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DYNAMICS HEALTH AND USAGE MONITORING SYSTEM - PROGRAMME UPDATE

by

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1. ABSTRACT

The Helicopter Airworthiness Review Panel report acted as the catalyst for initiatives to increase helicopter airworthiness. One result of this was the recommendation from the working party on helicopter health monitoring that monitoring installations should be trialled on helicopters. Support from the Civil Aviation Authority and the Department of Trade and Industry has led to Hawker Siddeley Dynamics Engineering Limited (Dynamics) and Stewart Hughes Limited joining with British International Helicopters Limited to produce and trial a Health and Usage Monitoring (HUM) System for the Sikorsky S61.

The task of any helicopter monitoring system is to check the safety-critical components in the drive train. Gearboxes, rotors and engines all require different techniques to ensure their health. Results must be available in time for preventative action to be taken. The objectives of the trial are to prove the techniques and reliability of the system and to investigate effective methods of integrating the results into an operators' maintenance management procedures.

2. INTRODUCTION

Reliance on periodic maintenance has proved to be not adequate under all circumstances to ensure the integrity of mechanical assemblies. Helicopters are currently maintained by fixed interval scheduled maintenance. For some major components such as a main rotor gearbox, there is only the most crude of indicators to show whether the assembly remains healthy between these inspections. For a main rotor gearbox, for instance, the only on-board indicators might be lubricating oil temperature and pressure. There is a clear need for a device that can predict incipient failures of safety critical components.

Last year this forum granted the author the opportunity to explain the background and rationale behind condition monitoring systems for helicopters in general and to describe one such HUM System. This paper starts with a discussion of the aims and benefits of such systems and a brief recap on the functionality, architecture and hardware involved in the Dynamics' system. Following this, the difference between health and usage is explained which leads to a discussion on certain design aspects. The results handling techniques are described in more detail and a programme update is given. Finally the extension of the system to include a Flight Data Recorder is discussed.

3. AIMS AND BENEFITS

The ultimate aim of airborne condition monitoring systems must be to provide on condition maintenance. It is necessary to check the condition of all the major dynamic assemblies. Further, from the safety point of view, all systems which could have a bearing on safe flight need to be monitored. The Dynamics' demonstrator system concentrates on those components known to be safety critical and for which inadequate methods of determining health were available until now.

The benefits of the system are to safety and life cycle costing. If faults can be predicted, the airworthiness and safety of the aircraft must be improved. This should lead to fewer incidents and accidents as well as increasing aircraft availability. This prediction will give warning of component degradation and allow fast fault diagnosis with fewer maintenance flights. Engineering staff should be able to plan maintenance work which may lead to a reduction of manpower. Capital tied up in spares holdings can be reduced.

4. SYSTEM DESCRIPTION

First, to recap on the current demonstrator system. The functionality is as follows:

a. Vibration analysis of the gears and bearings in the main, intermediate and tail rotor gearboxes

b. Chip detection in the main, intermediate and tail rotor gearboxes

c. Track and balance of main rotor and balance of the tail rotor

d. Power assurance and topping check and comprehensive usage logging functions for both engines

The on-board and ground support hardware required to achieve this functionality is shown in Figure 1.

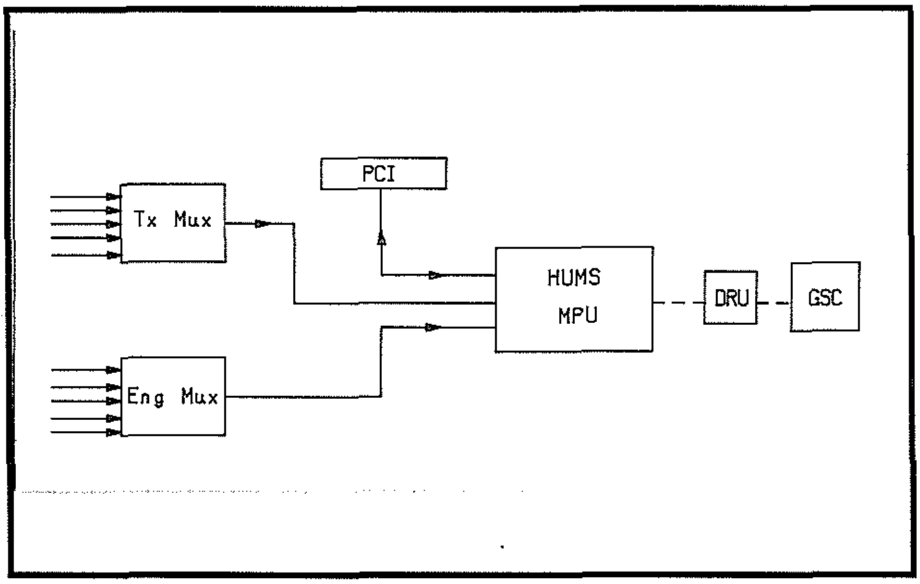

Fig.1 System Block Diagram

Data from sensors placed on the component to be monitored are fed to two multiplexers. One multiplexer (Eng Mux) collects the engine signals and the other (Tx Mux) the transmission signals. The primary purpose of these multiplexers is to reduce aircraft wiring so they are placed close to the major assemblies from which they collect signals. Multiplexed signals are fed to a Main Processing Unit (MPU) where the on-board analysis takes place. Certain routines are under the control of the crew via the Pilots Control Interface (PCI). The results of the analysis are stored in non-volatile memory and downloaded on the aircraft's return by means of the Data Retrieval Unit (DRU) to the Ground Station Computer (GSC). Here the historic files for the aircraft are updated and the results of off-line health techniques such as Spectrometric Oil Analysis are added. This allows all the evidence on health to be corroborated, the ensuing problems predicted and the latest trending lines displayed.

5. HEALTH OR USAGE

At this point, and before embarking on a discussion of certain design aspects, it is necessary to define the difference between health and usage. Ideally in a condition monitoring system the health alone of a component needs to be measured. Usage is a technique to be employed where the health cannot be adequately monitored. It is of little interest in itself. Indeed it is a secondary technique. With usage techniques the health of a component is inferred from a statistical model of its usage. If the component has undergone a lesser number of stress cycles than its safe life as predicted by the S-N curve, then it is deemed to be healthy; if it has undergone a greater number of cycles it is deemed to be unhealthy. This takes no account of the actual condition of the component and results in serviceable components being rejected.

Consider the simple example of blade creep in a turbine disc. This is conventionally measured by usage. When the disc has completed a certain number of temperature/speed cycles, it is deemed that the likelihood of blade rub is increased above an acceptable level, so the component is rejected. If a suitable proximity sensor could be fitted and the gap measured, then a health technique could be substituted and the component rejected only when a rub was about to occur.

The Dynamics HUM system concentrates on health techniques where possible. As a demonstrator system, it was not feasible to consider changes to assemblies, such as the addition of sensors, such that re-certification would be required, so a compromise between health and usage had to be made.

It is against this background that the rationale for on-board processing must be viewed. It will be argued that it is not just knowledge of the health of the component that is required, but the knowledge must be available in real time.

6. ON-BOARD PROCESSING

Arguments are developing in the industry between those who favour on-board processing and those who prefer data to be logged on- board with the analysis completed later on the ground. Dynamics believes that it is essential to complete the analysis on-board for three reasons:

a. The short time to failure of some high speed components

b. Continual analysis rather than snapshots is required

c. The time lag and cost of analysing the data on the ground

6.1. Time to Failure

Fatigue is the main mode of failure in the high speed components under consideration. Fatigue cracks usually begin at the surface, are caused by cyclic stress and advance a certain distance through the material with each cycle. Using the latest vibration monitoring techniques, fatigue cracks can be diagnosed when the crack has propagated through approximately 25% of the material area. Calculations indicate that in the worst case, when the component is transmitting high torque, propagation from this point to failure could occur in as little as one million cycles. A typical gearbox input speed in this type of installation is 20,000 RPM, which gives a time to failure of under one hour. This figure has been substantiated by rig tests.

This is a worst case and assumes that maximum torque is transmitted for the full period. However this is not a totally unrealistic scenario if you consider what might occur in a multi- failure situation such as in the case of a heavy helicopter following a single engine failure. The torque generated by the other engine would be near maximum. If a fatigue crack was already apparent on this input side and the helicopter was some way from a diversion, the crack could propagate to fracture before the helicopter landed. As torque and shaft speed are reduced, the elapsed time to failure increases but may still be within a typical sortie period. Two recent incidents involving helicopters operating in the North Sea are believed to have been caused by fatigue failures to components in the high speed input section of the gearbox.

This possibility makes it essential that an on-board warning becomes a necessary part of such systems. The range and endurance of modern helicopters continues to increase and the advent of in-flight refuelling for military helicopters will result in a near-limitless sortie length. The crew will have to be informed of the continued serviceability of their helicopter. Much thought needs to be given to this by operators, industry and the regulatory authorities. The method of displaying the information, the problems of false or spurious warnings and the crew actions following a warning all require investigation. Warning a North Sea helicopter captain that a potentially catastrophic failure will occur to his gearbox before he can reach a diversion in a Force 10 will concentrate his mind. To find out later that this was spurious would seriously erode his faith in such systems. This problem has been addressed in the Dynamics system by the use of multiple analysis techniques and the necessity to corroborate results before warnings are given.

6.2. Data Snapshots.

If incoming data is analysed as soon as it is available, the system memory requirement is reduced to that necessary to store the results. If the data is merely collected on board for later analysis, the memory requirement is of a different order entirely. It is no matter what memory medium is used, the capacity must be large. The figures for a tape based system yields some interesting facts.

At one stage in the development of the system, Dynamics considered taking tape data to provide some early information on gearbox vibration. An industry standard rugged tape recorder using video cassettes was to be used to keep costs low. Nine accelerometer channels each with a bandwidth of 0 to 20 kHz were required. The idea was abandoned when it was realised that a 10 minute snapshot of data was all that could have been obtained and that the volume of data stored during this 10 minutes was over 500 mbytes. As a permanent solution to monitoring the health of gearboxes, snapshots is not an acceptable solution. The monitoring process must be continuous

6.3. Data Handling

The final reason for on-board processing is to avoid the onerous logistic requirements of a large ground based data handling and analysis system, which leads to high costs and delays in obtaining results.

First, the analysis is likely to be completed by specialist personnel remote from the operating base. This is a disadvantage in itself as it prevents the direct involvement of the maintainer on the shop floor in determining the health of the aircraft for which he is responsible. It is the belief of the operator trialling this system that this link is essential for the acceptance of the technology and the change in working practices that such systems will entail. The alternative, if on board analysis is undertaken, is the ability to display the results immediately on landing (as will be shown in the next section). Here the maintainer has the ability to follow through an investigation himself without waiting for the results from an outside agency.

If data is merely collected on board, a system for handling a large quantity of tapes, discs or other storage media from a fleet of aircraft on a continuous basis must be devised. The bigger problem will be the analysis of that data in a reasonable elapsed time. With a fleet of aircraft completing several flights a day this will become unmanageable very quickly. Also the lengthy time delay between the data collection and the results production means that the helicopter may have flown again in an unhealthy condition or other maintenance work may have been carried out on the aircraft, thereby possibly invalidating the results.

An alternative is a half way house where the signal average of the vibration signal is completed and stored on-board. This reduces the storage requirements significantly but still suffers several disadvantages. An on-board warning cannot be given, significant on-ground analysis must be completed, again probably remote from the operator, and there is still a time lag between data collection and results availability.

7. RESULTS HANDLING

To return to the on-board analysis situation. Having obtained all these results on board, we need a method to communicate them to the maintenance engineer. This system uses two methods to display the results. The first is a Data Retrieval Unit (Figure 2), which is a portable computer.

This unit has two functions. One, which is discussed below, is to download the results from the airborne unit to the Ground Station Computer after the aircraft has landed. The second function allows interrogation of the results at the aircraft immediately the Data Retrieval Unit is connected. This is of considerable benefit if a quick turnround is required. Using the screen on the device, information critical to the serviceability of the aircraft for its next flight can be displayed. Events such as exceedances or changes in serviceability states can be shown. The unit can be used in

Fig.2 Data Retrieval Unit

this way to satisfy the maintainer that HUMS has detected no events during the last flight that require rectification action and obviates the need to download the results into the Ground Station Computer before dispatching the aircraft on its next flight.

The main method of displaying the results is the Ground Station Computer (Figure 3).

Fig.3 Ground Station Computer

This is a 386-based IBM PC or clone. The computer performs the tasks necessary to transform the results stored in the on-board unit to those which can be used effectively to plan long term maintenance and logistics. The system contains a comprehensive system of alarms which will alert the engineer to developing problems and also enable routine maintenance monitoring to be undertaken with the minimum of effort. In particular, the station has three functions:

a. To update the relevant aircraft files when a new input of results is received from the Data Retrieval Unit

b. To accept the results of off-line analyses (such as Spectrometric Oil Analysis) and corroborate the results

c. To produce trending graphs as requested by the operator

The philosophy on the structure and use of the Ground Station is unchanged from last year, but many detailed improvements have been incorporated during the period. In particular, the views of the helicopter operator have been taken into account with resultant improvements to the presentation and user-friendliness of the system.

The database is hierarchical and in 4 levels. The structure allows progressively more detailed information to be accessed in each succeeding level. The intention is that an individual need only investigate the status of the aircraft to the level needed to fulfil his particular task. For instance, the operations controller may need to know only how many of the fleet are serviceable, in which case there is no need to progress past the first level. However the logistics manager, who may be responsible for co-ordination with second line maintenance, may be interested in the individual component that is suspect, so that when the assembly is returned to second line, replacement components are available and there is the minimum of delay in returning the assembly to service.

An example may help to put this into perspective. The health of a main rotor gearbox will be used but similar displays are available for the other major assemblies monitored.

The top level (Figure 4) shows the operator's fleet of aircraft and allows access to information on the company's spares holding. The next level (Figure 5) shows an individual aircraft and the major dynamic components being monitored.

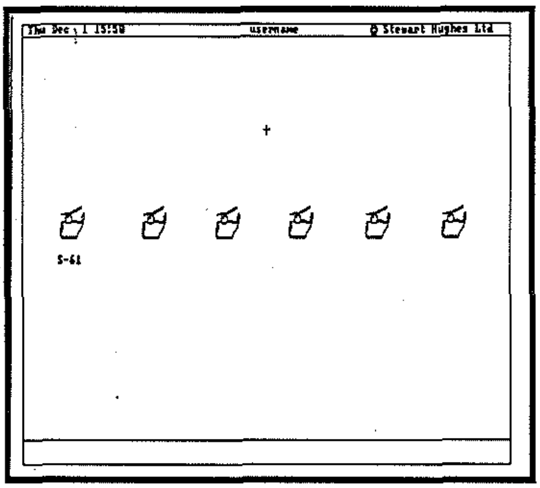

Fig.4 Report Format - Level 1

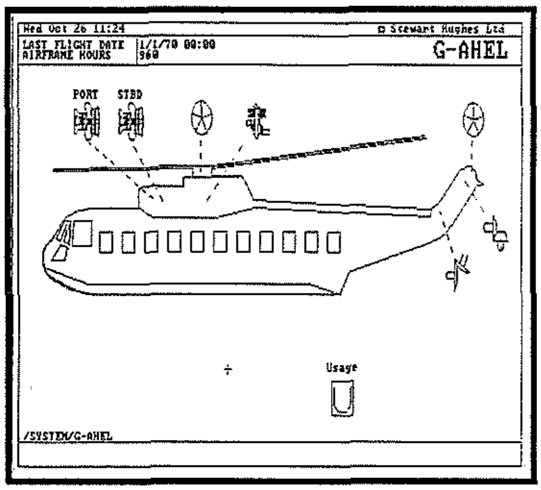

Fig.5 Report Format - Level 2

The next level (Figure 6) shows a graphic of the major assembly indicating the individual components. The final level (Figure 7) shows the results of the analyses on the individual components and a series of trending graphs as requested by the operator.

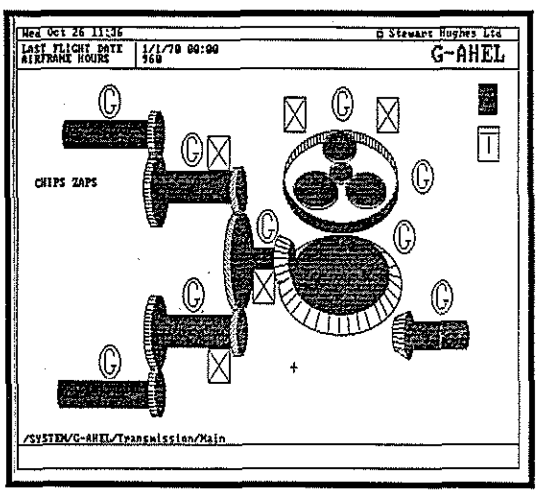

Fig.6 Report Format - Level 3

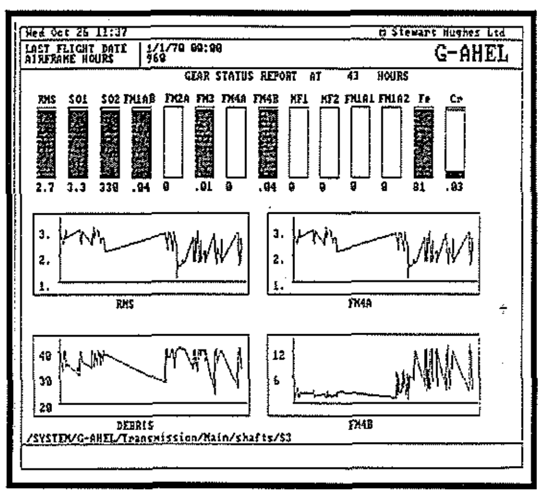

Fig.7 Report Format - Level 4

Throughout, the operator's attention is drawn to areas of concern by the use of graphical techniques on the VDU such as colour changes and flashing symbols for those aircraft, assemblies or components which require investigation.

8. FIRST RESULTS

The system is expected to fly during August on board a Sikorsky S61 operated by British International Helicopters Limited. The plan is for a 5-month commissioning phase during which the functionality will be built up gradually. Initially, following installation, the system will perform minor tasks such as statistics logging and oil debris analysis. The intention is to reduce the amount of data flowing around the system while the communications and general performance is assessed. Once any initial problems have been overcome, other functions will be added. The gearbox vibration package is likely to be added first and the final part will be the addition of the engine health monitoring package with its dedicated hardware, the engine multiplexer.

The writing of this paper coincides with the final system integration testing prior to delivery to the customer. Depending upon when the system first flies, it is hoped to show the first results during the presentation of this paper.

9. SYSTEM DEVELOPMENT

Plans to develop the system further by the addition of a Flight Data Recorder (FDR) are already in hand.

The UK Accident Investigation Board has commented consistently that helicopter accident investigations would have been considerably easier if FDRs had been fitted to the helicopters concerned. The Civil Aviation Authority (CAA) currently require all medium and large helicopters to carry Cockpit Voice Recorders (CVRs). The CAA now intends to introduce legislation requiring the mandatory fitting of Flight Data Recorders to all medium and heavy helicopters in the transport category by 1 February 1991.

The CAA is proposing that all helicopters over 7000 kg Max Total Weight Authorised (MTWA) are fitted with a FDR system that stores data on 31 parameters. Helicopters weighing between 2700 and 7000 kg need to store 17 parameters only. The CAA is permitting 2 equipment options. First, if the operator wishes to retain the current CVR, the FDR system must record either 31 or 17 parameters (depending on MTWA) for 8 hours. The architecture of these separate systems is shown in Figure 8.

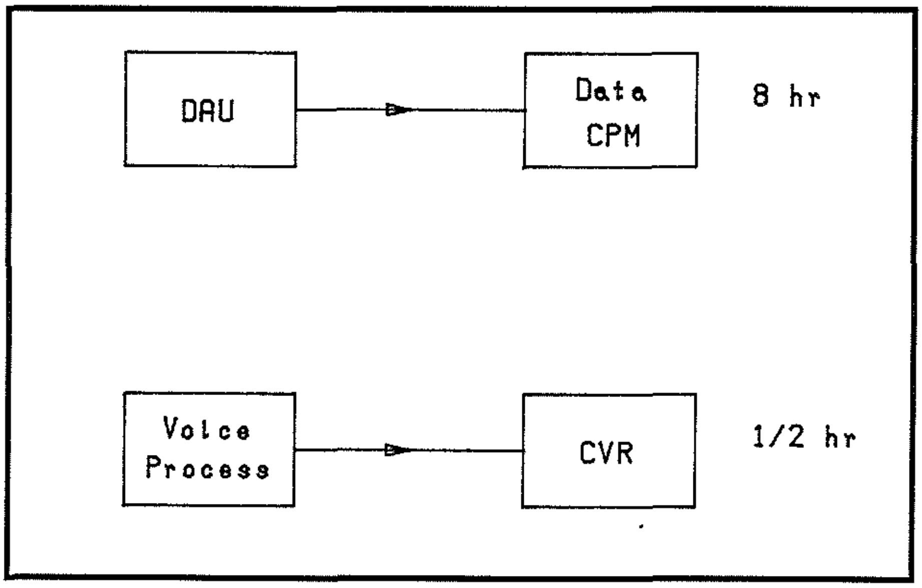

Fig.8 Separate CVR and FDR Systems

Secondly, an option of a combined voice and data recorder is permitted providing the following criteria are followed:

a. 5 hours of data from 31 or 17 parameters (depending on MTWA) are stored

b. 1 hour of voice from 3 positions is stored

c. Not less than 3 hours of unprotected FDR data immediately preceding the 5 hours stored in crash-protected memory, to be stored on the ground so that at any time 8 hours of data is available, 5 hours in crash-protected memory and 3 hours on the ground.

The architecture of this system is shown in Figure 9.

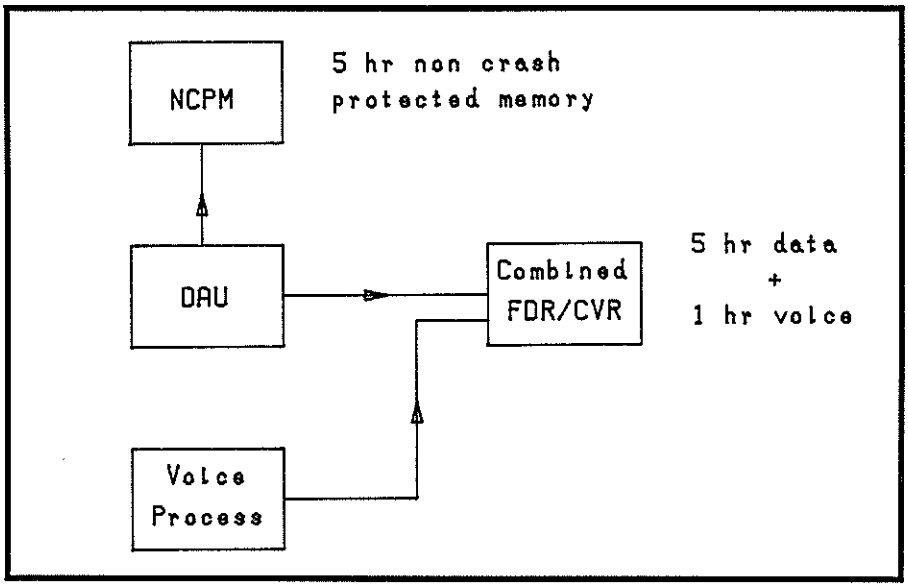

Fig.9 Combined Voice and Data Recorder System

There are many similarities between FDR and HUM systems. Both systems collect data from around the aircraft, process it to a greater or lesser extent and store the result in memory which can be either crash protected (the FDR) or non crash protected. The end result of the FDR system is intended to be used only in the event of a crash, while HUMS is intended to be used on a regular basis by the maintenance engineer. A simple FDR system is shown in Figure 10.

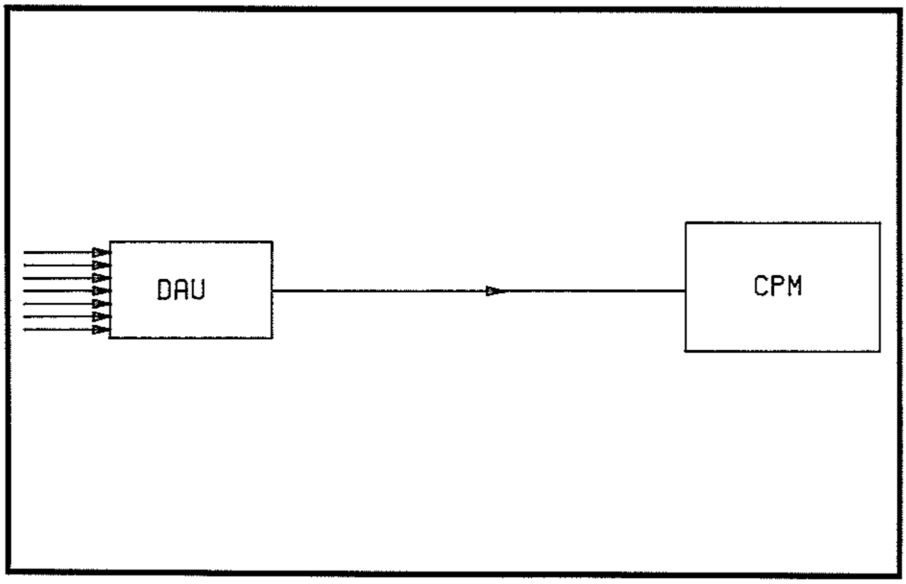

Fig.10 Simple FDR System

A possible architecture for a combined system is shown in Figure 11 where the FDR and HUM system have been 'integrated' merely by a two way communication link. It is worthwhile noting that the CAA has stated that 'an integrated FDR/HUM system is a reasonable objective for the industry to pursue'.

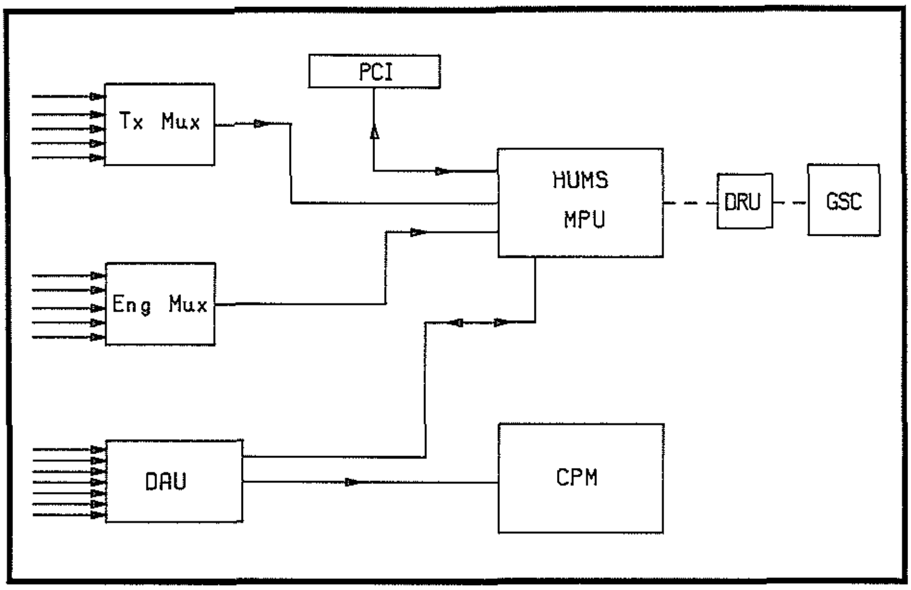

Fig.11 Integrated FDR/HUM System

There are two major advantages of integrating a HUM/FDR system in this way. The first concerns the storage of information about the health of gearboxes and rotors in Crash Protected Memory while the second concerns the additional capability of the monitoring system itself.

The current mandatory parameters required to be stored in the FDR Crash Protected Memory include little to indicate the health of the gearbox or rotor. For large helicopters, rotor speed and gearbox oil temperature and pressure are on the mandatory list. For medium helicopters, rotor speed alone is required. This is for the very good reason that no suitable measures have existed until the onset of the current demonstrator programmes. If the helicopter crashes from what is believed to be mechanical causes, it is most likely to be due to a failing in one of the gearboxes or rotors. Until the advent of HUM systems the accident investigator had almost no stored data from these assemblies to help him. Such information is now available and Dynamics believes it would be advantageous to the crash investigation authorities to have this data stored in Crash Protected Memory.

The intention is to store HUM results, not data, so the additional storage capacity is not great. The current accepted standard format for storing the FDR data is in a 64 words per second frame. The mandatory data for a twin-engined helicopter almost fills this frame, so the intention is to expand the frame to 128 words per second, thereby allowing adequate space for the additional data.

There are advantages to the HUMS analysis by having the FDR data available. The additional data giving aircraft attitude, speed and rates of change of various parameters will allow the HUM processor to calculate the flight regime that the aircraft is in at a given moment. This is called flight regime recognition. This will aid the HUMS diagnosis in two ways. Structural monitoring will become possible and the efficiency of the current processing can be improved as certain monitoring tasks can be inhibited if the aircraft is in a flight regime inappropriate for the collection of data. For instance there would be no point in taking certain vibration readings while the aircraft was completing a violent manoeuvre. Further it may allow for the automation of more functions. For instance, the Power Performance Index or Power Performance Check could be completed automatically when the engines are within the required band, rather than at present where the crew have to set up specific engine and flying conditions before such readings can be taken.

These are the advantages that can be gained if the two systems are joined by a communications link. However, the major practical benefit to the operator comes if several functions can be combined within one enclosure, thereby leading to a reduction in space, weight and cost.

The proposed architecture for an integrated HUM and voice and data crash recorder system is shown in Figure 12. The Engine Multiplexer, Main Processing Unit and Data Acquisition Unit have been combined into one unit.

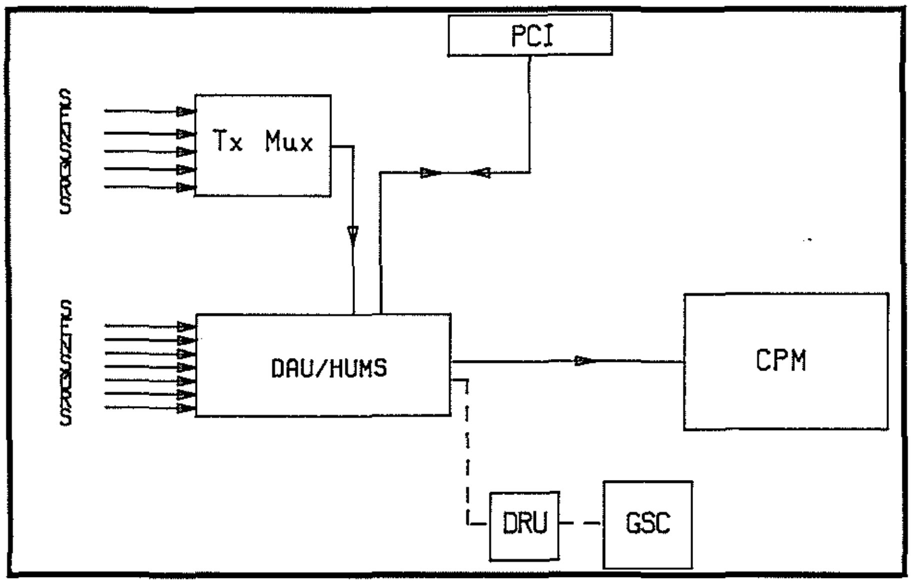

Fig.12 Fully Integrated FDR/HUM System

A fully integrated FDR/HUM system will consist of the following on-board equipment:

a. Sensors, transducers and interfaces to existing data collection devices (eg the air data computer)

b. Data acquisition and health monitoring computer (DAU/HUM)

c. Non crash-protected memory

d. Crash-protected Voice and Data Recorder

e. Transmission multiplexer

f. Cockpit display/interface

g. System wiring

In addition to the on-board equipment, the following ground support equipment is required:

a. Data retrieval unit

b. Ground Station Computer

c. Ground test equipment

Some operators may not wish to fit HUMS at present. Nevertheless these operators will have to fit a FDR system by February 1991. The architecture described above is adaptable and a modified design to meet this requirement is shown in Figure 13.

The differences between the system are as follows:

a. The Transmission Multiplexer is not required

b. HUMS processing boards are not required in the DAU

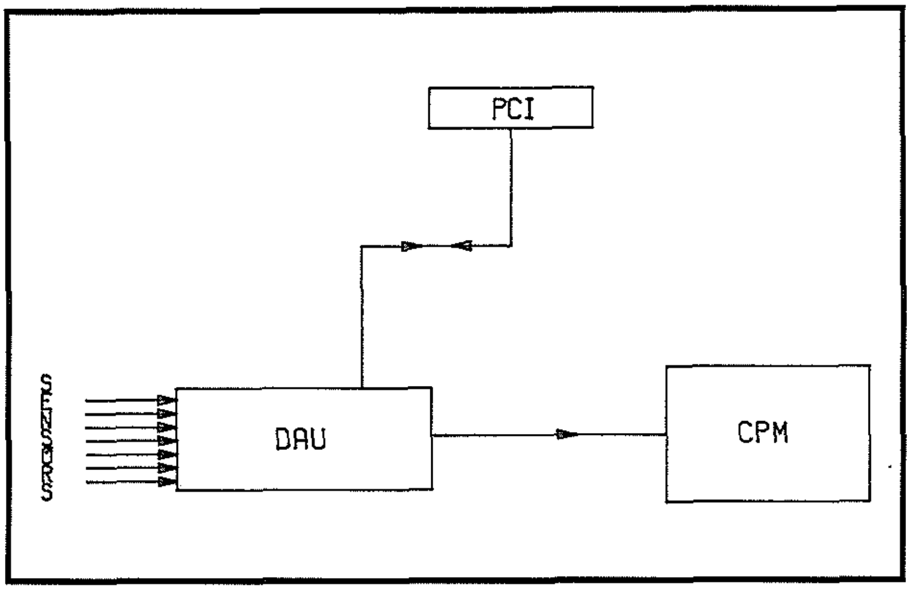

Fig.13 FDR System (without HUM)

c. The combined data and voice crash recorder is replaced by a data only recorder capable of recording 8 hours of data.

d. The Ground Station Computer and Data Retrieval Unit are not required

10. SUMMARY

Modern technology has now come to the aid of helicopter operators in the form of Health and Usage Monitoring Systems. Such systems can greatly improve safety and reduce life cycle costs. This paper has attempted to outline certain design aspects of the Dynamics HUM system, show how the current demonstrator is progressing and discuss the future addition of a Flight Data Recorder to comply with proposed CAA legislation. The operator can reap many benefits by combining the two systems.

Acknowledgement

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