COMMERCIAL ENGINE MONITORING STATUS AT GE AIRCRAFT ENGINES CINCINNATI, OHIO

by

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SUMMARY

This paper describes the design, introduction and development of expanded commercial engine monitoring systems by GE Aircraft Engines. The history of present systems is outlined starting from the introduction on the CF6-80A3 engine for the A310 aircraft of the Propulsion Multiplexer (PMUX) which has led to similar systems on the CF6-80C2 engine. The impact of the full authority digital control on future system is also discussed.

The introduction and application of the Ground-based Engine Monitoring (GEM) software developed by GE in conjunction with several airline users is recounted. This is an on-going team effort with the users playing a key role and where individual airlines have added unique features, integrated with GEM, into their own operations. The original software development occurred in parallel with the expanded sensor complement and digitization of data. A description of the functions of a typical ground software program is provided together with proposed improvements and future directions.

INTRODUCTION

The introduction of "on condition" maintenance concepts for high bypass turbofan engines encouraged the use of advanced engine monitoring techniques. Although GE had participated in several monitoring programs to support the CF6-6 and CF6-50, the CF6-80A3 engine on the A310-200 aircraft for KLM and Lufthansa Airlines was the first to be equipped with expanded capabilities. These capabilities included sufficient instrumentation for modular performance assessments, an expanded aircraft data system and an analytical ground software program.

Many airlines have in fact utilized engine monitoring techniques for a number of years, driven by the introduction of "on-condition" concepts in the late 1960's. Initially, expanded instrumentation complements resulted in widespread systems problems, many associated with the transmittal of analog signals over long distances in aircraft. The introduction of the PMUX on the CF6-80A3 engine, with the associated transmittal of highly accurate, reliable digital data, was a key factor in making the expanded engine monitoring approach work. The functions of the PMUX are now being incorporated into the new generation of full authority digital electronic controls with resultant reduction of unique monitoring hardware and software, yet with a further expansion of capabilities.

The ground-based engine condition monitoring (GEM) software for many GE and CFM International powered aircraft is described. This GEM system provides the capability to monitor and analyze a wide range of engine thermodynamic and mechanical measurements with a single, flexible computer program.

Measurements acquired with the standard engine instrumentation as well as extended monitoring instrumentation if available, are recorded during normal engine operation. These data are generally stored for subsequent retrieval using an on-board data acquisition system. The data recorded during flight, along with test cell performance measurements, are input into the airline's computer system for ground-based processing with the GEM system. The results from the GEM processing are made available to various airline organizations in order to monitor and manage the engines within their fleet.

The GEM monitoring system is designed to provide an airline with a valuable tool with which to manage its aircraft engines relative to such concerns as safety, availability, maintainability, fuel costs, and improved performance.

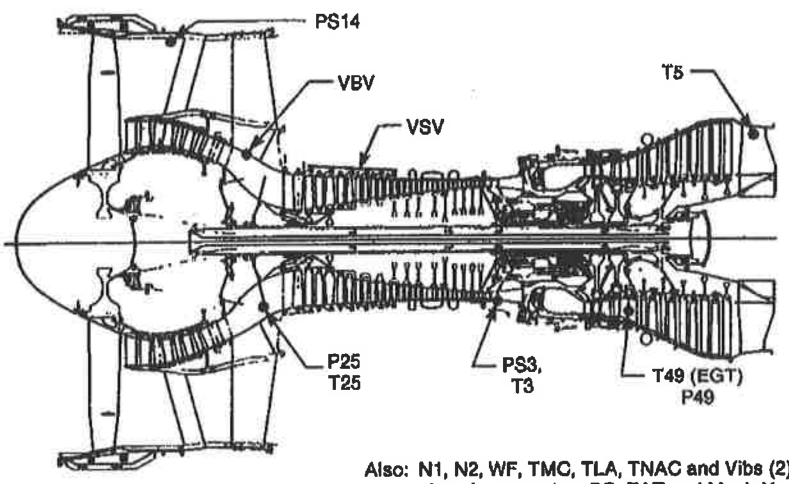
Directions for the future show that some of the functions which are presently performed on the ground will be performed airborne where useful to flightline operations. Airborne diagnostics will be enhanced and results, rather than raw data, will be transmitted across the avionics data bus thus making available to the line mechanic useable information for accomplishment of his maintenance tasks. The paper concludes with a discussion of these future plans for commercial engine monitoring and current operational experience.

SYSTEM DESCRIPTION

On-Engine Hardware

The PMUX was developed to provide consistent, accurate data suitable for gas path analysis or modular fault isolation. It is a convection-cooled, microprocessor-based unit which houses pressure transducers, signal conditioning and analog to digital conversion. It has extensive built-in-test and signal validity checks. All of the signals critical to the gas path analysis/modular fault isolation function are routed through the PMUX to maintain consistent, accurate data, other than N1, TMC and TLA, which are processed by the Power Management Control (PMC) and made available on the digital data link.

CF6-80 Condition Monitoring Parameters



Also: N1, N2, WF, TMC, TLA, TNAC and Vibs (2) plus aircraft parameters PO, TAT and Mach No.

Figure 1

The instrumentation complement for the CF6-80A3 engine is shown in Figure No. 1. Instrumentation for the CF6-80C2 is essentially the same. These sensors can be sub-divided into the following categories:

A. Signals required for indication/control purposes and routed through the Propulsion Multiplexer (PMUX) or Power Management Control (PMC):
- Fan Speed (N1)
- Core speed (N2)
- Throttle Lever Angle (TLA)
- Fuel Flow (WF)
- Main Fuel Flow Torque Motor Current (TMC)
- LP Turbine Inlet Temperature (T49)

B. Additional signals required for Engine Monitoring which are routed through the PMUX:
- Fan Discharge Static Pressure (PS14)
- Compressor Inlet Pressure (P25)
- Compressor Inlet Temperature (T25)
- Compressor Discharge Static Pressure (PS3)
- Compressor Discharge Temperature (T3)
- LP Turbine Inlet Pressure (P49)
- LP Turbine Discharge Temperature (T5)
- Variable Bypass Valve Position (VBV)
- Variable Stator Vane Position (VSV)

C. Additional signals required for Engine Monitoring but not routed through the PMUX or PMC:
- #1 Bearing (Fan) Internal Accelerometer
- Alternate Fan Frame External Accelerometer (Optional)
- Compressor Rear Frame External Accelerometer
- Nacelle (core compartment) Temperature (TNAC)

D. Aircraft parameters required for engine monitoring (not including anti-ice and bleed discretes):
- Pressure Altitude (PO)
- Total Air Temperature (TAT)
- Aircraft Mach No. (MN)
- Other instrumentation available as part of the inflight data record consisting of oil temperature, oil pressure and oil quantity.

The interfaces with the PMUX and PMC are shown in Figure No. 2.

CF6-80C Fan Compartment Interface Wiring and Connector Schematic

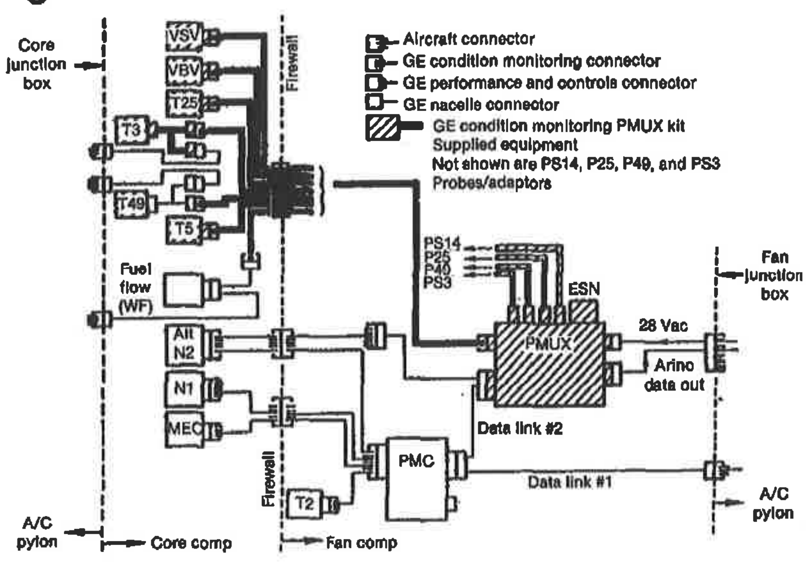


Figure 2

The PMUX is mounted on the engine fan case. Electrical leads are combined in a harness and routed from the core to the fan compartment and to the PMUX. The pressure sensors (sources) are connected by tubing to the pressure transducers which are contained within the PMUX unit. In addition a raw N2 (core) signal is routed to the PMUX and an ARINC data link connects the PMC to the PMUX. Thus, the PMUX accepts analog and digital inputs from various added and existing engine sensors. These inputs are conditioned, multiplexed, and converted to digital format (ARINC 429) for output to the Aircraft Integrated Monitoring System (AIMS).

In addition, an encoded Engine Serial Number plug (ESN), lanyarded to the fan case, interfaces with the PMUX and provides the means for "Tagging" acquired data with the appropriate engine serial number.

A more detailed description of the hardware is contained in Ref. 1.

Instrumentation for the Full Authority Digital Controlled (FADEC) CF6-80C2B 1F/DIF and CFM56-5 is similar to that described above, but the system no longer requires a separate PMUX. The functions of the PMUX are contained within the FADEC which provides the signal conditioning and the digital interface with the aircraft. The parameters which required an analogue interface (e.g. vibration) still require that interface in this first generation of FADEC controlled engines. It is anticipated that future applications, such as the GE36 engine for the UDF™, will possess a purely digital link with the aircraft. (See Figure No. 3). The majority of the engine monitoring, fault isolation and detection will be performed on engine. Space and flexibility considerations are presently dictating that there be two on-engine boxes, one for control and flight critical purposes and the other for engine monitoring.

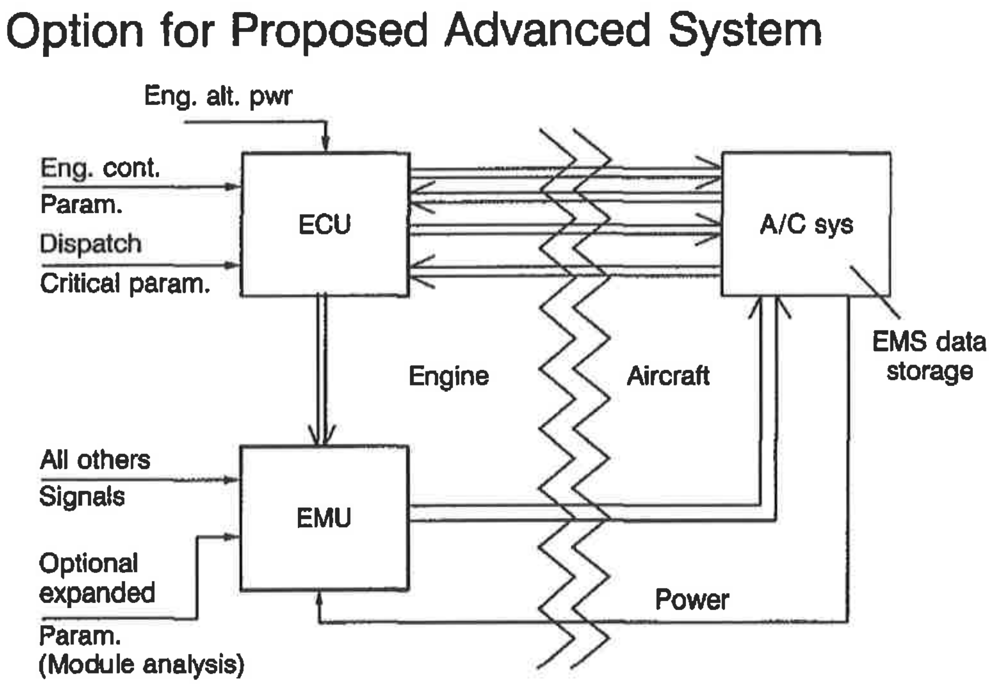


Figure 3

Ground-Based Engine Monitoring

The flow of engine monitoring data is shown in Figure No. 4. The Ground-based Engine Monitoring (GEM) system provides the capability of handling a wide range of engine thermodynamic and mechanical functions (see Figure No 5) within a single very flexible program. The software was developed as a co-operative effort involving GE and a group of airlines (originally KLM, Lufthansa and SAS). The resulting design is shown in Figure No. 6.

Schematic of Engine Monitoring Information Flow

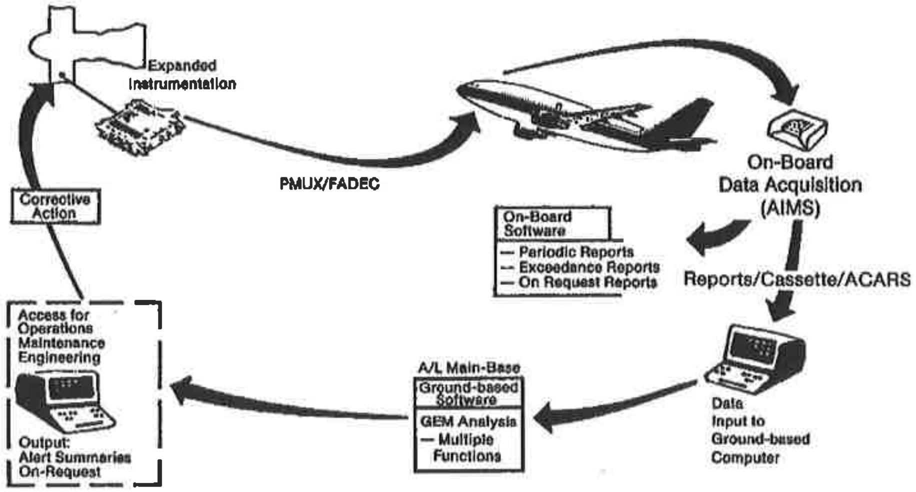


Figure 4

Ground-based Engine Monitoring System Analysis Functions

Function	Purpose
On-wing temper*	Analyze cruise gas path data to determine overall engine and module health
Test cell temper*	Analyze acceptance test gas path data to determine overall engine and module health
Takeoff margin assessment	Analyze takeoff data to determine the EGT margin of the engine
Control schedule analysis	Compare measured control variables to nominal schedules and limits
Vibration trend analysis	Compare measured vibrations to limits to identify potential imbalances
Fan rotor imbalance	Use measured fan vibration amplitude and phase angle to determine balance weights to correct fan imbalance
Fleet average	Compute fleet statistics for engine family and identify low performing engines

*For turbine engine module performance estimation routine

Figure 5

DOCKET ALARM

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