to provide a test facility for students to test the engine and develop their abilities in gas turbine performance analysis. The test results show that the compressor efficiency, discharge temperature and pressure are in good accuracy close to the manufacturer's specification; the turbine efficiency is too high. The exhaust temperature shows stronger non-uniformity than total pressure.

The simulation is in good agreement with the test. The accuracy is within 2%. The gas turbine thermal efficiency drops as the ambient temperature rises at the constant shaft speed, but the turbine entry temperature rises quickly.

The gas path analysis has been applied to determine the component faults. In the current study, non-linear gas path analysis can give better results.

REFERENCES

Cohen, H., Rogers, G.F.C. and Saravanamuttoo, H.I.H., "Gas turbine theory", Longman, 1996.

Escher, P.C, 1995, "Pythia: An object-orientated gas path analysis computer program for general applications", PhD Thesis, School of Mechanical Engineering, Cranfield University, UK

Garrett/Honeywell, 1951, "GTCP30-92 Maintainance Manual"

Klaus Hünecke, "Jet engine, fundamentals of theory, design and operation", Airlife, 1997.

Palmer, J.R. 1983, "The TURBOMATCH scheme for Gas-Turbine Performance Calculations: Users' Guide", School of Mechanical Engineering, Cranfield University, UK

Walsh, P.P., Fletcher, P., "Gas Turbine Performance", Blackwell Science, 1998.

British Standards Institution, "Methods of measurement of fluid flow in closed conduits / British Standards Institution" Volume title: Part 1 Pressure differential devices: Section 1.1 Orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full", London: BSI, 1981, Series: BS 1042: Part 1: Section 1.1: 1981