Improving the Diagnosis of Mechanical Systems, and Structure to Reduce Aircraft Downtime at 1st Line and Improve Mission Reliability

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ABSTRACT

With the ever increasing cost of aircraft and aircraft operations, significant effort is being expended to reduce the total cost of ownership whilst increasing aircraft availability. A significant method for achieving this objective is through vehicle health management. New commercial and military aircraft (namely the Boeing 787 and the Joint Strike Fighter, respectively) are integrating vehicle health management technologies that incorporate, extend, and go beyond the traditional engine and exceedance monitoring systems in place on many conventional aircraft. Not only are the new aircraft incorporating new systems, but also new monitoring systems to aid in line maintenance, diagnostics, and prognostics.

The development of systems to provide diagnostics, prognostics, and health management is a continuing endeavour. This paper will highlight some of the methods and techniques both currently employed and in development that can aid in improving aircraft availability.

1.0 INTRODUCTION

There are a variety of methods to improve the diagnosis of mechanical systems. Many of these methods can be applied to aircraft already in service, while others require the diagnostic tools and sensors to be designed-in at the beginning stages of the system development. These diagnostic tools and techniques fall into essentially three categories: data fusion methods, retrofittable troubleshooting systems, and fully integrated sensor suites. The objective of each system is slightly different, but the overall thrust is to increase the availability of the aircraft, and to reduce the amount of maintenance time required to keep the aircraft in a ready state.

2.0 DATA FUSION

Data fusion methods, or statistical fleet monitoring approaches involved using software and database systems to archive and analyse recorded data from each aircraft in a specific fleet. These concepts are currently applied in the civil aviation arena as FOQA (Flight Operations Quality Assurance) and MOQA (Maintenance Operations Quality Assurance). Data from the aircraft flight data recorder or quick access recorder is downloaded, stored and analysed by a central system. Historical trends can be produced and exceedences can be captured. There are a variety of companies offering systems to perform this analysis. Among the leaders in this market is Sagem Defense/Securite with their Analysis Ground Station (AGS) suite of products. The AGS system handles the downloading, archiving, analysis, and reporting on a fleet of aircraft. Using technology developed through a NASA research effort, the AGS is capable of running complex heuristic analyses on data to highlight not just pre-set limits, but also to spot anomalies. This functionality is called the '*morning report*' and it is an important tool to spot early warning signs of impending system failures.

An alternative system is offered by SAAB Avitronics (formerly Aerospace Monitoring Systems Pty.). Their ground station is uniquely configurable to work with a variety of data recording devices. While the Sagem DS offering is aimed at FOQA and MOQA, the Avitronics ground station incorporates the capability to perform structural analyses and fatigue damage counting. Their ground station (and associated data recorders) are in service with a variety of BAe Hawk fleets.

Ground analysis systems can be put in place for aircraft that have some form of downloadable recorder. The usefulness of the resulting data analysis will, of course, depend heavily on the measurement parameters available. Retrofit data recording systems are available that record information present on aircraft data busses (MIL-STD-1553, ARINC-429, etc.) These vary from the Aircraft Condition Monitoring System (ACMS) by Sagem DS which offers a full suite of measurement capabilities to the Avionica miniQAR, which is a palm sized data bus recorder.

Trending and analysis of existing data can provide significant maintenance benefits. In the civil aviation world, Federal Express was able to reduce maintenance costs on their fleet of A300 aircraft by using an ACMS system to detect slat system mis-rigging. Highlighting the mis-rigged configuration early on allowed a savings on the order of millions of dollars per year.

Innovative analysis techniques looking at the large quantities of data already generated on aircraft can lead to signature detection, and the ability to identify failing components before they compromise flight safety and mission availability. The National Research Council of Canada has performed work in this area. In addition, the Morning Report analyses developed by NASA and exploited by Sagem in their ACMS include some aspects of this functionality.

However, some systems may not have appropriate sensors currently installed on the aircraft. In some instances, it may be helpful to retrofit sensor systems to allow for improved maintenance.

3.0 RETROFITABLE TROUBLESHOOTING SYSTEMS

There are two sub categories of retrofitable systems: those that meet an ongoing maintenance need, and those that are employed to solve a short term problem.

One area where a recurrent, ongoing maintenance need can be alleviated through a retrofit system is the landing gear shock strut. Most aircraft employ an oleo-pneumatic shock strut (air spring and oil damping). These systems require frequent pressure checks with manual comparison against a servicing chart. These single point checks (so-called because they involve simply checking the air pressure at one shock strut position) do not reveal if oil has been lost in the shock strut. To complete a full servicing check, the aircraft must be jacked, and measurements be taken at two positions of the shock strut. This is a time consuming approach. The addition of shock strut measurements – pressure, temperature, and position, and a recording system to take measurements both in flight and on the ground, can alleviate the requirement to perform any manual inspections on the shock struts.

The changing economic environment for operators, one where there is significant pressure to reduce total cost of ownership, and to reduce lifecycle costs, presents an opportunity for service state monitoring systems to be designed into landing gear offerings. The airframe manufacturers are beginning to see the benefits of this concept – the Airbus A380 has some shock strut monitoring capability and Airbus intends to include full monitoring capability on its new widebody airliner.

Internal studies conducted at Messier-Dowty Inc. have indicated that an operator of a regional aircraft could expect to save 180 hours over the life of the aircraft just by eliminating the need to perform annual dual point servicing checks. Significantly more regular maintenance is reduced by automating line pressure servicing checks.

Technically, there are several approaches that could be followed to determine the shock strut service state. For any oleo pneumatic, single state shock strut, there are four important parameters – nitrogen pressure, oil volume, temperature, and shock strut position. Mathematically, the simplest approach would be to measure all four parameters. This would allow an instantaneous assessment to be made as to the appropriate servicing state. However, there are several design considerations that make this approach less than ideal. Having four sensors means high cost. The oil volume sensor, by design, must be internal to the shock strut – making field repair impossible, and requiring an additional hole to be drilled in the shock strut wall (for the extraction of the measurement wires).

An alternative approach is to include the element of time in the measurement. In this system, the oil volume sensor is not included, and two measurements (at different shock strut positions) are made. The simplest approach is to make one of these measurements prior to landing, and the second once the shock strut has settled (potentially at the gate).

This “two-point” method allows the shock strut state to be determined reliably with conventionally available sensors. Particular attention needs to be paid to the maintainability of these systems – if the system is not rapidly repairable, or requires the aircraft to be removed from service, then the value to the operator is significantly reduced.

Monitoring systems analogous to the shock strut servicing system can be applied to aircraft hydraulic systems, accumulators, and compensators.

There are often occasions when a short term, or unexpected problem occurs that necessitates an on-going inspection, such as a structural inspection. These inspections may be of a crack detection nature, employing eddy current probes, ultrasonic inspection, or other non-destructive inspection techniques. In order to alleviate the inspection requirements somewhat, it may be possible to permanently attach the NDT probe in the problem location. Alternatively, newer NDT methods such as Jentek Sensors Inc. MWM sensor technology may lend itself well to permanent mounting.

When cracks occur in service, it may be desirable, as part of an aircraft structural integrity programme, to determine what the actual fatigue loads on the structure are, and to relief the part accordingly. This can be done using existing HUMS or data recorders if the channels of interest are already recorded, or if spare channels exist that can be added to the recorder.

In those cases where additional channels cannot be added, it may be desirable to use a stand-alone data logger to collect data from the area of interest. Messier-Dowty’s Strainlogger technology, a battery powered, flight qualified data logger is designed for exactly such an occurrence. The Strainlogger is useful where no connection to the aircraft electrical system is desired (for ease of installation, and deinstallation) and where short term (on the order of months) recording is required across a sample of the fleet. Features in the Strainlogger systems, such as removable battery/memory modules allow rapid servicing of the recorder unit by minimally trained personnel. Output from the Strainlogger is a strain vs. time history for each channel measured.

Where longer term structural life monitoring is required, an aircraft powered recorder is recommended.

In moving aircraft structure from an intensive maintenance inspection regime to a monitored, on-condition regime, the certification basis of the structure needs to be considered. Older airframes, and major components of new aircraft (such as the landing gear) are certified using *safe life* criteria. New aircraft are predominantly design using *damage tolerant* approaches. In the former, no cracks are permitted in the structure. Structural monitoring of safe life structure is essentially limited to measuring strains or loads in the components and then performing fatigue life computations. Monitoring of damage tolerant structure offers a multitude of possibilities all geared towards the measuring of crack length.

There exist several crack detection technologies, both flyable and ground inspection based non destructive test means. Recent developments in NDT technologies has improved the probability of detection of small cracks and corrosion.

Jentek Sensors Inc. of the United States is actively marketing and developing a ground based NDT system utilizing an array of meandering winding magnetomers (MWM). Significant modeling capability and sophisticated software allow portions of airframe and equipment to be scanned with the MWM arrays to measure material conductivity (or permeability in permeable materials). The system can rapidly display full colour two dimensional plots of scanned areas, highlighting discontinuities – crack locations. Jentek is involved in a research program to develop their technology for in-flight use. The technology is already in use for specific inspections with United States forces.

For in-service determination of crack growth, the comparative vacuum monitoring (CVM) system offered by Structural Monitoring Systems Ltd. Of Australia is both an innovative and attractive solution. A moulded silicon patch is placed over a crack (or suspected crack) location. Small alternating channels moulded into the silicon patch are connected to either atmosphere or an accurate, metering, vacuum pump. The existence of a crack will allow air to flow from the atmospheric channel to the vacuum channel. Larger cracks allow more airflow, so by tracking the flow rate from a given patch, one can determine the crack size and crack growth with time. The system has the advantage that the patches are essentially inert, that the tubing to each patch is relatively small and light and may be easily routed. CVM systems would not normally be monitored in flight, but would be used to alleviate a more intrusive NDT inspection.

Significant quantities of work has been conducted with the field of ultrasonics – both for direct inspection of a component, or to monitor the behaviour of an entire assembly. Direct signal/echo methods are routinely used for crack or inclusion detection. More advanced ultrasonic technologies, still predominantly a research topic, investigate the behaviour of surface waves on complex assemblies. This technology is of significant interest for airframe structure as it has the promise of detecting not just fatigue cracking, but battle damage as well.

4.0 FULLY INTEGRATED SENSOR SUITES

The concept of fully integrated sensor suites is now coming to fruition in aircraft like the Joint Strike Fighter. Disparate sensors, each suited to their specific task, are connected to the aircraft data bus and a central diagnostic system. The aircraft is able to assess damage, faults, and inconsistencies. In addition, it is able to recommend to the pilot or maintenance technician an appropriate course of action to either operate the weapon system in a reduced capability mode or how best to solve the problem.

To provide this diagnosis ability, algorithms are being developed that both exploit existing sensors in new ways, and interpret data from new sensors. New sensors are employed where there is a specific need. New sensors may include new sensor technologies – ultrasonic sensors deposited directly to the vehicle structure, or may simply mean existing sensors added to non-traditional locations. In all cases, the decision to include a new sensor has to be based on a cost-benefit analysis.

The provision of diagnostics and prognostics is not only limited to on-aircraft systems. Indeed, the full capability of most systems only comes to bear when the appropriate infrastructure is provided to compare and contrast data across a fleet, or when timely and correct information is provided to maintenance personnel.