EXAMPLE OF RECORDING

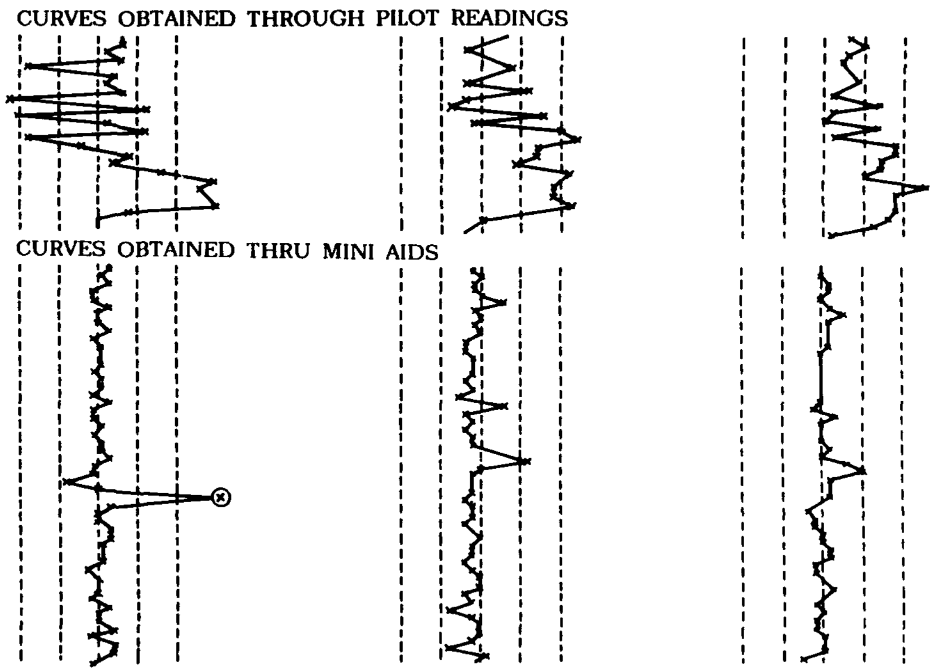

Figure 2A

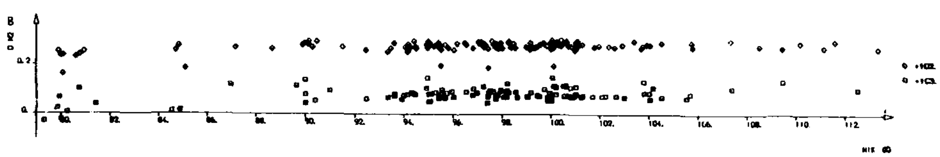

Figure 2B

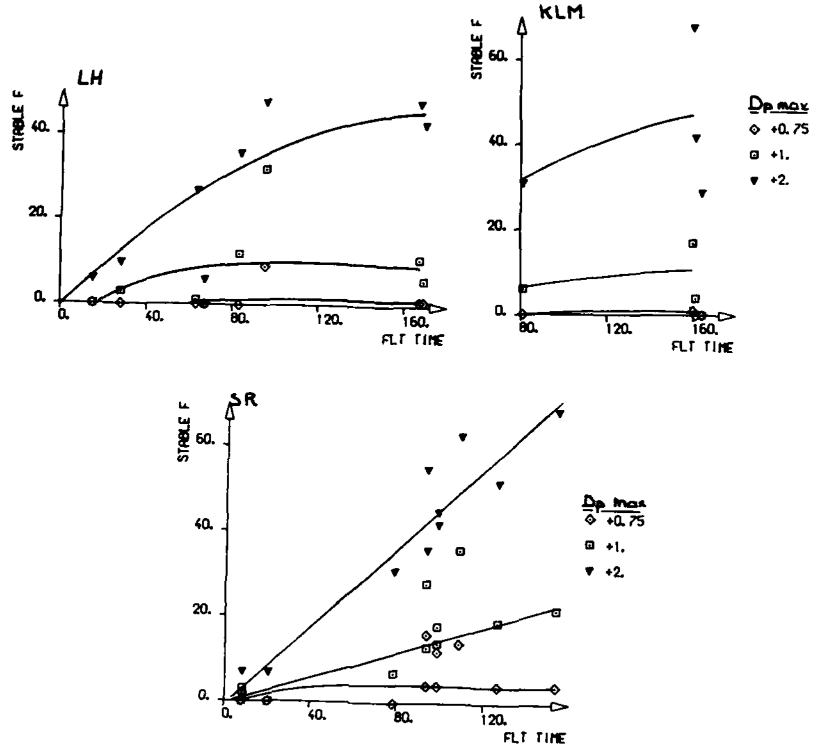

Figure 3

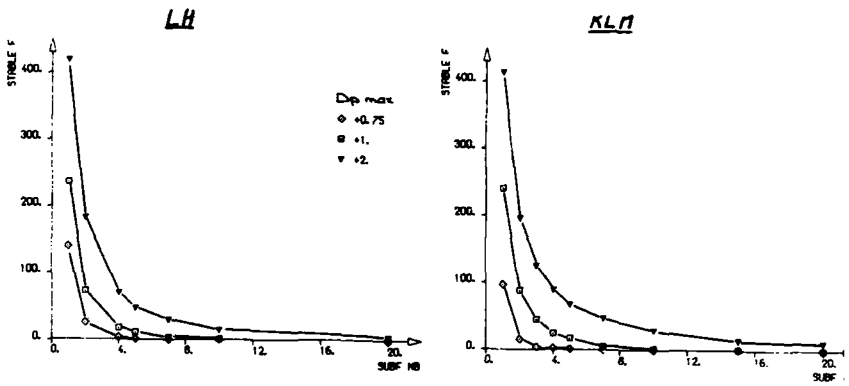

Figure 4

F100-PW-220 ENGINE MONITORING SYSTEM

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FOREWORD

This discussion reviews the development and operational experience of the F100-PW-220 Engine Monitoring System currently in service with the United States Air Force and other national defense air forces utilizing the F100-PW-220 engine and its derivatives.

INTRODUCTION

The F100-PW-220 Engine Monitoring System (EMS) is one of the most advanced logistics support tools in production for the Pratt & Whitney F100 family of gas turbine engines. The highly successful introduction of the PW-220 EMS represents over ten years of diagnostic system and maintenance technology development using the latest in aerospace electronic component design and digital, engine control system implementation. The PW-220 EMS is a comprehensive engine support system that is fully integrated with in-flight aircraft operating systems, as well as, ground-based maintenance and logistics systems.

BACKGROUND

The PW-220 EMS was developed by Pratt & Whitney and Hamilton Standard, both of United Technologies Corporation, in conjunction with the F100 Digital Electronic Engine Control (DEEC), for the Aeronautical Systems Division, Air Force Systems Command, USAF. Many of the PW-220 EMS hardware and monitoring concepts were derived from an earlier development system, known as the F100 Engine Diagnostic System (EDS), which acquired over 2500 flight hours of operational testing with F100-PW-100 engines in USAF F-15 aircraft. Experience from the initial F100 production engine monitor, the Events History Recorder (EHR), also contributed to engine usage algorithms for the PW-220 EMS. The "lessons learned" from these early efforts, along with the improved data acquisition and self-testing capabilities of the DEEC system, provided the basis for development of an effective diagnostic, maintenance and logistic support system.

PW-220 EMS development began in April 1982 and achieved an interim milestone with first production deliveries in November 1985. Engineering work continued through November 1987 to incorporate additional aircraft integration and logistics database compatibility features. System growth and improvements are an on-going effort, as field experience is accumulated.

SYSTEM OBJECTIVES

The primary objective of the PW-220 EMS is to provide information to assist in identifying faulty engine control system components, detecting and documenting engine operation beyond acceptable limits, recording normal engine usage, and tracking engine performance. Encompassed in this single objective a redesign goals which include: 1) Fully automatic in-flight operation, 2)Electronic data transfer to aircraft and ground systems, 3) No off-engine mounted flight components, 4)Modular component design for enhanced system maintenance, 5)Minimum dedicated flight sensors, 6) Field upgradable software and flightline reprogrammability, and 7) Engine and aircraft interchangeability.

For the maintenance/logistics user, achieving the system objectives means fewer maintenance actions, fewer maintenance man-hours expended, fewer on-site spares required, increased maintenance effectiveness and increased engine/aircraft availability. For the operational user (pilot), a reliable EMS provides better real-time analysis of propulsion system integrity, higher probability of successful mission completion, and an overall reduced cockpit workload. For the engineer, the PW-220 EMS provides in-flight operational data automatically or on pilot request, without adding extensive instrumentation and specialized recording equipment; however, unlike earlier, less successful attempts, the PW-220 EMS is designed for maintenance support first, and engineering data acquisition is accomplished as a secondary benefit.

SYSTEM DESCRIPTION

The PW-220 EMS is comprised of five subsystems (Figure 1). There are two engine mounted units: 1) the digital control, DEEC, and 2) a dedicated engine monitor designated the Engine Diagnostic Unit (EDU). Two ground support units are used for flight line and uninstalled engine test stand operations: 1) the Data Collection Unit (DCU), and 2) the Engine Analyzer Unit (EAU). The fifth subsystem is the link to the user's engine logistics database system; in the USAF, this interface is called the Ground Station Unit (GSU).

Digital Electronic Engine Control (Figure 2)

During engine operation, whether installed in an aircraft, or a stand-alone test cell, the DEEC continuously transmits engine parametric and control system fault data to the EDU across a simplex, serial digital communication bus, at the rate of 9600 bits per second. Approximately 300 individual pieces of information are transmitted every 250 milliseconds.

In the process of controlling the engine, the DEEC is measuring and evaluating temperatures, pressures, speeds, positions and interface conditions to maintain stable, safe operation in response to the pilot's power lever or discrete input commands. If a failure is detected in the internal electronics of the DEEC, or in the sensor input circuits, or the DEEC is unable to maintain control, automatic fault accommodation takes place to regain control or operate in a degraded capacity. The resulting fault data is transmitted to the EDU in the form of an eight bit "Fault Code", for each failure.

Engine Diagnostic Unit (Figure 3)

The EDU performs a passive function as an electrical junction box, routing analog electrical signals to the aircraft for display. In its active role, the EDU operates on a basic computational cycle determined by the update rate of the data being received from the DEEC; ie., 250 milliseconds or four times per second. Within the nominal compute cycle, the EDU: 1) receives serial data from the DEEC, 2) conditions and measures the analog cockpit signals , 3) evaluates the integrity of the data acquired, 4) executes a pre-determined diagnostic logic sequence, 5) records in non-volatile memory the fault codes from the DEEC, data exceptions identified from the logic execution and data from the engine usage algorithms, 6) performs a comprehensive internal electronic self-test, 7) responds to high-speed digital communications from aircraft data systems, 8) generates a real-time serial digital data transmission for off-engine acquisition systems, and 9) activates aircraft-mounted engine status indicators, when faults are detected.

Data Collection Unit (Figure 4)

On the flightline, the DCU is used by the aircraft support technican to retrieve and review flight data recorded in the EDU. The portable, battery-operated DCU is connected by means of an integral cable assembly to a readily accessible engine harness. By following the menu-driven instructions displayed on the hand-held unit, the operator automatically downloads the recorded data into non-volatile memory devices housed in a removable cartridge within the DCU. Electrical power for the EDU, during the 30 second download operation, is provided by the removable DCU battery pack.

If the engine status indicators, located in the aircraft, are tripped denoting faults detected during the flight, the technician may choose to review the fault codes and event data recorded. The DCU will also evaluate the combinations of reported faults against an internal set of engine trouble shooting logic, and display a "maintenance code", which is referenced to the detailed maintenance instructions needed to isolate and correct the fault. Normally, a single DCU with a fully charged battery pack and a clean memory cartridge has sufficient capacity to service a complete squadron of aircraft.

Engine Analyzer Unit (Figure 5)

When an engine fault has been detected and the DEEC or EDU may be suspect, the EAU is used to assist in fault isolation. With access to the underside of the engine, special circuit simulators, stored on the EAU, are substituted for the normal electrical interfaces on the DEEC. Duplex serial communication is established between the DEEC and EAU, and, once again, by following the menu-driven instructions, the operator performs a complete check of the DEEC, executed by means of temporary diagnostic programs uploaded automatically from the EAU. The pass/fail results displayed to the technician either confirm the location of the fault within the DEEC, or direct further troubleshooting. A similar capability exists to test the EDU, and the EAU can be used to perform all the data retrieval functions of the DCU, except non-volatile data storage.

Although the EAU requires an external electrical power source, it does supply conditioned power to the DEEC and EDU, when under test, to permit trouble-shooting without engine operation. If the fault isolation procedures do require engine operation, or for post-repair operational verification testing, the EAU may be used as a real-time monitor and display; data from the DEEC, EDU or both serial digital outputs may be viewed simultaneously. Changes to the programmed control law limits in the DEEC or the diagnostic constants in the EDU are also accomplished using the EAU, with the components remaining installed on the engine.

Ground Station Unit (Figure 6)

The GSU hardware may vary from user to user, but it is generally some microcomputer-based device capable of standard serial digital communication. For the USAF, the GSU is a desktop, commercially available computer standardized for use in multiple applications. It is the interface device to the base-level logistics system from, not only the flightline, but the various base maintenance facilities, as well.

PW-220 EMS data products are downloaded to the GSU by electronic transfer from a DCU. The recorded memory cartridge is first installed in a local DCU, or the flightline DCU is carried to the aircraft maintenance support hangar and then connected by means of interface cabling to the serial port on the GSU microcomputer. Selecting the appropriate operating mode from the DCU menu, the GSU operator follows a second GSU menu of instructions to complete the data transfer to GSU memory. GSU software processes the EMS data to formulate engine history records, calculate engine life-limited part parameters and evaluate engine performance margins.

DIAGNOSTIC LOGIC

Analysis of engine data in the PW-220 EMS is accomplished in real time, any time the engine is operating. Decisions concerning control system health and engine operating conditions are made continuously by the EDU during every computational cycle. (Figure 7). For some conditions, where the four hertz data rate from the DEEC is not adequate for the EDU to reliably capture high speed events, the DEEC, which operates on a shorter compute cycle, pe forms the event detection function in the process of accommodating the anomaly, and the EDU records the occurrence later, when notified in the DEEC serial data.

The EDU uses the parametric data obtained from the DEEC for diagnostic logic execution. Data which the EDU acquires from its own measurements or from aircraft systems generally supplement the DEEC data, in case of communication failures or DEEC input faults. Prior to executing the diagnostic logic, data validity checks are performed to avoid erroneous conclusions. If a required parameter is determined to be invalid, a substitute parameter is selected, an alternate logic path is executed, or the logic function may be bypassed entirely.

At the end of each logic sequence, the results are evaluated against any faults previously stored during the current flight cycle, and, in the condition is the first occurrence during the flight, a fault code, similar in format to those transmitted by the DEEC, is recorded along with the relative time of occurrence in the flight. During each subsequent compute cycle in the EDU, the condition is re-evaluated. Depending on the type of anomaly in progress, raw and or computed data may accumulated, which describes the severity of the condition or provides some key information necessary to accurately assess the effect of the occurrence on engine health or assist in directing post-flight investigation and repair. As an example,the duration and maximum temperature reached is recorded, when a turbine over temperature event is detected.

Engine Events

The following table identifies the engine events recorded by the PW220 EMS:

Table 1. F100-PW-220 EMS Engine Events

Turbine Overtemperature	Low Rotor Overspeed
Augmentor Anomaly	High Rotor Overspeed
Stall Detect	Compressor Vane Flutter
Stagnation Detect	Control Auto-Transfer
Dieout Detect	Low Oil Pressure
Hot Ground Start	High Oil Pressure
Hot Air Start	Start Bleed Failure
No Start	Inhibited Augmentor
Anti-Icing System Overtemperature	Low Thrust
Anti-Icing System Failed Open	Anti-Icing System Failed Closed
Slow Turbine Temperature Probe.	

AIRCRAFT INTEGRATION

The availability of high-speed data bus communications with aircraft systems, offers an excellent, relatively inexpensive data source for engine monitoring purposes, as well as, an opportunity to provide the pilot better indications of the propulsion system health, without the need for analyzing cockpit gauges or stuffing indicator panels with confusing lights. Through interaction with the aircraft cockpit display and data management computer, the PW-220 EMS is capable of supplying real-time engine operating data to augment or replace normal analog data systems. It also provides a continuously updated message identifying every fault detected and each engine event recorded. In exchange, the EDU acquires aircraft altitude, speed and attitude information to supplement recorded event data.

OPERATIONAL EXPERIENCE

The F100-PW-220 engine entered production service in November 1985 with USAF F-15 aircraft. During 1986 and 1987, F-16 aircraft were delivered with F100-PW-220 engines to the USAF, as well as, the air forces of South Korea and Egypt. Approximately 400 units have now accumulated over 20,000 flight hours in world-wide operations,including scenarios ranging from routine training missions to full defense alert. The PW-220 EMS has also supported remote site deployments for extended time periods. In all applications, the performance of the EMS has met or exceeded its operational objectives.

System Performance

EMS performance monitoring is primarily accomplished by tracking the detection of engine faults and events by both EMS and the pilot. Each report is evaluated for validity and then the pilot and EMS reports are compared to determine an interim classification of "HIT" or "MISS", where:

HIT = Valid EMS detected occurrence

MISS = Invalid EMS detected occurrence, or
Valid pilot detected occurrence, within the EMS detection criteria,
but not detected by EMS

These categories are further subdivided for detailed analysis as follows:

HIT = ACTUAL, or INDUCED occurrences

where,

ACTUAL = Real fault or event

and,

INDUCED = Real occurrence resulting from pilot or maintenance actions

Also,

MISS = FALSE, or UNDETECTED occurrences
where,

FALSE = Invalid fault or event

and,

UNDETECTED = Real occurrence not detected

For the purpose of determining a figure of merit for EMS performance, two additional values are needed:

OPEN = Occurrence of undetermined validity

and,

GOOD = Sortie (flight) with no occurrences

From these statistics, two performance factors are derived:

The first, system effectiveness, is a measure of the EMS capability to correctly detect occurrences or confirm the absence of them. In equation form:

EFFECTIVENESS = 1 { (OPENS + MISSES) / (GOODS + HITS) }

The second factor, confirmation rate, only considers the validity of detected occurrences, and is expressed as:

CONFIRMATION RATE = (HITS) / (HITS + MISSES)

Both performance factors are generally calculated as percentages.

Field Results (Figure 8)

Based on operations through August 1987, with 19043 total engine flight hours and 9502 sorties flown, the PW-220 EMS performance factors are:

EFFECTIVENESS = 99.3 %

and

CONFIRMATION RATE = 92.7 % 8

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