COMMERCIAL AIRCRAFT MAINTENANCE EXPERIENCE RELATING TO ENGINE EXTERNAL HARDWARE

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Abstract

In today's business environment, airlines are extremely sensitive to the amount of dollars spent on maintaining the external engine hardware in the field. Analysis reveals that many problems revolve around a central issue, reliability. Fuel and oil leakage due to seal failure and electrical fault messages due to wire harness failures play a major role in aircraft delays and cancellations (D & C's) and unscheduled maintenance. Correcting these items on the line requires a large investment of engineering resources and manpower after the fact. Today's issues are being corrected, but only after many costly delays and cancellations, unscheduled maintenance visits and extensive upgrade programs. And in some cases there have been two or three different design improvement campaigns. In terms of maintenance and reliability of engine external hardware, there is much room for improvement. The smartest and most cost effective philosophy is to build the best hardware the first time. The only way to do that is to completely understand and model the operating environment, study the field experience of similar designs and to perform extensive testing.

Pratt & Whitney PW4000 Engine External Components

This discussion will be limited to the Pratt & Whitney PW4000 engine, one of the newest and most technically sophisticated jet engines operating today. There is over 5 years of field experience relating to the reliability and maintainability of the engine's external components in which to analyze. Presented below are the results of a reliability analysis of external engine components.

External engine components consist mostly of fuel, oil and pneumatic lines, valves, actuators, heat exchangers, gearboxes, fuel and oil pumps, fuel metering units (FMU), engine electronic controls (EEC), wiring harnesses, sensors and switches and all the hardware necessary to support it such as brackets, clamps and nuts and bolts. All are essential to the proper operation of a jet engine. For example, external components which control the engine's secondary airflow systems are extremely important to efficient and reliable operation. It was determined during the design phase of the engine that the cost to design, test, and manufacture these systems let alone the cost of the additional weight, is greatly offset by their gain in Specific Fuel Consumption (SFC). If one of the systems has to be inopted because of a component seal failure, it could mean upwards to 2% additional fuel burn. Over a long mission this additional fuel burn quickly adds up. Thus it is extremely important that all systems are operating properly.

Delays And Cancellations

One of engineering's main objective, in the airline business, is the reduction of delays and cancellations in the fleet. Over the past five years, 1157 delays and 111 cancellations were incurred due to engine related items in the PW4000 fleet for United Airlines alone. A large number of delays and cancellations are related to the reliability of the engine external components. When studying the

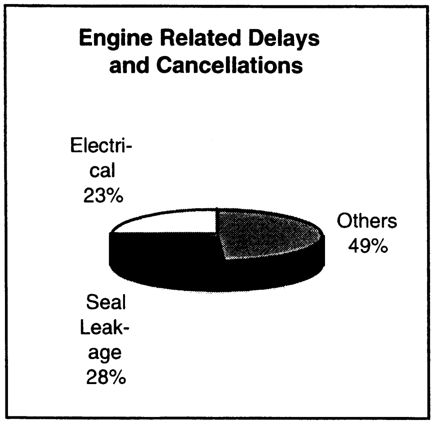

Figure 1

data in even more detail, the majority of reliability items are related to carbon, fuel and oil seal leakage followed by electrical wiring problems. See figure 1. The other category contains items such as bird strikes, hung starts, HPC compressor stalls, etc.

Seal Reliability Issue

Since the introduction of the fleet in 1991, there has been a number of seal related problems which were uncovered in service. Early on there were premature failure of fuel seals in the intercompressor bleed (2.5), stator vane actuator (SVA) and turbine case cooling (TCC) actuators. In addition, fuel leaks within the FMU began to cause a delay and cancellation situation. Later in the program carbon seal leaks appeared in the gearbox and bearing areas. Most of the premature failures resulted in a delay or cancellation which drove the need for aggressive engineering research, development and testing of new designs. In addition, line maintenance personnel was given extensive training on how to recognize leaks which could be safely deferred to the next convenient maintenance opportunity. Because of aggressive projects to replace older, less reliable hardware with newly designed hardware several thousands of revenue dollars were saved on unscheduled line maintenance resulting in on-time departures and an increase in customer satisfaction. A drop in delays and cancellations is finally being realized for in the first half of 1997, the level is one-third less then the first half of 1996. See figure 2.

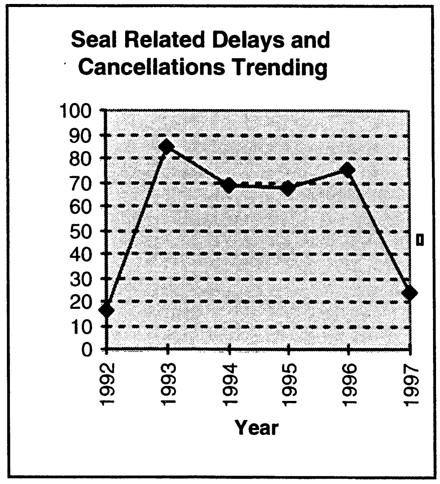

Figure 2

Electrical Reliability Issue

A similar trend can be seen for delays and cancellations caused by electrical problems. See figure 3. Early in the program, actuators also experienced internal wire harness chafing problems which resulted in component failure messages. These units where quickly replaced on the line with units which contained a more robust wire harness design. At the same time, problems with engine wire harnesses and connectors surfaced. Since this is one of the first FADEC engines, both, the manufacturer and end user, had some lessons to learn about how important it was to have a robust harness system. From a manufacturing standpoint the harness design was not robust enough. The aluminum backshells used for the connectors proved not to be durable in service. All backshells were speedily replaced with stainless steel backshells.

Electrical problems with the permanent magnet alternator (PMA) also began to surface. As it turns out, the environment in which this unit is placed was not well understood during the design phase. The original design could not handle the heat and vibration and would fail prematurely. A large amount of engineering effort is now going into developing a more durable unit for the future. As with the leakage problem, additional line training has gone far to reduce the delays and cancellations. Personnel were trained to better troubleshoot and identify electrical issues and how to solve them on the line. What can be seen in

the figure 3 below is all the effort in engineering and
education that is paying off with the reduction of

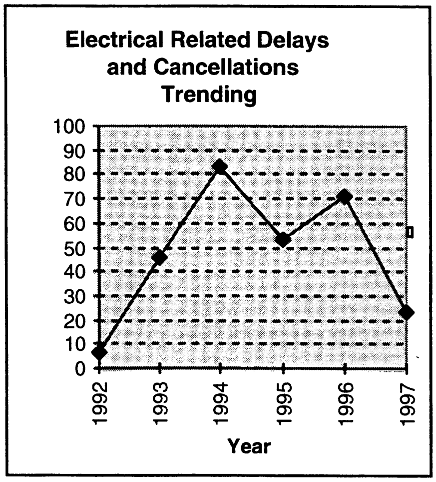

Figure 3

delays and cancellations. The first half of 1997 is also one-third less then the first half of 1996.

Delay's And Cancellations Are Not The Only Story

The delays and cancellations caused by component failure are relatively easy to tabulate. However, component failures have an even greater impact on the system as a whole. A large amount of money is spent on unscheduled maintenance, removal of components and occasionally removal of engines that are damaged by an external component failure. Additionally, there are numerous campaigns to replace older, less reliable hardware with newly upgraded hardware. On the PW4000 engine, the actuators (2.5 bleed, SVA and TCC) alone have had their share of reliability issues from wire management problems to seal failures. From 1992 through 1995 there have been 113 unscheduled component removals due to these problems. Although these failures did not caused a delay or cancellation, they did interrupt the normal engine maintenance schedule.

In order to accomplish the upgrades on these units, over half a million dollars was spent by the airline alone on projects to replace older hardware with upgraded hardware. And then some units were upgraded two and three times since their introduction in service. Factor in the cost to engineer, manufacture and test new components, it can be clearly seen that an opportunity for substantial cost savings exists. It is here where the airlines and the engine manufacturers can save money in the long run by investing in good research during the design phase of the program.

Engine Performance Is Affected By Reliability

FAA regulations allow an engine to operate with only the minimum essential equipment. The definition of essential equipment is negotiated by the FAA, the engine manufacturer and the airline before engine certification and spelled out in a document call the Minimum Equipment List (MEL). Many of the secondary airflow systems controlled by the external engine hardware is listed in the MEL since they are systems which are not necessary for the safe operation of the engine. And so these systems can be inopted before flight if there is a problem. These systems are mainly used to fine tune the performance of the engine. When one of these systems is inopted, the result is higher fuel burn, lower engine efficiency, and higher exhaust gas temperature (EGT). In this situation, fuel burn can increase anywhere from 0.3 to 2.0 %. The impact of this additional fuel burn on a long mission is serious. Not only will there be the extra cost in fuel but a flight may be weight restricted, thus leaving passengers at the gate or causing an expensive fuel stop at a remote location in the world. The latter two can affect customer trust and comfort in the airline. There is no way to put a price tag on the cost to the airline in this situation.

The Ultimate Goal

The PW4000 engine itself is a robust and reliable engine. A typical engine will operate on wing on an average of 14,000 hours or 4 years between overhauls. What is also expected is that the external components and their systems operate reliably for the same amount of time or longer between overhauls. Once an engine is removed from wing and shipped to the shop for overhaul, all the external components are removed and sent out for complete overhaul. The units are disassembled, cleaned, inspected, reworked, repaired, replaces with new internal parts and assembled with all new seals. Much of the work is done within United so the component engineers are able to see first hand the condition of the external components after years of service. After assembly, the units are then acceptance tested and made serviceable for use on the production floor or on the line.

Once an engine is overhauled in the shop, the external components assembled on that engine have all been overhauled. The intent is to have these components perform flawlessly in the field until the next engine overhaul. Some components are extremely reliable and some are still less then reliable. The ultimate goal of the component engineer at United to get closer to 100% reliable performance out of each and every component. This is being done right now by reviewing chronic components of removal from service, completing reliability modifications which directly improve performance of the component and partner with suppliers to United in meeting or exceeding performance goals of each component.

Summary

United Airlines has operated the Pratt & Whitney PW4000 engine for over 5 years. This amount of time has built a good database of experience. Serious study of the data can be very enlightening and reveal opportunities for improvement in current and future component designs. A large amount of time and money is consumed in the field maintaining, repairing, and replacing external engine component due to premature failure.

Today reliability of external engine components and systems are of most the importance. The opportunity exist to have a great impact in the operating cost to airlines by reducing delays and cancellations, improving engine performance, reducing unscheduled maintenance and improving customer thrust and satisfaction. It must start at the design phase. Better modeling of the engine external operating environment will lead to more robust components. This is the challenge for all current and future hardware.

HOW UNITED SERVES THE WORLD TODAY

- AVERAGE 200,000 TO 250,000 PASSENGERS A DAY
- AVERAGE 2000 TO 2500 FLIGHTS A DAY
- AVERAGE TURN TIME FOR A DOMESTIC FLIGHT IS 55 MINUTES
- AVERAGE TURN TIME FOR A SHUTTLE FLIGHT IS 30 MINUTES

ReCAT

RELIABILITY IS VERY IMPORTANT

- DELAYS AND CANCELLATIONS
- UNSCHEDULED MAINTENANCE
- HIGHER FUEL BURN
- EXPENSIVE UPGRADE PROGRAMS

ReCAT

RELIABILITY IS VERY IMPORTANT

- PW4000 ENGINE PROGRAM ALONE
- DURING 1992 - 1995
  - 1157 DELAYS AND 111 CANCELLATIONS ARE ENGINE RELATED
- AVERAGE OF ONE D & C PER 0.9 DAYS
- MAJORITY OF THESE ISSUES ARE EXTERNAL COMPONENT

ReCAT

SIMILAR ISSUES ARE SHARED ACROSS THE FLEET

- ACTUATOR SEALS LEAK
- GEARBOX CARBON SEALS LEAK OR COKE
- SENSORS AND FEEDBACK SYSTEMS GIVE ERRONEOUS MESSAGES
- HARNESSES WILL CHAFE

ReCAT

THE IMPACT IS GREATER

- 1992 - 1995
  - 113 UNSCHEDULED ACTUATOR REMOVALS ALONE
- OVER $0.5M SPENT IN UPGRADE CAMPAIGNS

- UP TO 2% INCREASE IN FUEL BURN

ReCAT

THE GOAL

- AVERAGE ENGINE OPERATES FOR 14,000 HOURS OR 4 YEARS

- BRING EXTERNAL COMPONENT RELIABILITY UP TO 100%
- COMPLETE RELIABILITY MODIFICATIONS
- PARTNER WITH SUPPLIERS TO MEET GOAL

ReCAT

LEARN FROM EXPERIENCE

- RELIABLE COMPONENTS ARE IMPORTANT TO EFFICIENT OPERATION
- BETTER MODELING DURING DESIGN PHASE
- STUDY OF THE CURRENT DESIGNS AND THEIR RELIABILITY
- PARTNER WITH THE CUSTOMER TO LEARN FROM THEIR EXPERIENCE

ReCAT

United Airlines Engine Condition Monitoring System

United Engine Data Acquisition

United utilizes a automated data collection system to acquire on-wing engine data that is to be used for engine condition monitoring. With the exception of a few airplanes, United's airplane fleet uses the Aircraft Communication Addressing and Reporting System (ACARS) either through pilot input or by automated data acquisition equipment.

Once data is transmitted from the airplane, the Aeronautical Radio Incorporated (ARINC) network receives and processes the message and transmits the message to the United ground station at CHICAGO. The message at the ground station is then processed by a number of UAL software applications. The data is then databased for a period of 6 months. Airplane message data is then used by other software applications for engine parameter trending (ECMII), engine fuel consumption guarantees, airplane aerodynamic guarantees, engine reduce thrust statistics, etc...

United Engine Condition Monitoring (ECM)

United Airlines engine condition monitoring program consists of a number of software application tools to monitor on-wing engine health. Engine problems transparent to the pilot can be identified using certain data analysis techniques. The use of these techniques allow United Airlines to identify and correct engine problems before an operational penalty is encountered. The software tools that allow these techniques to work are summarized below.

- On-Board Monitoring Equipment:
  Some of United's airplanes utilize Digital Flight Data Acquisition Unit (DFDAU) and Aircraft Monitoring System (ACMS) equipment to monitor engine conditions. This equipment uses real time software to monitor data parameters for given engine conditions. When a given engine condition exists, a message is compiled and transmitted through ACARS. Routine reports used by United Airlines include engine start, takeoff, and stable cruise. In addition, abnormal engine conditions are monitored continuously for aborted takeoff, in-flight engine shutdown, engine limit exceedance, engine stall, N1 overboost, etc...
- Fault Analysis Alerts:
  When an airplane message is received, corrected and/or raw parameters are compared to expected minimum, maximum, or difference between engine values, redundant instrumentation (e.g, TAT and T2), engine control schedules (e.g.. N2 vs VSV position, etc...). If the transmitted data parameters fall outside of the expected window, a Fault Analysis Alert message is sent to the applicable engineering group.
- ECM Manual Message Table:
  When an airplane is required to be closely monitored, this table allows the applicable engineering group to specify the airplane, departure station, and/or airplane messages that need to be seen. When the airplane meets the input requirements an ECMMSG message is sent to the applicable engineering group. This allows the group to monitor engines to confirm a given engine condition or troubleshooting fix.

United Engine Condition Monitoring (ECM) continued

- Electronic Engine Control (EEC) and Vibration Monitoring Unit (AVM) Status Alerts:
  Under normal operating conditions, the configuration of the input and output to the EEC/AVM is known. Data on the EEC/AVM configuration is provided in messages transmitted from the advanced technology airplanes (757, 767, 747-400, A320, etc...). Tables are set up to identify inputs and normal EEC/AVM configuration for routine messages. Data from the airplane message is compared to the table data. If differences occur which would identify an abnormal configuration, an EEC/AVM Status Alert is sent to the applicable engineering group. The status alert identifies the suspect input/output component so that troubleshooting action can be taken. This application provides the ability to replace the correct FADEC system component therefore reducing EEC unconfirmed removals.
- ECM On-Line Database:
  As data is received by the ground station, collection of data is stored in a database. The data stored is accessible on-line for view and electronically for ad hoc applications for engine troubleshooting and performance studies. In addition, other software applications use this database to acquire data for their use.
- Pratt and Whitney ECMII:
  This software provide basic trend monitoring for primary engine parameters for short and long term trending. Airplane collected during the day is processed daily. Output from this application is used for engine failure prevention, troubleshooting, and engine removal planning and repair requirements.
- Pratt and Whitney Engine Fleet Ranking Report:
  This software uses stable cruise data to determine an Exhaust Gas Temperature (EGT) index that is used to rank engines from worst performance to best. Output from this application is used for engine failure prevention, troubleshooting, and engine removal planning and repair requirements.
- Pratt and Whitney TEAMIII:
  A product of Pratt and Whitney Diagnostics Systems Group and supports PW products such as the PW4084 and IAE V2500 engine. This software uses takeoff and stable cruise data to determine a broad diagnosis of the engine health. Output from the program provides information on engine primary parameter trends, internal pressure and temperature parameter trends, engine module performance analysis (FAN, LPC, HPC, HPT, and LPT), and engine instrumentation analysis. Output from this application is used for engine failure prevention, troubleshooting, and engine removal planning and repair requirements.
- Engine Reduce Thrust Statistics
  The software provides United Airlines to trend how many reduce thrust takeoffs are performed and the amount of reduced thrust for each aircraft fleet.
- Fuel Consumption Guarantee
  Each engine manufacture provides a fuel consumption guarantee. The collection of engine stable cruise data and processing through ECMII is the base for administration of the guarantee.

Other United Airlines Applications

- Aircraft Performance Monitoring
  Stable cruise data collected in flight is processed through Uniteds Cruise Data Survey to determine specific range for each operating aircraft. Output from this application is applied to the fuel load planning to ensure fuel loads are adequate for a given flight. On newer generation aircraft Airplane Performance Reports are generated for input into this application; other aircraft use data from the engine reports. This application is equivalent to the Boeing and Airbus airplane performance software.
- Other Reports Transmitted and Used
  Auxiliary Power Unit (APU) Reports
  Environmental Control System Reports
  Autoland Reports
  Weather Reports

UAL DATA FLOW SCHEMATIC