

Aircraft Auxiliary Power Unit (APU) Condition Monitoring

Avwunuketa, Ayedun Alex
Aircraft Engineering
Department,
Faculty of Air Engineering,
School of Postgraduate studies,
Air force Institute of
Technology,
Kaduna, Nigeria.
alexavwunuketa@gmail.com

Danko, Aminu Umar
Aircraft Engineering
Department,
Faculty of Air Engineering,
School of Postgraduate studies,
Air force Institute of
Technology,
Kaduna, Nigeria.
mauaminu@gmail.com

Kadiri, Mudashir Olalekan
Aircraft Engineering
Department,
Faculty of Air Engineering,
School of Postgraduate studies,
Air force Institute of
Technology,
Kaduna, Nigeria.
alexavwunuketa@gmail.com

ABSTRACT

This paper is about diagnostics, prognostics and condition monitoring of aircraft auxiliary power Unit with the aid of a model. Auxiliary power unit (APU) is a gas turbine. Whenever energy is needed to perform other function other than propulsion of the aircraft, the APU is required. During ground operation such as loading, boarding and disembarking of passenger, there is need for good lighting and air conditioning for the comfort of passengers who are the source of income to the airline. For all these to be achieving, the APU at all-time should be serviceable. To sustain the reliability of the APU, it should be maintain against sudden or catastrophic failure. Condition monitoring is maintenance approach against sudden or catastrophic failure by predicting faults with the use of equipment that obtain data from the system itself. To achieve condition base maintenance (CBM) on the APU, models where developed, to monitor the conditions of all APU components such as the starter, compressor, combustor and the turbine against faults. The models are APU steady state performance model (ASSPM) and thermodynamic model (TM). These models make use of data from exhaust gas temperature (EGT), generator loads, shaft rotational speed, fuel flow and bleed pressure to monitor the conditions of the APU against failure, and also predict the cause of fault so that unnecessary maintenance action may not be carried out to save time and cost.

General Terms

Condition monitoring

Keywords

APU, Diagnostic, Exhaust Gas Temperature, Fuel flow, Prognostics, Rotational Speed.

1. INTRODUCTION

The section contains definition, classification and functions of auxiliary power Unit and condition - Based maintenance.

1.1 Auxiliary Power Unit (APU)

An auxiliary power unit is equipment in the aircraft that supply power to the systems that required power, when the main engines are shut down. The APU is a small gas turbine that allow the aircraft to be independent of ground power supply, it supply power to all electrical components and air conditioning systems. In adverse condition operation such as high altitude and high weight take-off or in an abnormal operation when the engine fails in-flight, APU supply power to the electrical systems to relieves the working engine load [1]. One of the most crucial components of the APU is the starter. It accelerates APU to a high rotational speed at

starting process to provide sufficient air compression for self-sustaining operation. The APU combustion temperature increases significantly when the starter performances reduce and its output power decreases. As the APU combustion temperature increases, it shortens the APU life span and cause immediate thermal damage. This causes economic losses and it is a menace to the safety of the airline. This paper focus on the conditioning monitoring of the APU to diagnosed incipient faults. Faults often manifest as a deteriorating trend in APU performance and there is a need to perform repairs and overhaul activities. Timely detection of incipient faults enables preventive maintenance and it has significant economic importance [2].

1.2 Condition-Based Maintenance

Maintenance is a very crucial, for keeping equipment and machines in safe and reliable state. In the early stage of the aviation maintenance, there is a philosophy of fly until something broke; this strategically allows aircraft equipment to run until it fails. No action was taken until the equipment fail. After the era of fly until equipment fail, preventive maintenance (PM) came into existence. With the strategy of preventive maintenance, actions are performed at time interval according to machine-run base schedule and can only avert the degradation of the equipment. The disadvantage that preventive maintenance has is that, it does not know the level of reliability or the actual health of the equipment. If the actual causes of equipment malfunction are not detected, catastrophic failures are still likely to occur and maintenance actions are perform unnecessarily.

Condition-based maintenance (CBM) is a more recently developed strategy that recommends maintenance decisions based on the information collected through system condition monitoring and equipment failure prognostics [3]. The condition-based maintenance could be able to accurately predict the actual health of the equipment and necessary actions are to be performed. This eliminates cost of unnecessary maintenance action that might have ignorantly been performed.

Three key steps are involved in a Condition-based maintenance (CBM)

- Data acquisition.
- Data processing
- Decision-making.

Data acquisition is the collection of useful data from targeted equipment for the purpose of CBM. Data processing involves the analysis and interpretation of data for the purpose of extracting features related to equipment health conditions.

Decision-making consists of two main aspects, diagnostics and prognostics. Diagnostics monitors the historical data and current status of the targeted equipment to detect the faults occurrence. Prognostics anticipate future status changes and prevent faults before they occur. [3] To ascertain the reliability of APU, data obtained aboard the aircraft are to be analyzed in order to know its deteriorating state and provide preventive maintenance. Typically there is considerable amount of data available regarding several parameters of the engine's performance, such as the EGT or Fuel Flow (FF) [4].

2. SYSTEM DESCRIPTION

2.1 Functions of the APU

An APU is a gas turbine device in aircraft with the purpose of providing power to other systems when the main engines are shut down. The power can be pneumatic, extracted from the bleed system or of electrical power extracted from the generator. The primary purpose of the APU is to provide bleed to start the main engines. It also provides power to run auxiliary devices such as electric pumps and air conditioning. Civil aircraft, however, may require power for considerable periods with the engines shut down; aircraft servicing and the loading of passengers, baggage and freight must be done before starting the engines. The passenger compartment must be maintained at a comfortable level of both temperature and relative humidity in ambient temperatures ranging from -50 to 50C [5].

2.2 Sections of the APU

The APU consists of an air intake, located in the middle of the unit, a centrifugal compressor and its discharge port for bleed air, a combustion chamber, a single stage turbine, an exhaust duct and an accessory section. The accessories include the APU fuel control unit, the fuel pump, the oil pump and a gearbox with the starter-generator and protective components such as anti-surge and a guide vane. The logics and control are executed by the Full Authority Digital Engine Control (FADEC) [6]. The APU is usually located at the tail section of the aircraft. Figure 2.1 shows the layout of APU and figure 2.2 shows a simplified APU schematic representation.

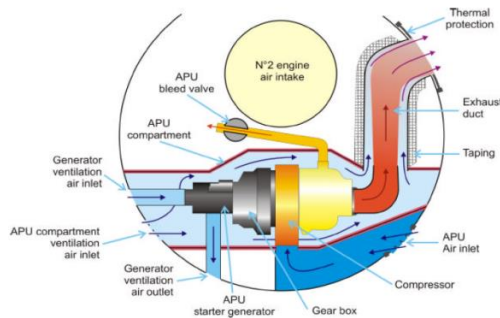


Fig 2.1 shows the layout of APU [7]

For information to be provided to the FADEC, the system must have sensors for several variables, such as exhaust gas temperature (EGT), rotational speed, bleed pressure and fuel flow.

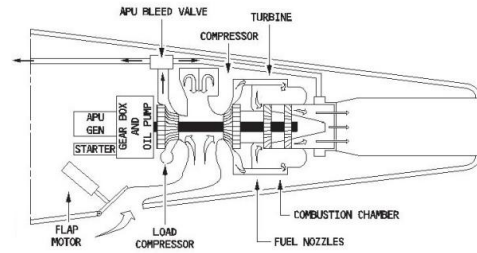


Fig 2.2 shows a simplified APU schematic representation [8]

The starting of the APU is an automatic sequence performed and monitor by FADEC through an electronic control box (ECB). Once the flight crew select the master switch ON in the cockpit and presses the APU START push button switch, it initiate the starting process. The FADEC controls the flows of fuel, by considering the rotational speed (N), exhaust gas Temperature (EGT) and air inlet condition.

3. CONDITIONING MONITORING METHODOLOGY

3.1 ASSPM Model

APU control architecture consists of individual subsystems controller that provide information to FADEC. The sensors are selected based on the systems requirements and not only for the benefit of conditioning monitoring. The overall areas of conditioning, diagnostics, trending and prognostics for faults are known in the industries as predictive Trend Monitoring (PTM)[6]. The model used for this paper is the APU steady state performance Model (ASSPM). The model diagram is shown in figure 3.1

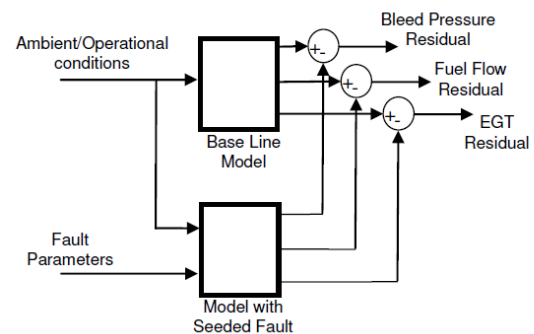


Fig 3.1 APU Steady State Performance Model

The Model is represented by the equation below

$$\hat{Y} = K * \hat{G} \dots \dots \dots (3.1)$$

Where $\hat{Y}$ is a vector representing performance prediction, $\hat{G}$ is input data vector and K is the fault parameter. The model is shown in the vector matrix form.

$$\hat{Y} = \begin{bmatrix} EGT \\ BP \\ FF \\ RS \end{bmatrix} \dots \dots \dots (3.2)$$

$$\hat{G} = \begin{bmatrix} T_{inlet} \\ P_{inlet} \\ IGV_p \\ L_{Gen} \end{bmatrix} \dots \dots \dots (3.3)$$

Substituting equations (3.2) and (3.3) into equation (3.1)

$$\begin{bmatrix} EGT \\ BP \\ FF \\ RS \end{bmatrix} = K \begin{bmatrix} T_{inlet} \\ P_{inlet} \\ IGV_p \\ L_{Gen} \end{bmatrix} \dots \dots \dots (3.4)$$

Comparing discrete data collected on the APU against the outputs of the simplified APU performance model accounts for much of the variation in the operating conditions [8], it gives the variations in the operating condition of the APU. The conditions monitored such as the Exhaust gas temperature, bleed pressure, fuel flow and engine rotational speed may vary from predetermine or required operating conditions. The different between the actual operating variable and the output from the variables monitored is called prediction residual variables (PRV). The prediction residual variables are the fault detected. This prediction residual variable model is shown with an equation 3.5

$$R_n = Y_n - \hat{Y}_n \dots \dots \dots (3.5)$$

To detect the APU faults and make the needed maintenance recommendations the residuals are trended [2].The model use for residual trending is shown in equation 3.6

$$R_n = R_0 + F_n + \delta_n \dots \dots \dots (3.6)$$

Based on residuals from faulty and healthy data in steady state condition, The first implementation step was to choose the failure modes variables used for model seeded fault, list of sensors and operational data snapshots for analysis.[6]

Eight types of faults were considered:

1. Increase in shaft torque extraction.
2. Increase in bleed.
3. Reduction in compressor efficiency.
4. Reduction in turbine efficiency.
5. Speed sensor
6. EGT sensor
7. Reduction in combustor efficiency.
8. Decrease in fuel flow

3.2 Thermodynamics Model

Mathematical model of an APU derived from thermodynamics principles were used to generate healthy and faulty data. The thermodynamic model has four inputs and three outputs which represent APU sensors. The compressor, combustor and the turbine are the blocks in the model that has thermodynamic behavior. The model is shown in figure 3.2

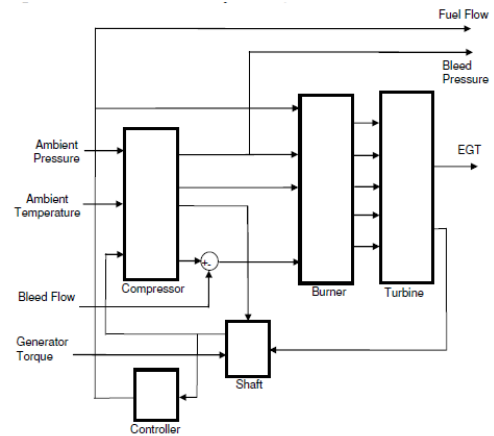


Fig 3.2 Thermodynamic model

3.2.1 INPUT TO COMPRESSOR

The ambient temperature, ambient pressure and shaft rotational speed are inputs to the compressor. The compressor outputs are airflow, compressor pressure and temperature and compressor torque. The compressor behavior is based on the pressure ratio, temperature, speed and airflow Figure 3.2 show the compressor map.

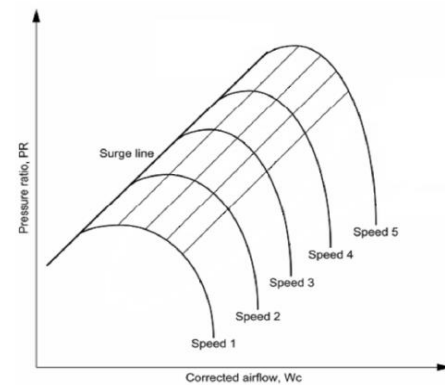


Fig 3.2 The compressor map

Pressure ratio (P_R)

$$P_R = \frac{P_{out}}{P_{in}} \dots \dots \dots (3.7)$$

Corrected airflow (W_c)

$$W_c = W^* \sqrt{\frac{\theta}{\delta}} \dots \dots \dots (3.8)$$

$$\theta = \frac{T_{in}}{T_{ref}} \dots \dots \dots (3.9)$$

$$\delta = \frac{P_{in}}{P_{ref}} \dots \dots \dots (3.10)$$

Corrected Rotational Speed (N_c)

$$N_c = \frac{N}{\sqrt{\theta}} \dots \dots \dots (3.11)$$

3.2.2 INPUTS TO COMBUSTOR

Compressor pressure and temperature, air flow and fuel flow are the input into the combustor. The outputs are combustor pressure and temperature, air flow and air-fuel ratio. The input-output characteristic of the combustor is represented with equation 3.12

$$h_{out} = \frac{m_{air} \times h_{in} - H_V \times m_{fuel}}{m_{air} + m_{fuel}} \dots \dots \dots (3.12)$$

4. CONCLUSION

Based on the present study on condition monitoring of the APU, the following concluding remarks are drawn:

- The detail analysis of data required for APU starting, can be obtained from overall start time, using peak EGT and the speed at which the peak occurs.
 - Only relevant components are used for integrating a model intended for diagnostic during starting mode.
 - Collecting data from the sensors can give more accurate diagnostic of the APU faults.
 - The level of APU reliability can also be predicted or monitored by collecting data from the sample
 - APU condition can also be monitor by including noise and vibration sensors.

The present models used for the condition monitoring of aircraft APU can be functionally improve by using various computer simulation programs. These results need experimental data to validate it.

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