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THE MODULAR HUM SYSTEM

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1.0 INTRODUCTION

At present there is much concern over the safety of rotor wing aircraft. Unlike fixed wing aircraft the rotor wing aircraft is supported by a mechanism, and not its structure. Any impending failure within this mechanism may have catastrophic results. To improve the safety and reliability of the rotor wing aircraft, investigations have been carried out into what is termed Health and Usage Monitoring Systems (HUMS), permanently installed digital devices which continuously monitor the integrity and life of components within the rotor wing mechanism. The objective of this paper is to highlight some of the problems that must be addressed when designing a HUMS, and to show how Stewart Hughes Limited and Hawker Siddeley Dynamic Engineering have accommodated these ideas into a practical demonstrator.

2.0 WHAT SHOULD BE MONITORED?

The simple answer to this question is that every component within the rotor wing mechanism should be monitored, from the engines to the rotor. The HUMS should not just address itself to whatever part of the aircraft failed last. The fact that a failure has occurred should ensure that there is a change in design or maintenance practices to ensure that it does not occur in the same way again.

Failure mechanisms that do occur are by their very nature not predictable, otherwise the airframe designer should have designed in safety margins, or life for the component. Endurance tests and life calculation can be used to provide the operator with safe operating limits, but unforeseen events or variations within environmental or operating conditions could produce failure in a different form.

Failure modes do not always occur in the same way. Due to the human influence in manufacture and assembly a component upon an endurance test may not fail in exactly the same way. So although the final failure condition, and subsequent catastrophic events can be defined, the mechanism that reaches this failure condition may not be a single type of failure.

It must be remembered that the types of failures that occur within one type of airframe may not occur in another.

So this results in two main problems, firstly we do not necessarily know what the failures are going to be until they actually occur, and secondly if we do know from previous experience what components actually fail, we cannot guarantee the failure mechanism. Therefore we must monitor everything.

From another viewpoint though it will not actually be practical for a HUMS to monitor every component within the aircraft for every conceivable failure mechanism, for two main reasons. Firstly analysis techniques do not exist for all failure mechanisms of all components, and secondly the weight of sensors and equipment will be prohibitive. So we must come to some solution that offers the most effective cover for a particular aircraft.

The Stewart Hughes approach to this problem which has been applied to a variety of different mechanical systems, is to define which components should be monitored, from examination of the systems failure or fault history, or if it is a new design, an analysis of the failure modes needs to be undertaken. From this components within the aircraft can be selected for monitoring based upon the following criteria:

(i) *Safety:* If a failure of a component can cause catastrophic failure then it should be monitored.

(ii) *Maintenance:* Failure of a component may not be catastrophic but it could result in costly unscheduled maintenance.

Using this approach a ranked order of components can be identified, when can then be used to select the analysis suite that will be required within the HUMS.

3.0 WHAT ANALYSIS TECHNIQUE SHOULD BE USED?

The obvious answer to the question is that the analysis should be sufficient to detect the failure, but there is more to the question than this. It cannot simply be detection of a failure, as at what point in time must the failure be predicted? There is no point in identifying a failure five minutes before it occurs, if the aircraft cannot be safely landed in this period. So there must be a sufficient detection period to ensure that the information generated can be acted upon. Typically this must be at least the maximum duration of the aircraft. Therefore the analysis must be of a form that gives early detection of potentially catastrophic failures.

The second point is that a more complex analysis may give us a better picture of what is the actual state of a component. Each analysis should tell us about the condition of the aircraft, but just because an analysis shows us that a component is healthy, is the component actually healthy? To illustrate this point let us consider a common level of analysis performed within aircraft at the moment by the chip detector. There are only two outputs from a simple chip detector, debris is or is not present at the detector, but what does it tell us about the following four events:

(i) The system is producing debris due to gross damage within the gearbox. The debris is detected.

(ii) The system is producing debris due to the normal operation within the gearbox, and this does not affect the health of the gearbox. The debris is detected.

(iii) The system is not producing debris, because the gearbox is healthy. No debris is detected.

(iv) The system is producing debris but due to the mechanical nature of the gearbox, the debris is not washed down to the sensor. No debris is detected.

Clearly this low level sensor cannot give us complete coverage of this element. To differentiate between the first two cases further examination of the debris needs to be undertaken by a more in depth technique. The second two cases show that although the technique may show that there is no debris this does not mean that there is a fault. Other analysis techniques will be needed to differentiate between the failure conditions. So more than one analysis technique may be needed for an individual element to detect different failure modes or provide corroborating evidence of a particular failure. The second analysis technique may not be part of the HUMS system but could consist of ground support equipment such as a Rotor Track and Balance system, or could be a ground based service such as oil analysis.

From this we can see that a simple form of analysis can often give us a general picture of the component health, but further analysis must be run to validate a diagnosis or to cover all failure cases of the system. These more detailed analyses will more than likely be more complex but they may not need to be run as frequently as the simpler analysis.

The converse case also applies with more complex analysis. Due to their nature they are intended to identify particular failure mechanisms that are not detectable by simpler techniques, and so only provide limited coverage of components. A technique such as the Stewart Hughes Limited (SHL) rolling element bearing vibration analysis [1], may in certain mechanical configurations be unable to detect a failure due to mechanical or sensor problems, a simple technique like debris monitoring in parallel will frequently prevent these failures from passing undetected.

An important point to remember with the analysis techniques available to HUMS is that most analysis techniques do not directly detect faults but measure or indicate the presence of some secondary effect, eg engine health is determined from power assurance checks, gearbox health from gearbox vibration analysis or chip detectors. The secondary effect itself may indicate the presence of more than one type of fault, so further analysis will be needed to differentiate between the failure mechanisms.

From the earlier discussion of the debris monitoring case, it was shown that reliance on a single indicator can lead to false alarms, and faults passing undetected. From experience Stewart Hughes have had in diagnosing faults within rotating machinery, more accurate diagnosis has always been achieved through using more than one technique, or more than one indicator to diagnose a fault. Within the SHL gear analysis package [2], a suite of indicators are produced based upon the vibrations produced from the gearbox. Each of these indicators measure a known secondary effect within the gearbox. When considering the different failure mechanisms each one causes two or more secondary effects, so greater confidence can be placed within the diagnosis as more secondary effects are detected.

The final point to be made is that not all analysis performed by the system need to run continuously, some are only required for particular parts of the flight envelope, eg engine start up temperature exceedance, rotor track and balance measurements. So complex analysis can be selected if they are only used intermittently.

In summary the analysis techniques should be selected on the following basis:

Provide sufficient advanced warning of the failure so that it can be acted upon.

Provide corroborating evidence for other techniques.

Complexity of an analysis need not prohibit its use if it is only used intermittently.

The HUMS being developed jointly between SHL and Hawker Siddeley Dynamic Engineering Limited (HSDE) that will be trialed in conjunction with the Civil Aviation Authority by British International Helicopters Limited (BIHL) on a Sikorsky S61-N, is analysing gearbox, main rotor and engine, plus some basic usage of the airframe. There are ten different types of analysis being performed from simple lubrication oil monitoring and shaft order measurement, to real time identification of faults of rolling element bearing. This shows the diverse complexity and type of analyses that must be performed by the HUMS.

4.0 WHO DO WE TELL?

At this stage the decision of which components are to be analysed and what techniques are to be applied has been made, but no real consideration of what data is being produced and what will be done with it. This is normally the least considered part of a monitoring system but is probably the most important. No matter how comprehensive the system is and how clever and accurate the diagnosis, if the information about health and usage of the aircraft cannot be presented clearly and unambiguously to the personnel operating the system, the system will fail in its objectives.

The first point to recognise is that there are different levels of information required from the system which will be presented to the different personnel involved with the system.

(i) *The pilot:* The HUMS should only present information to the flight crew, which the pilot can use to make decisions on the operation of the aircraft, or which can affect the safety of the aircraft. In particular this could be status of aircraft systems, such as oil levels, vibration levels, engine power assurance levels, limit exceedances etc.

The overriding factor in deciding what information the system should present to the pilot, is that it should improve the safety of the aircraft, and not overload the pilot with additional requests and tasks. In certain critical phases of flight such as take off and hover all pilot information would be suppressed.

(ii) *Ground crew:* The ground crew would be the first main interaction with the HUMS and will have access to the majority of the HUMS analysis results. The HUMS will report occurrences within the last flight that would result in the aircraft being unsafe for the next flight. It would inform them of events that have occurred upon which maintenance actions could be carried out, eg a rotor out of balance was detected so Rotor Track and Balance equipment should be fitted for the next flight, or a gear fault was detected so a boroscope inspection of the gearbox should be carried out.

The interface between the HUMS and the operator will need to be sophisticated in terms of graphical and numerical presentation in order to allow rapid and easy interpretation of results. The ground crew will also be required to transfer the results from the airborne HUMS to the maintenance personnel for long term trending and analysis. The SHL approach is to use a hand held micro-computer that has a graphical display, and a limited keyboard that can be used in conjunction with a series of menus presented to the operator. This device will also contain a non-volatile storage medium for transfer of data to the maintenance department.

(iii) *Maintenance personnel:* The data from the HUMS must be presented so that information on used life and developing faults is clearly identified, so allowing maintenance and overhaul of the line replacement units to be scheduled. This scheduling will not be carried out on the basis of one aircraft, but will be performed fleet wide, so the maintenance personnel will want to compare data produced from more than one aircraft. Similarly trends that occur within vibration or engine power levels on one aircraft may want to be compared against another.

The ground based system will receive its data from the ground crew hand held device, but should also include information from existing inspection or testing of the aircraft, results from other analyses, eg oil analysis, so that the maintainer has a complete picture of the state of the aircraft, and the fleet.

The last class of information gives some hint to the amount of data that will be produced by the HUMS. The ground based system will need to hold not only data produced by the aircraft in the last flight but will require comparison against previous flights, and other aircraft. To estimate how much data this is, let us consider the HUMS system being developed by SHL and HSDE. It is expected that during the BIHL trial at the end of a typical days flying, between 2000 and 4000 separate analysis results will be recorded. The majority of this will indicate good data, but all of it has to be recorded for trending and comparison purposes. When this is equated against months of flying plus data from other aircraft, and other analysis or maintenance actions (recording oil debris analysis, oil top us, component change on aircraft, etc), the operator will soon be swamped with data unless a sophisticated automatic system is employed.

In summary the data handling system must:

Filter the data so that the correct level of information is presented to the different levels of personnel.

Collate data to allow comparison in time for one aircraft, or across fleet for similar events.

Capable of handling large amounts of information.

Accept data from other analysis techniques and maintenance actions.

5.0 WHAT SHOULD THE SYSTEM BE LIKE?

Although we now have a system defined in terms of what it is monitoring, how it is monitoring and where the information goes, there are still further requirements to be met. These are:

(i) The system requires minimal interaction with the pilot in order to operate. The pilot already has a large workload so the system should not add to it. The pilot should not be expected to start analysis other than existing practices such as power assurance, and rotor track and balance measurement, although ideally this should also be removed from the pilot.

(ii) The system should not require modification to the aircraft flight plan in order to operate. The system should not require special manoeuvres or holding of particular flight patterns in order to operate.

(iii) The system should be capable of expansion. It is not long since Stewart Hughes felt it would not be possible to include the gear and bearing diagnostics techniques within an avionic system [3]. It is only the advances made within the semi-conductor industry over the last four years that has made this possible. New techniques are being developed and will soon be available for inclusion within a HUMS, so provision for expansion should be made now. Also analysis that may be applied to one aircraft type may require a larger or smaller system when applied to another type.

(iv) Make effective use of the system processor architecture. Some analysis techniques are computationally intensive, others are trivial. Selecting a single processor to perform the complex tasks in real time will mean that when it performs the trivial tasks it will not be used efficiently. By distributing the tasks amongst a number of processors more efficient use can be made of the resources.

(v) Offer true parallel processing so that more than one analysis or acquisition can be performed simultaneously.

(vi) Improve reliability. If a single part of the system fails the HUMS must still perform even in just a limited mode.

The system itself will comprise of a number of elements. If we consider each analysis sub system then there are five stages :

(i) Front end signal conditioning, which will contain driver circuits for sensors, filter, gain ranging etc.

(ii) Digitisation and conditioning of the the signal. This covers the production of the signal in a digitised form required by the analysis technique.

(iii) Analysis of the data. Examination of the digitised signal.

(iv) Storage and assessment of the analysis results.

(v) Control and synchronisation of the analysis tasks. The acquisition phase in particular may need to be synchronised to the operational conditions of the aircraft.

If each of the above stages was implemented for each analysis technique to be used within the HUMS, then there would be considerable redundancy within the system. Additionally most of the elements would be under utilised, as some of the analysis would not be performed during the whole operational cycle of the aircraft. So this approach will tend to abandon the avionic principles of weight, form factor, and power consumption. What we have got is a lot of conventional avionic systems lumped into one box, a solution that does not fit in with the above requirements at all.

6.0 WHAT IS THE SHL SOLUTION?

Instead the SHL approach has been to share resources between the different analysis tasks. This not only applies to the processing required but also to the sensors, and storage of data. Within the system a series of modules is defined. Each module has a processor, memory and ancillaries capable of performing a number of functions. Each module can perform part or all of the analysis cycle for a variety of different analysis task, analysing and compressing the data before moving it onto the next stage in the analysis. Complex tasks that require more resources or processing power than can be achieved in a single module can share the resources of two or more modules.

This type of architecture is already used within existing avionic applications, but the difficulty has always been with sharing tasks around the system and expanding or modifying the system. The modules in the system are usually of a limited size and so the tasks have to be shared across the modules, in particular as further tasks are included within the system. This has resulted in the modules having to communicate along a dedicate link, the microprocessor bus. This link will be shared by all of the modules in the system. A simpler comparison is to think of this link as a single track railway connecting number of towns. Each town having its own train, but only one train can be used on the railway at a time. As further towns are connected to the railway more and more trains are waiting to use the track so that train journeys start to become more infrequent and become delayed. Most of the journeys tend to be local services between adjacent towns, coupled with the occasional long journey from one end of the railway to another. The short journeys cause a bottleneck in the system stopping the longer journeys from being run regularly. The same thing happens when more modules are placed upon the microprocessor bus. The SHL solution has simply to build more tracks between the towns so that there are many routes and new towns that wish to be connected to existing towns have their own railway. The SHL tracks cannot carry the capacity of the original railway, but the small local services between the towns operate efficiently, and the long journeys having their own line. This allows an efficient sharing of resources within the system, and provides a simple route for expansion and modification.

This architecture has been applied to the HUMS developed between SHL and Hawker Siddeley Dynamic Engineering (Figure 1). In this system not all of the modules are contained within the same enclosure but are connected by their own dedicated links. There are three separate enclosures within the airborne system. The enclosures are referred as the Main Processor Unit (MPU), the External Transmission Multiplexer (ETMX), and the External Engine Multiplexer (EEMX). The ground based parts of the system, the Data Retrieval Unit (DRU) used by the ground crew to read and transfer the data, and the Ground Station Computer (GSC) used by the maintenance department, use the same approach but the communication links between the units are only connected when required.

The MPU performs the majority of data acquisition and analysis within the system, but by explaining the functions of the ETMX and EEMX the design approach can be illustrated.

One of the prime considerations for fitting a HUMS to an aircraft is not the cost of the equipment, but the cost and weight of fitting sensors and wiring to the aircraft. This was one of the first main issues that was addressed by SHL. The purpose of the the multiplexers is to reduce the amount of wiring required within the aircraft. The ETMX is used for signal conditioning, filtering and gain ranging of vibration sensors within the system. These sensors are used to analyse rotor, gear, bearing and engine performance. The MPU will only accept a limited number of sensors simultaneously so this unit multiplexes all of these lines into the number of line acceptable by the MPU. By placing the ETMX or a number of ETMX around the aircraft, the high bandwidth screened wiring required by the vibration sensors can be reduced. The ETMX has to be controlled by the MPU so a serial communication link is used between the two units. Since the data bandwidth along this link is low, further ETMX units may be controlled using the same link. For much of its operation, the ETMX unit is idle as it simply selects the options required by the MPU. To make further use of its resources, when it is idle it monitors the status of the chip detectors within the system, informing the MPU whenever there is a change of status.

The EEMX performs much the same function in reducing cabling costs but goes further. The bandwidth of the data produced by the engine and airframe sensors is considerably less than that required by the vibration sensors used within the HUMS, so this multiplexer not only multiplexes all of the input signal but also digitises the data. This digitised data can then be sent to the the MPU along a standard communication link.

Another important issue is the processing requirements needed to perform the analysis of the engine, gearbox and engines within the aircraft. The total processing power in the system is capable of performing between 10 and 20 millions of instructions per second (MIPS), or the equivalent computational power of 2 micro Vax, with a capability of expanding the system further. This processing power is not allocated to a single processor, but within the complete HUMS across six different processors each performing different tasks. For some analysis tasks only a small fraction of this power is required, for others sixty percent of the power may be allocated for a short time to allow fast execution of complex tasks. Similarly, the multi-processor configuration allows tasks to take place in parallel, in fact the requirements for the engine analysis are completely different for the majority of other techniques, so these tasks can run continuously in parallel to the rest of the system.

7.0 CONCLUSION

This paper has tried to show some of the considerations that have to be made when defining a Health and Usage Monitoring System, with some indication of the direction taken by Stewart Hughes Limited in producing their demonstrator. The steps that must be taken are to identify the components that should be analysed, then select the appropriate techniques. From this the techniques can be simply mapped into the SHL HUMS architecture.

Only by adopting this computer system architecture, based upon the independent module with its dedicated communications, do SHL feel that they can develop Health and Usage Monitoring Systems. The flexibility and built in expansion capability means that not only can current techniques be shown to work in the current CAA sponsored S61-N trial, but that the system can easily be adapted for other aircraft and new analysis techniques.

8.0 REFERENCES

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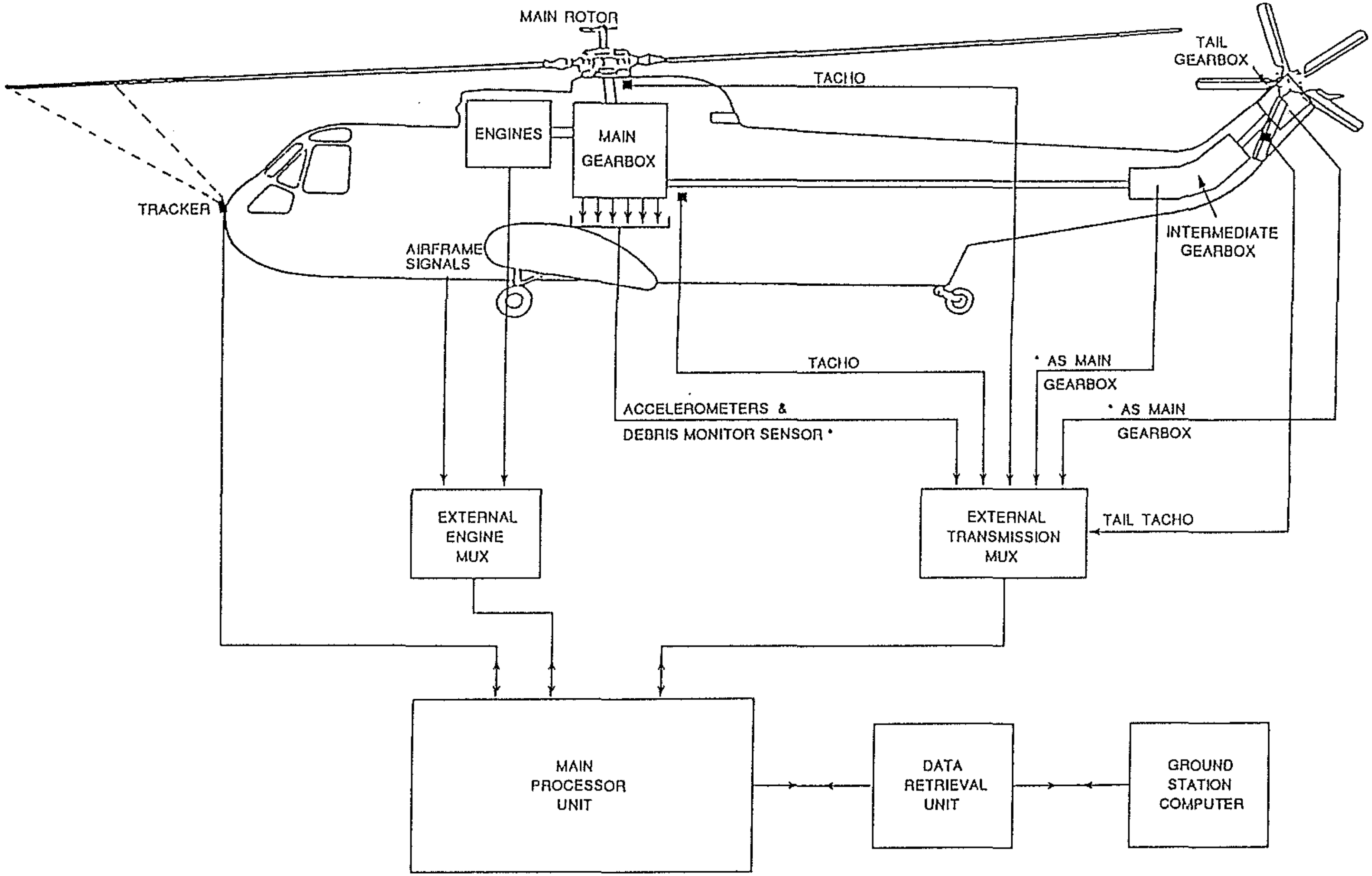

FIGURE 1 : Overall system block diagram