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HELICOPTER HEALTH MONITORING FROM ENGINE TO ROTOR

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1. ABSTRACT

Recent tragic accidents have focused attention on the dangers of unmonitored helicopter dynamic assemblies. Methods are available to monitor the entire power train from the engine to the rotor. Apart from the obvious safety advantages, such systems offer the additional benefits of increased availability, a planned maintenance schedule and a reduction in life cycle costs.

Historically, monitoring systems have evolved from isolated processing units, each performing single functions. Hawker Siddeley Dynamics Engineering Ltd, in conjunction with Stewart Hughes Ltd is developing a modular and integrated health and usage monitoring system. After a brief discussion of health monitoring equipment evolution, this paper focuses on the practical application of the techniques required to ensure the health of the modern helicopter.

2. INTRODUCTION

The use of health monitoring techniques on helicopters has as its ultimate target the twin goals of improving aircraft safety, and reducing operating costs. Aircraft safety and airworthiness improvements can be achieved by providing a reliable means of predicting critical component failures in time for corrective maintenance action to be taken. The ability to keep the aircrew better informed about faults within the power train in- flight will contribute to improved flight safety. On- condition maintenance allows engineering work to be planned more effectively, and capital tied up in excessive stocks of spare parts can be reduced. Further, there is the potential for improved aircraft availability and a reduction in life cycle costs. For new designs, monitoring systems can speed the process of extending Time Between Overhauls (TBOs).

Significant progress in the development and proving of health monitoring techniques has been achieved in recent years. These techniques include vibration, wear debris and performance monitoring amongst others. Such techniques have been used increasingly on static plant for many years, but their use in airborne applications has been slowed by the size, weight and complexity of the equipment required. Recent helicopter accidents have focussed attention on the dangers to safety of unmonitored aircraft gearboxes and other dynamic assemblies relying on fixed overhaul periods to provide sufficient maintenance. Analysis techniques and system elements now exist in a form suitable for airborne applications. For helicopters, the critical elements are the single load path, non-redundant gear trains and rotor systems. Vibration analysis is likely to be at the centre of any system which is monitoring helicopter gearboxes, but many other functions need to be incorporated. These not only increase the functionality of the equipment, but also can provide corroborative evidence between techniques such as vibration and oil debris monitoring for transmission systems. Such integrated systems, known as Health and Usage Monitoring Systems (HUMS) are vital to the safety of modern, complex helicopters.

This paper outlines the history of helicopter health monitoring, discusses the practical aspects of what is possible now and finally comments on a system actually under development.

3. MONITORING SYSTEM EVOLUTION

Until relatively recently many health and usage monitoring systems consisted of 'carry on board' tape- based recording equipment. Measurements were taken at periodic intervals during special flights and the analysis carried out later on the ground. This approach has been used particularly for vibration and rotor monitoring due to the complexity of the analysis required, but it is inefficient in terms of time and resources. Technology has now advanced to the point where continuous monitoring by equipment permanently fitted to the helicopter, producing results in flight in real time is possible. These improvements are due in no small part to the advances in processor power increases and memory density increases over this period.

Typical of a health monitoring system produced some nine years ago is a stand alone Low Cycle Fatigue counter for engine monitoring. This unit, monitoring a single function, is illustrated in Figure 1. It employed a single 'second generation' 8 bit microprocessor to perform all internal operations.

Figure 2 shows an example of the next generation of monitoring equipment, designed some four years ago. This is a combined digital engine control and health monitoring unit. The advance in technology using 16 bit microprocessors has increased the available computational power to approximately 12 times the single function unit. This improvement in performance, coupled with the larger capacities of available memories enabled multiple health and usage monitoring functions to be simultaneously performed on one microprocessor.

The system illustrated was designed for the Rolls-Royce Gem engine, and combined a comprehensive engine health and usage monitoring capability within the same enclosure as a Full Authority Digital Engine Controller (FADEC). Separate isolated processors were used for the engine control and monitoring functions, with a one-way data communication link from the engine control processor to the monitoring processor. Engine monitoring functions included the following:

Low Cycle Fatigue.

Turbine blade creep usage analysis.

Power performance checks in flight.

Comprehensive limit exceedance logging.

An engine failure warning function.

Although multi-function, nevertheless the unit monitored one engine only. To meet the computational requirements of a fully integrated and comprehensive HUM system for the whole helicopter, there is a need for a significant increase in computational power. Some of the newest 32 bit microprocessors have the required power making real- time vibration monitoring a practical possibility. These new microprocessors can offer approximately 480 times more useable power than the single function unit. Also there has been an equally dramatic advance in memory design. Memory capacity for similarly-sized elements has increased 64-fold in the last 8 years.

4. MONITORING SYSTEM REQUIREMENTS, FUNCTIONS AND OUTPUT

4.1 General Requirements

What of a comprehensive system designed for today's needs. To be effective and operationally acceptable the monitoring system must satisfy many general requirements, a number of which are listed below:

-It must provide advance warning of long-term unserviceability to the maintenance organisation.

-It should provide useable advance warning of short- term unserviceability to the aircrew.

-The equipment must be very reliable, with an extremely low probability of spurious warnings.

-It must not hazard the airworthiness of the aircraft to which it is fitted, or alter the normal flight characteristics.

-Data must be stored with a very high degree of integrity, particularly where usage, exceedance or executive lifing functions are included.

-On-board equipment must be compact, of low weight and have a low power consumption.

-The sensors and transducers associated with the on- board equipment must be robust and reliable. They must be capable of operating in the presence of environmental extremes resulting from faults which the system is designed to detect.

-The cost of operating the HUM system, including the ground based data management must be acceptably low.

4.2 Functions

There is a wide range of monitoring and diagnostic techniques available for helicopter health monitoring. A typical comprehensive HUM system could include some or all of the following functions:

Transmission

- Gear and bearing vibration diagnostics.
- Torque usage.
- Oil debris monitoring.
- Oil Temperature, Pressure and Quantity

Rotor Head

- Track and balance.
- Torque usage monitoring.
- Overspeeds
- Bending moment during taxiing.
- Control failure warning.
- Hydraulic Temperature, Pressure and Quantity

Engines

- Usage monitoring:
  - Low Cycle Fatigue. (LCF)
  - Thermal fatigue.
  - Creep usage.
- Power Performance Index / Power Performance Check
- Oil debris monitoring.
- Gas path debris analysis.
- Broadband vibration monitoring.
- Logging functions:
  - limit exceedances
  - starts and run time
  - run down time
- Engine failure warning.

Some of these functions require little processor power, but others like vibration monitoring ideally require 10,000 times more computational power than engine usage monitoring. Many of the monitoring and diagnostic tasks need to be performed in parallel, and this further adds to the overall processing power required for the on-board HUM system.

The number and combination of functions available requires that the design of the monitoring system should be based upon a flexible modular concept, enabling a user to select the particular combination of options required.

4.3 Results Display

So far we have been considering the on-aircraft equipment. We need the means means to sort, analyse and display the data on the ground. The on-board unit completes the initial number-crunching and stores results in memory. These need to be downloaded to a device, normally referred to as a Ground Station. First, a method is required to transfer the data from the aircraft to the ground station. Two devices could be used, one a dumb data transfer device, the other an intelligent terminal.

The dumb device is typically a personalised memory card used with a simple read/write device. Data is downloaded into this card at the aircraft at the end of each period of flying and this data is subsequently transferred to the PC running the database.

The intelligent terminal option is a hand held computer. This has many benefits (except cost!) over the memory card. Data can be transferred to the Ground Station in the same manner, but also a limited interpretation can be made directly whilst at the aircraft by using the display on the device. This is significant if the helicopter is away from its base location or if it becomes unserviceable away from base during the day.

Once the results are available in the Ground Station, further manipulation and analysis is possible. Results from the last flight can be used to produce statements on aircraft health and probable faults or they can be combined with those taken previously to produce a trend analysis. Exceedances can be identified and displayed. The results of any off-line programme like SOAP could be added at this point. Where possible, the Ground Station should coroborate the results obtained from more than one analysis method. This increases the probability of the diagnosis being correct and decreases the false alarm probability. Hence a historical picture of the aircraft's health can be built up, enabling long-term trending and statistical threshold values to be calculated.

It is crucial that the final result is presented to the maintenance engineer in a useable form. This can be either in a graphical mimic style display or as a textual message. The maintenance engineer wants the answer to the simple question 'what must I do to this helicopter tonight to get it serviceable for tomorrow morning?' Access to more detailed engineering information will be required to enable fleet comparisons to be made. However, the messages displayed to the shop floor staff, who will be using the system on a daily basis, must be easy to understand and act upon.

Other methods of displaying the results to either the aircrew or maintenance organisation should be available depending upon the severity of the occurance and the location of the helicopter at shutdown. Results could be obtained as follows:

a. In Flight.

If a significant event occurs during flight which places the safety of the aircraft in doubt, the main processing unit should be able to generate a warning which could be displayed on a dedicated alpha-numeric panel or on the pilot's centralised warning panel. A dedicated panel will allow the display of more information than a single light warning which in turn will allow the crew to decide the criticality of the component to that particular flight taking into account the weather conditions, flying time to landing and whether the component is on a redundant load path.

b. On the Ground, after Normal Shutdown.

Recognising that helicopters, especially military ones, do not always return to base at the end of each flight or that it may not be convenient to complete a detailed analysis of the data in the ground station, the crew need to be informed if the helicopter is fit for its next flight. After an event occurs which a sensor recognises as a normal shutdown (say, the tachometer noting that the rotor speed has fallen below 50%), if a fault had been detected which might make the aircraft unfit to fly again, a warning must be displayed to the crew. Using a dedicated panel, status messages can be displayed easily. If the light warning only is used the same light in the centralised warning panel could be utilised, but this time in flashing mode. In this case, details of the possible fault could be displayed on the data retrieval unit if carried. Limit exceedances and significant changes of state can also be displayed.

4.4 Operating Standards.

The production equipment must operate in a hostile environment and give long maintenance-free service. The usual requirements of vibration, operation and storage temperature range, sealing and RFI protection must all be considered. The choice of the software criticality category needs careful consideration. If an in-flight warning is to be included in the system this may require software to be Level 1 category as defined in RTCA/DO- 178A.

4.5 Operating Requirements

The ideal system will require no aircrew involvement in the normal running of the system. The collection of data in flight will be completely automatic with no special flight conditions needing to be set up. Engineering staff will be required to download the data at suitable intervals from the on-board unit to the ground station using the data retrieval device.

5. THE DEVELOPMENT SYSTEM

So much for the theory, now for the practice. Two systems are being trialled in the UK at present. One of these is a system for a Sikorsky S61 which my own company is developing in collaboration with Stewart Hughes Limited and with support from the DTI and the CAA.

The objective of the trial is to investigate the suitability, reliability and capability of a Health Monitoring System in a typical working environment (North Sea oil support) and to determine effective methods of integrating health monitoring techniques into an operators maintenance procedures.

The functionality of the system is as follows:

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

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

Rotor track and balance of the main rotor and balance of the tail rotor.

Engine monitoring of both engines.

The components of this system are:

- Airborne equipment
  - Sensors
  - Multiplexers
  - Main processing unit
  - Pilots Control Interface
  - Wiring
- Ground support equipment
  - Data retrieval device
  - Ground station

This is shown pictorially in Figure 3.

5.1 Sensors.

Piezo-electric accelerometers are used as they are robust, have stable characteristics and are reasonably priced. Although many types exist, choosing a suitable one to fufill all the requirements for this demanding environment is difficult. Firstly, the choice has to be made between integral or external charge amplifers. Integral amplifier types are preferred as the output signal is less likely to be affected by RFI and it saves having to mount a separate charge amplifier close to an unamplified accelerometer. A flat frequency response from 2 to at least 10,000 Hz is required so a resonant frequency in the order of 45k Hz is required. We expect to measure 'g' levels of up to 500 and the accelerometer must survive shock loads in the order of 3000 'g'. The ideal sensitivity is 10 mV/g which gives a maximum output of +/- 5 volts. Practical requirements demand that the accelerometer must be mounted by a single stud or bolt to prevent peppering the helicopter gearboxes with holes; locking, either by wire or locking compound must be incorporated; the cable orientation must be omni-directional to allow cabling to clear possible obstructions; electrical isolation must be provided without reducing the resonant frequency so that earth loop effects are minimised; and the size must not be too small for the maintenance engineer to inadvertently damage it. About 25mm diameter and 25mm height is thought to be ideal. The unit must be hermetically sealed and not be affected by contamination from fluids typically present in that environment. To provide protection against RFI, high quality, shielded wiring is required.

The number of accelerometers required on a gearbox and their position depends on the design of the gearbox. The S61 main gearbox contains an epicyclic system which is the most difficult to obtain signals from. In this case a ring of accelerometers is placed around the annulus. Bevel gears are much easier to monitor and suitable signals can usually be obtained with one accelerometer.

The technique used for the vibration monitoring of gears within gearboxes is to employ data sampling in synchronisation with the exact period of rotation of each gear within the gearbox. These samples are taken at time intervals which are electronically derived from a once- per-rev signal. This is provided from a tachometer mounted on a high speed shaft. A clean, stable once-per- rev pulse with minimal jitter is required.

5.2 Multiplexer.

In general the signals from the sensors attached to each major dynamic assembly are fed to a multiplexer and then via single cables to a main processing unit. This adds little to the weight of the equipment but dramatically reduces the amount of wiring required.

5.3 **Main Processing Unit.**

The main processing unit is in an enclosure which generally conforms to 1/2 ATR (Air Transport Racking) dimensions. The connections, all of which are made to the front face, consist of inputs from each multiplexer, the power supply and a communications interface to a data retrieval device. The approximate weight of this demonstrator unit is 8 kg. Inside, the unit consists of a power supply to power the internal circuits, and 3 printed circuit boards. The unit incorporates BITE. There are no planned maintenance functions.

5.4 **Pilots Control Interface**

The Pilot's Control Interface is essentially a 'data capture' button so that the crew can initiate data capture by the HUMS unit when the correct flying conditions for engine performance monitoring and rotor track have been set up.

5.5 **Wiring.**

Great care must be taken with the routeing of cables to reduce the effects of RFI and induced noise from surrounding cables and equipment.

5.6 **Data Retrieval Unit**

The data retrieval device used is a hand held computer. Apart from downloading results to the Ground Station, it can allow the display of exceedances at the aircraft when time precludes a full analysis in the ground station and track and balance information could be displayed on this unit in flight if so required. Also, the unit is used to load reconfiguration data into the MPU from the Ground Station.

5.7 **Ground Station.**

The ground station consists of a PC and customer configured database software. The PC is a standard IBM AT or compatible running in the Xenix operating system. The system operates a comprehensive database management system, allowing data to be presented in a form which highlights problem areas and allows maintenance to be efficiently managed.

The results of the vibration analysis are presented using a hierarchical structure. The next 3 figures show examples of a typical VDU presentation. First (Figure 4), the aircraft with the problem is identified with alarms displayed at the bottom. By paging down the hierarchy, next the major assembly at fault is highlighted (Figure 5) and the faulty component identified. The analysis method produces sets of non-dimensional parameters for each gear or bearing. These can be displayed in histogram form (Figure 6). A specific type of fault is identified by noting increases in value of a certain sub-set of these parameters.

CONCLUSION

This paper has studied the evolution of health and usage monitoring systems, discussed what modern technology will allow and described a development system. The future for these systems is encouraging but much work needs to be completed to ensure their widespread acceptance.

Acknowledgement

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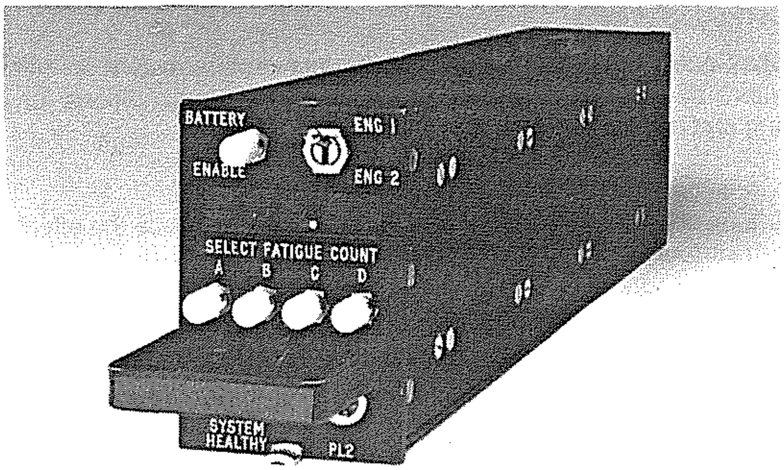

Figure 1

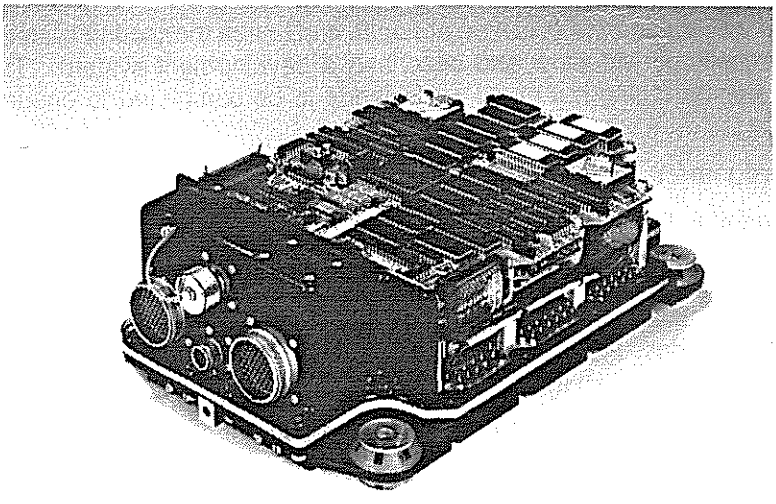

Figure 2

SYSTEM DIAGRAM

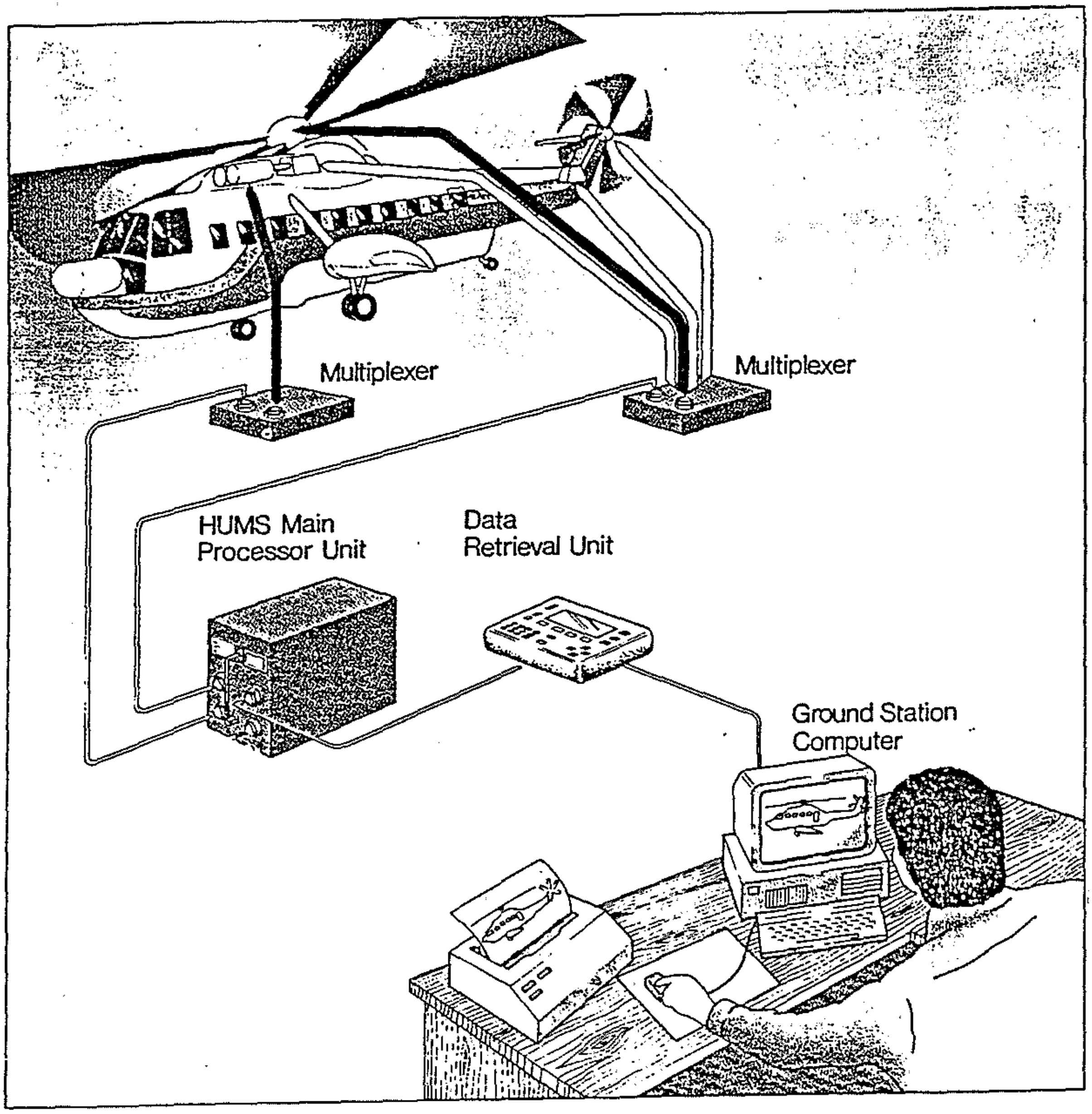

Figure 3

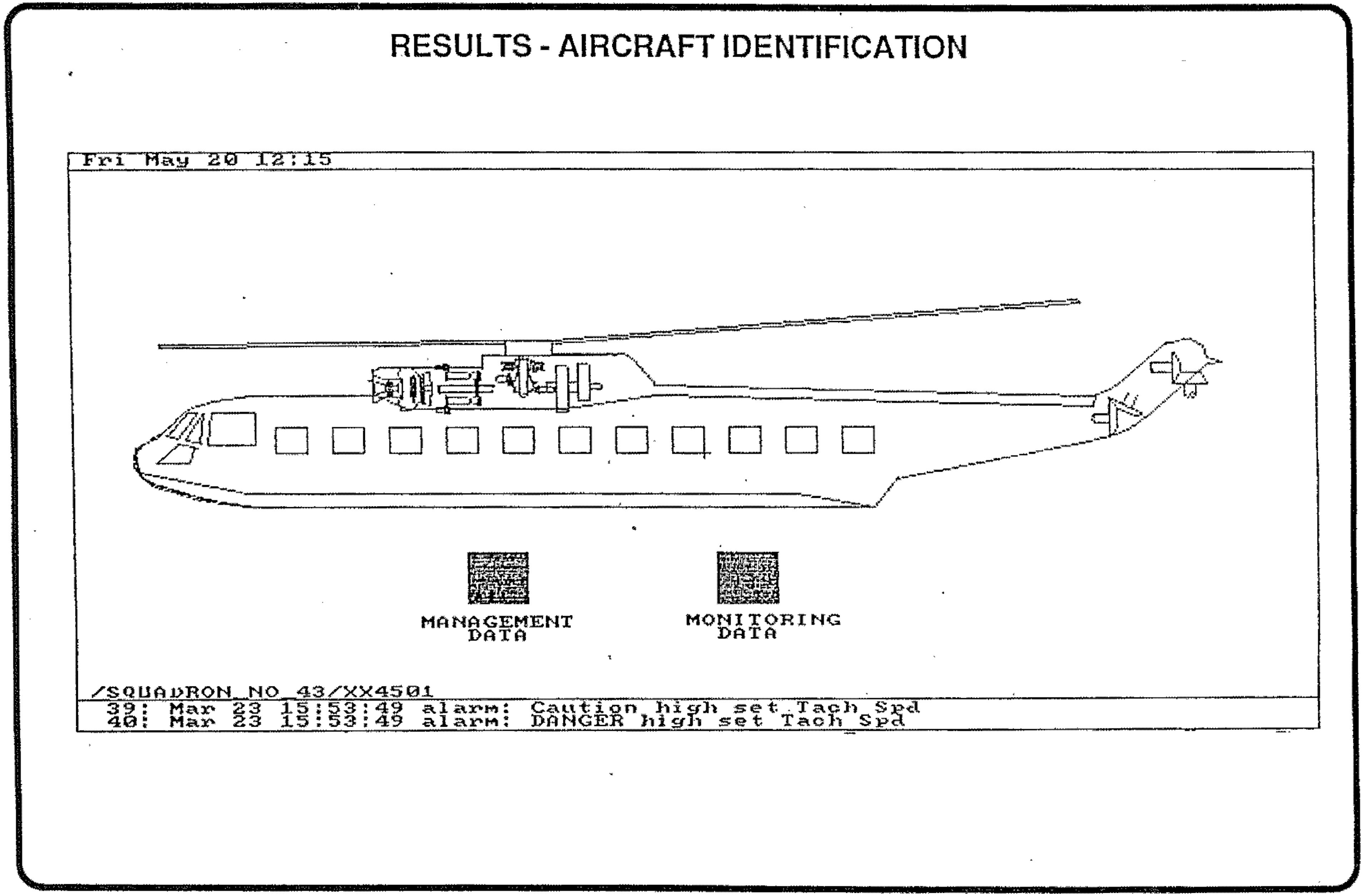
RESULTS - AIRCRAFT IDENTIFICATION
Fri May 20 12:15
MANAGEMENT DATA
MONITORING DATA
/SQUADRON NO 43/XX4501
39: Mar 23 15:53:49 alarm: Caution high set Tach Spd
40: Mar 23 15:53:49 alarm: DANGER high set Tach Spd

Figure 4

RESULTS - MAJOR COMPONENT IDENTIFICATION

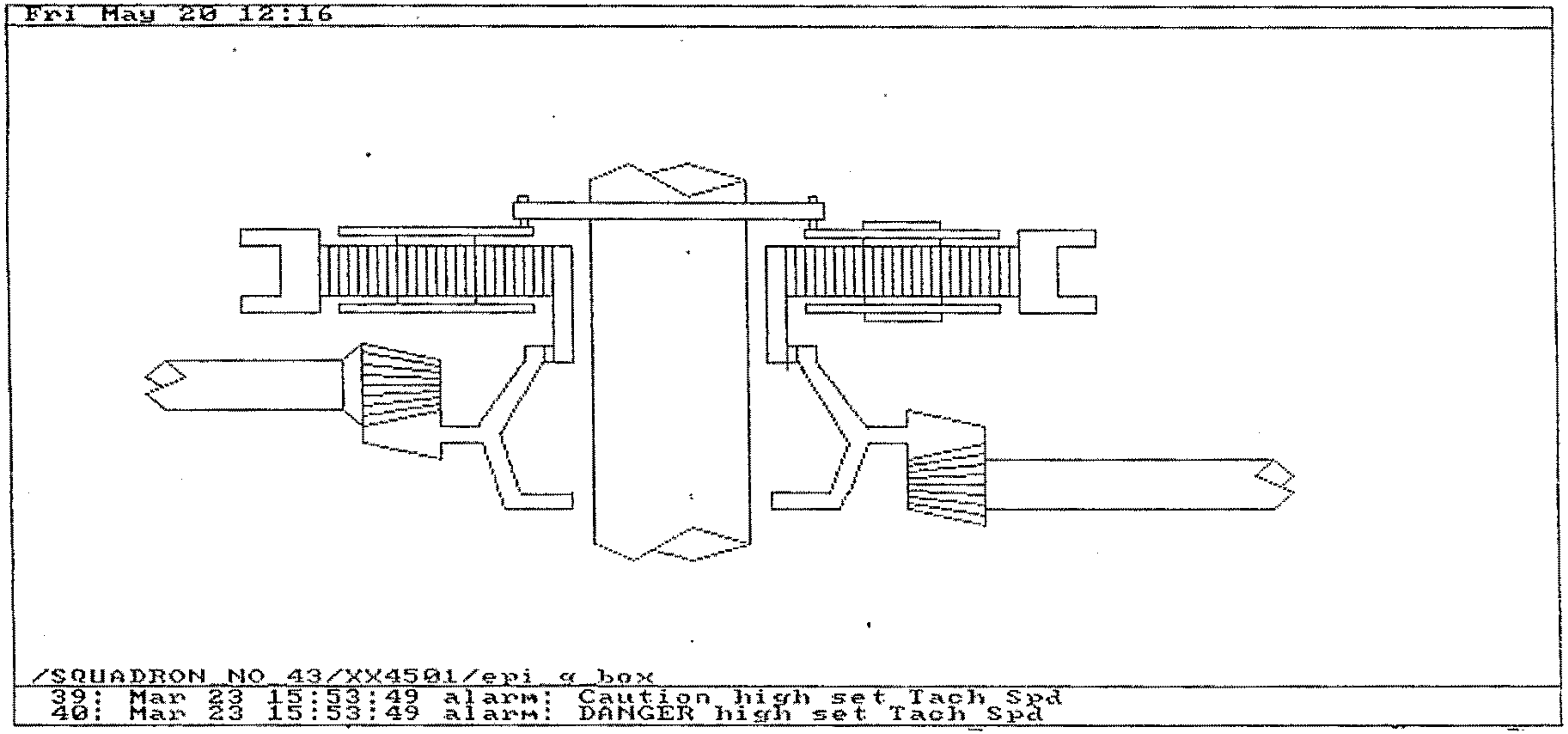

Figure 5

RESULTS - FAULTY COMPONENT IDENTIFICATION

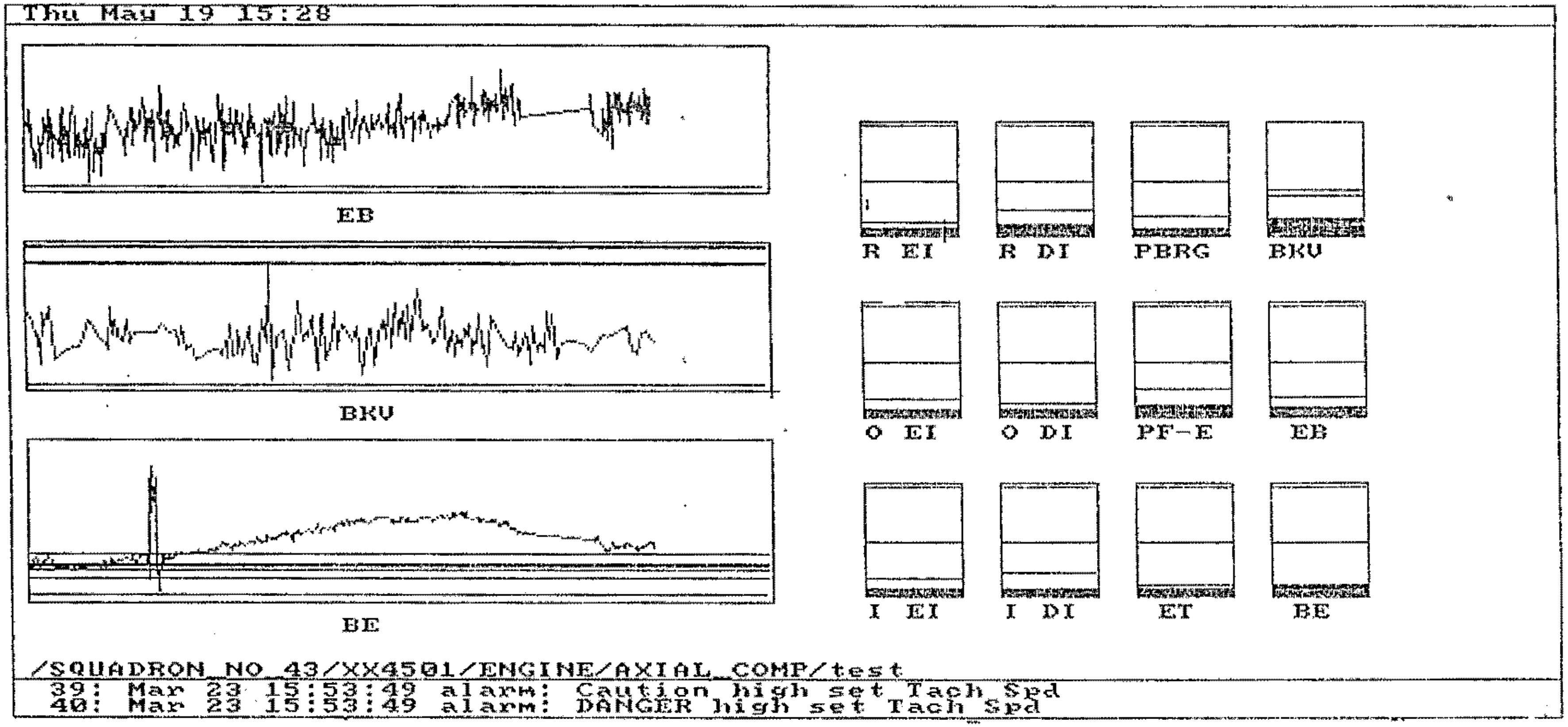

Figure 6