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MANAGING HELICOPTER DYNAMIC COMPONENTS

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ABSTRACT

Managing helicopter dynamic components in an on-condition environment requires a fundamental rethink of maintenance management procedures which extend far beyond the design of sensor and monitoring system design. This paper sets out the constraints to be observed in designing an on-condition maintenance system for helicopter machinery, and profers a low cost data base solution which is an extension of a system which has already been successfully demonstrated to the RAF for fixed wing aeroengine management.

INTRODUCTION

Maintenance of a helicopter's machinery package is a compromise between the requirements of flight safety and economy of operation. For the most part in a helicopter the critical components of its machinery are not spared, multi-engined aircraft being the exception. Because of this Time Between Overhauls (TBO's) and routine servicing intervals have to be very conservatively set in order to be safe. This policy results in a very high consumption of spares and maintenance man hours per operational flight hour.

It has been postulated for some time that if the condition of an active component subject to stress can be determined to an adequate integrity, then fixed TBO's or hard life maintenance practices can be replaced by a policy of only replacing components when they are worn out. This would, for example, dramatically increase the usable life of a transmission system by a factor of 5 with the encumbent dramatic reduction in maintenance costs.

Condition monitoring, though, places very high demands on instrumentation, signal processing and data interpretation technologies, and Stewart Hughes has been in the vanguard of research into the application of condition monitoring technology to helicopter machinery. The target has been to produce high integrity fault diagnostics, i.e. greater than 95% Probability of Detection and less than 10% False Alarm Rate. Stewart Hughes has just completed a major research programme for the Ministry of Defence (NGAST 6638) to develop high integrity diagnostic technology for the major components of a helicopter machinery package, i.e. the rotor, transmission and engines. The results of this work are reported elsewhere in the conference, and I am not going to discuss them here. The object of this paper is to discuss the problems of implementing a condition based maintenance system, assuming that adequate condition monitoring technology is now available, and has an acceptable performance.

Westland Helicopters have demonstrated in the WG30 that an instrumentation and data logging system for machinery management can be designed and built. Condition monitoring is also pencilled into the specifications of the "Aircraft Management Computers" of most of the next generation aircraft, EH101 in Europe and JVX and LHX in the US. But without exception there is no specification covering how maintainers will use the data provided, or what assistance they will require to handle the data.

What follows is a presentation of a system designed to support an on-condition maintenance policy for a helicopter. This system is a result of work undertaken for the RAF (in conjunction with SCICON LTD.) to demonstrate how an "On Condition" maintenance system for Aeroengines could be implemented utilising the latest monitoring techniques. The first part of the paper discusses the problems relating to implementing an On Condition based maintenance system. The second part is a synopsis of the features of the PIMS (Prototype Information Management System) presented to the RAF. The author has chosen to present this data rather than a hypothetical helicopter because the RAF demonstration was based on real data gathered from a squadron of Hawk aircraft over twelve months and the system designers had to tackle the problems of handling real data. The resulting system is correspondingly more realistic than any hypothetical case. The information is specific to fixed wing aeroengine management, but the concepts are germain to any machinery management problems. The final section discusses the extension of the system, designated HIMMS, to the problems of helicopter management.

CONDITION MONITORING, IS IT A PRACTICAL PROPOSITION?

The problems of achieving the economic advantages that are the target for condition monitoring are not restricted to the development of measurement and diagnostic techniques.

The current hard life system of maintenance is expensive but it is easily managed. The workshop manager, given a flying hours per month target that has to be achieved on the flight line, can then schedule his labour and resource the spare parts. This is all the maintenance engineer wants to know.

Any maintenance planning has also to cope with the problems of unscheduled maintenance, or arisings, and this is on top of implementing modification campaigns. In the extreme in a condition based system all maintenance effort would be as a result of anticipated failures, which will be random in distribution, the same characteristic as for arisings. Clearly as arisings are a problem then the resourcing of "On Condition" maintenance will be a continuous problem.

Clearly if a system cannot predict maintenance requirements over a period complient with the logistics of supplying maintenance support, then the worst fears of the maintainer will be realised. The logistics of helicopter repair are highly dependent on the item being repaired. The effort required to change a rotor blade is very small and ready availability of spares contrasts with the effort required to change a transmission and the associated high costs. Clearly any system would have to cope with this large spectrum of requirements, i.e. prediction of requirements ranging from hours to months.

The management system has to be capable of supplying information to the various levels of the logistics chain. Figure 1 defines the levels of the maintenance hierarchy in general terms. The machinery supervisor or flight line engineer has the day to day responsibility for machine availability. He probably makes the least demand of the system. If there are engineering problems to solve then the machinery manager requires a much more comprehensive and detailed data base to support his fault finding diagnosis. The operations manager requires wide ranging statistical information to assist in the planning of spares and predicting availability.

What is needed is **one** system that can provide information about how each component is coping with stress, meeting the prediction and hierarchy requirements set out above. Then the engineer organisation can base its servicing decisions on the actual life expectancy of each particular component with sufficient knowledge to provide the confidence that the safety of the aircraft is not encroached upon.

The area where condition monitoring technology is most advanced in practical use is aeroengines. Current trends for aeroengine management are: heavy investment in the instrumentation necessary for monitoring engine performance in flight, for oil analysis systems, and for boroscopic inspection instruments. But to inspect components such as turbine discs, the engineer must still remove the engine from the aircraft. More research and development will be necessary before all Grade A components can be managed on-condition to an acceptable degree of confidence.

While the technology for on-condition monitoring is being continuously developed, the engineer must still continue to rely to some degree on the hard-life data provided by the manufacturers. However, even with hard-life systems, improvements can be made. The rate at which you consume life (exchange rate) can vary substantially from squadron to squadron. A computerised system can be used to monitor sorties cycle counts and to then calculate exchange rates on a historical basis so that the engineer can maximise TBO (Time Between Overhauls) for each individual aircraft. The key characteristic of any engineering management system is that it must cope with both types of maintenance policy simultaneously.

THE PIMS SOLUTION

In Britain, the Royal Air Force has a declared policy of putting all aircraft engines under on-condition maintenance. As part of the eventual changeover to total on-condition management, a consortium of companies with expertise in this area was asked to demonstrate an on-condition management system, to operate within the constraints described above. For this demonstration, this team has developed PIMS - the Prototype Information Management System (see Figure 2).

In the consortium, Stewart Hughes of Southampton, England, has applied its experience of machinery management to the writing of the system specification. Scientific Controls Technology of Palo Alto, California, supplied their proprietary data base system: the Maintenance Information Management System (MIMS-TM). This system has already undergone successful trials with USAF in the management of engines for their B52s and A10s. Finally, Scicon of London, England, have implemented the database as PIMS, and integrated the system with new graphics displays for use with RAF procedures.

We chose to use a data base system for two reasons. Firstly, because the data can be stored and processed in different ways to accommodate different operating practices. Secondly, because the data can be stored and processed more quickly than by other methods. Typically, it takes from 5 to 15 seconds for PIMS to compute any required analysis and display the results graphically from the data accumulated over a sequence of sorties.

Because the RAF manage their aircraft on a different basis from the USAF, we reconstructed the data base in its entirety. Stewart Hughes had to adapt the software, analyses, and diagnostic to national requirements. For example, the RAF manages engines at First Line, but manages engine modules at Second Line.

Stewart Hughes also converted the package to run on a portable, intelligent, graphics display terminal instead of a bulky PDP11/70 minicomputer on which MIMS was originally implemented. This is a more cost-effective solution, built using the proven technology of the Stewart Hughes Machinery Systems Diagnostic Analyser (MSDA), and incorporating a Winchester hard disk for fast storage and retrieval of large quantities of data, as shown in Figure 3.

THE HEALTH PROFILE

PIMS reduces the vastly increased quantity of monitored data that would be recorded on each sortie for an aircraft with appropriately instrumented engines to a routine Health Profile report (see Figure 4) for the aircraft engine. The Health Profile is available on demand, and summarises all aspects of the current performance data and maintenance information.

The display itself contains only data that can be assimilated quickly and efficiently by the First Line engineer when he is taking operational decisions.

On the left of the Health Profile, the monitored data is shown: performance data; whether any operating limits have been exceeded, and for how long; the oil analysis from the Early Fault Detection Centre (EFDC); and current rates of critical life usage (in cycles) for Grade A components. For the usage data, PIMS presents the monitored exchange rates rather than the assumed rates given by the design authority.

On the right of the Health Profile, the checklists for Management action show: any alarms that have been triggered by changes in performance; significant maintenance actions that have been completed; and life remaining on critical components; and the servicing instructions to be carried out.

You can change existing alarm levels, other than the mandatory ones, or add new alarms to any of the monitored parameters in the system.

Typically, the engineer would examine the alarms first, and then the table for Module Life Remaining. From these data he can clear all the relevant maintenance actions on an aircraft engine for a predicted number of hours flying without reference to any other sources of information.

If an alarm is indicated, the engineer may accept it at face value, even though the operating limits are usually set well inside safety limits. If he wishes to investigate further, he can use the extensive trending and graphics facilities to estimate the time to go before a safety value would be transgressed. This produces an Estimated Operating Time Remaining (EOTR) (as shown in Figure 5) for this item of monitored data. If the EOTR for the alarm measurement is longer than the specified hard-life of the component, then the alarm can be viewed less seriously, although the engineer may request a bar chart (not illustrated) to check performance of the engine against that for each of the other engines in the squadron. If the projected EOTR is less than the specified hard-life, then the component should be scheduled for appropriate maintenance action before the end of the projected EOTR.

There are extensive graphical features to facilitate these investigations, with up to four graphs shown in a single display for comparison, and up to six times per graph. The flexibility of the data base means that each computation takes only 5 to 15 seconds from command to display. In this way, trending converts monitoring data into management information: namely, which component has a problem, and how long the engineer has to rectify it.

To examine the analysis and data that underlies the conclusions summarised in the Health Profile, the engineer can refer to historical data displays or consult Expert Systems as an aid to decision making. An output from the engine performance analysis expert is shown in Figure 6. A key aspect of decision making is planning. Here again, the data base can provide information for engine bay loading and sortie planning. For example, graphics displays are produced from extensive statistical analysis based on measurements of actual MTBF (Mean Time Between Failure) for each module. These measurements are used to predict the future distribution of life remaining among the engines in the squadron or the fleet, as shown in Figure 7.

As a side-benefit, the statistical functions can be used to compress the size of the data base before performance data is passed on to the Engineering Authorities.

The Engineer can also review the effectiveness of his maintenance strategy by inspecting a Maintenance Summary (see Figure 8); this uses an Historical Data Display to relate performance data to maintenance actions. An essential feature to enable the performance of maintenance to be measured, and to provide a psychological boost for the maintainers.

PIMS has features for using condition data: in the workshop to assist in module selection for engine building; in the test house; and for the Engineering Authorities, but would be topics for a different paper.

HIMMS IMPLEMENTATION

The general features of PIMS are required to support an engineer operating in an On Condition regime, irrespective of the machine type. The graphics facilities are essential to ensure the rapid assimilation of the monitored data. The key analysis undertaken by the engineer is the ability to trend data, and extrapolate on it to produce estimates of time to go before action is required. This is the essential item of information that allows condition and hard life systems to be interfaced. The correlation and statistical analysis features, possibly combined with an expert system, are required to ensure that the prediction of failures is accurate and, perhaps more importantly from an economic point of view, false alarms are effectively eliminated.

The routine monitoring requirement of the rotor has nothing in common with the transmission or the engines. Consequently these elements of the machinery package will require separate Health Profiles. The rotor requires regular adjustment and inspection; it is essentially modular in construction i.e. blades and hub, but has a long hard life replacement interval. Whilst the engines have shorter hard lives, the structure of a rotor Health Profile will be similar to that discussed previously.

The rotor's performance can be measured as track deviation and the vibration transmitted to the airframe. Utilising newly developed technology both of these items can be monitored on an automatic basis. There is also the possibility of using the same data to infer blade root stresses to use for the basis of both exceedence and usage recording. There are of course no oil lubricated components. The likely performance aspects of a health report for a rotor are shown in Figure 9.

The transmission's Health Report will be slightly more simple in structure, as there is little in the way of regular adjustments. Whilst a very large quantity of data is monitored, very little needs to be reviewed on a routine basis.

What would be the elements of a Health Profile for a transmission system? Taking the structure of a PIMS Profile as a general model. As stated above a gear system does not have a performance as such. The only reason that it would fail to transmit torque would be because of the failure of a component or loss of lubricant, which is covered by the rest of the monitoring system. The torque on shafts and gears can exceed nominal design levels, after which health should be checked. Torque exceedence would be monitored. Debris analysis would certainly be routinely reviewed, probably the output of a Quantitative Debris Analyser. Usage will certainly be monitored, an example of which is shown in Figure 10. Vibration will be monitored, but only reviewed and trended if an alarm is triggered, indicating a fault. In this mode the general features of HIMMS would be required.

The engine's Health Profiles will be a simpler version of what has been discussed, with special attention to torque margin.

Any resulting system would contain a significantly large data base than the fixed wing case. The data base would have an extra layer to its "hierarchy", as shown in Figure 11, which would affect both the storage requirement and data retrieval time, but not significantly. In terms of system design, this does require a more powerful computer, but it does mean a larger disk to store the data. With Winchester disk storage costing less than £50.00 per megabyte this is not likely to be a cost sensitive consideration.

The ability to provide a remote terminal to maintain the essential monitoring functions whilst the helicopter is on detachment or is deployed away from the maintenance base would be an essential component of a system designed to support a helicopter.

Taking all the above system engineering conditions into account, the resulting hardware specification, the elements of which are shown in Figure 12, could be met by most professional 16 bit desk top micros, supported by a large Winchester. This would be at a cost similar to a single helicopter's instrumentation and associated avionics pack required to support the monitoring needs. These systems can be networked to provide a system for the engineering authorities, without the enormous overhead of transmitting the raw data to a very large mainframe, but this use of the system would be the subject of a another paper.

In conclusion this paper demonstrates that a low cost ground support system to assist the maintenance engineer to manage his machinery in an On Condition environment is both technically feasible and economically viable. But, more important than this, what the paper should demonstrate that to consider implementing a comprehensive condition monitoring policy for the principle machinery of a helicopter without a system such as HIMMS would be a severe problems for the maintenance organisation.

INFORMATION REQUIREMENTS

OPERATIONS DIRECTOR	FULL DATA FULL REPORTING FUNCTIONS NO DIAGNOSTICS NO DATA ENTRY
MACHINERY MANAGER	PARTIAL DATA BASE FULL REPORTING FUNCTIONS FULL DIAGNOSTICS PARTIAL DATA ENTRY
MACHINERY SUPERVISOR	MINIMAL DATA BASE MINIMAL REPORTING FUNCTIONS PARTIAL DIAGNOSTICS FULL DATA ENTRY

FIGURE 1

PIMS

PROTOTYPE INFORMATION MANAGEMENT SYSTEMS

PURPOSE

TO DEMONSTRATE THE INTEGRATION OF CONDITION MONITORING TECHNIQUES INTO THE ENGINE MANAGEMENT SYSTEM, WITH A VIEW TO IMPLEMENTATION ON SEMA (STATION ENGINEERING MANAGEMENT AID)

CONTRACTOR

SCICON/STEWART HUGHES/SCT

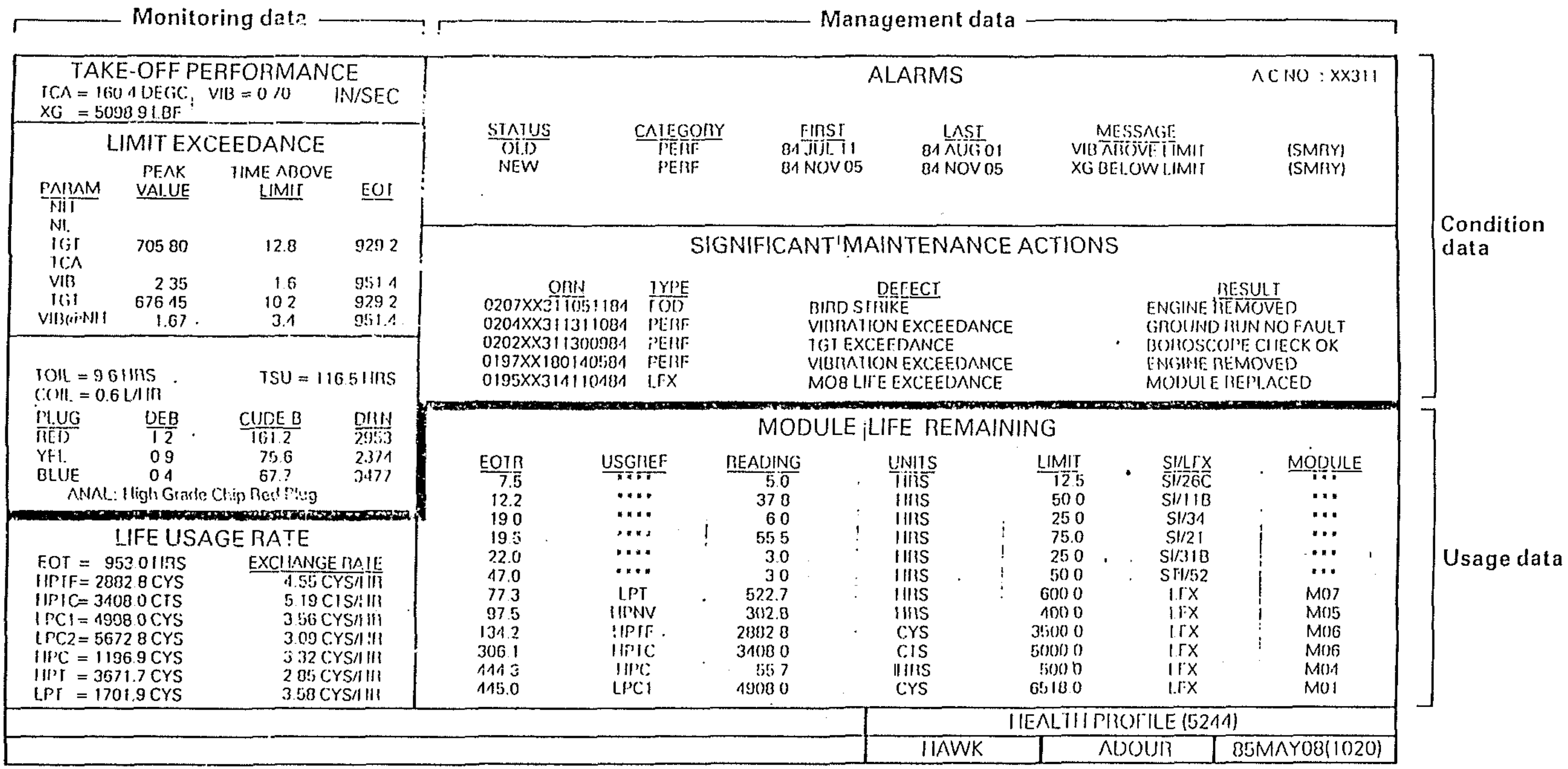
DEMONSTRATION

APRIL 1985

SPONSOR

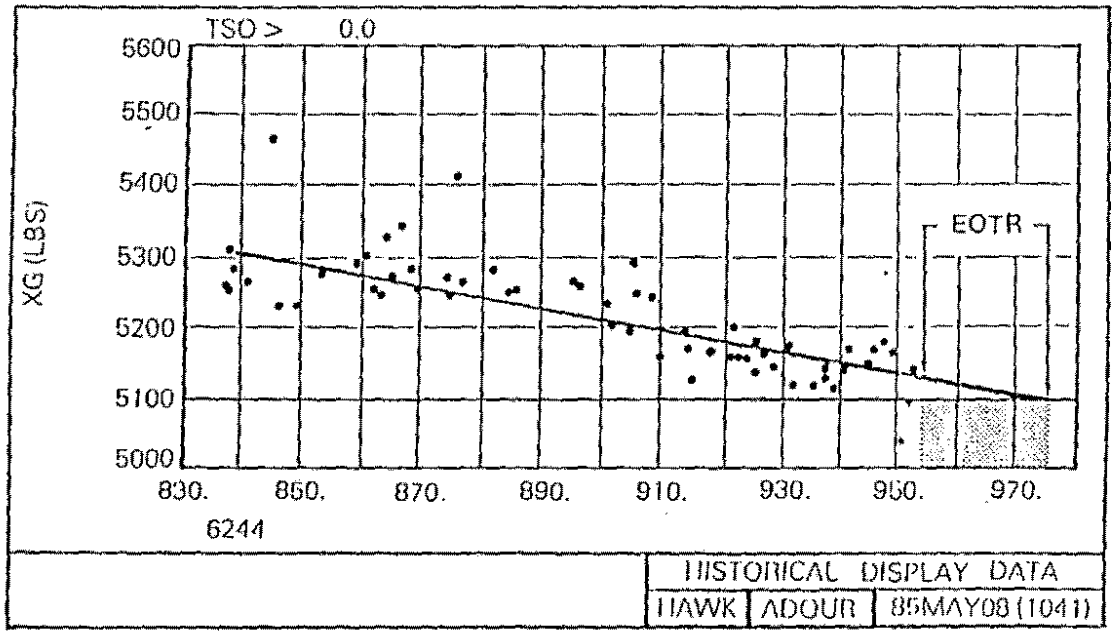
MODPE AIR ENG 2B

FIGURE 2



A Health Profile

FIGURE 3



Trending for EOTR (Engine Operating Time Remaining)

FIGURE 4

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                                        Single unit diagnosis
                                        ------ ---- ---------

Probability                    0    10   20   30   40   50   60   70   80   90   100

widened low pressure NGV       **************************************************

low pressure compressor        ***********************
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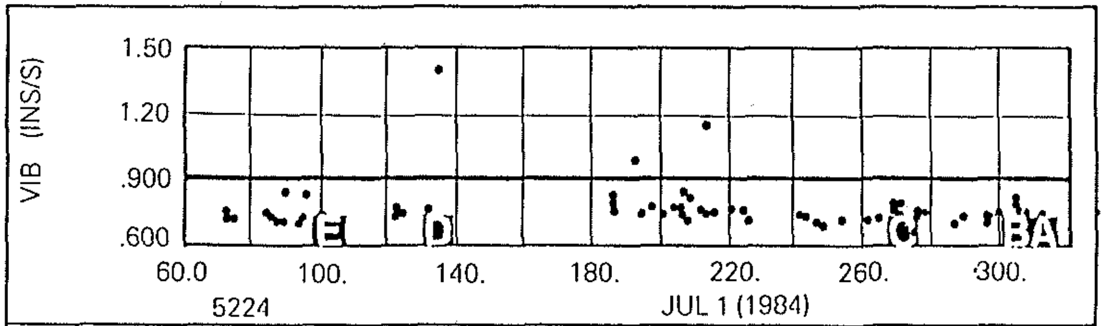
Probabilities of less than 30% not displayed.

FIGURE 5



MAINTENANCE CORRELATION

A:	84NOV05/1 –	BIRD STRIKE	ENGINE REMOVED
B:	84OCT31/1 –	VIBRATION EXCEEDANCE	GROUND RUN NO FAULT
C:	84SEP30/1 –	TGT EXCEEDANCE	BOROSCOPE CHECK OK
D:	84MAY14/1 –	VIBRATION EXCEEDANCE	ENGINE REMOVED
E:	84APR11/1 –	M08 LIFE EXCEEDANCE	MODULE REPLACED

HISTORICAL DATA DISPLAY

HAWK | ADOUR | 85 MAY 88(1036)

Maintenance/Performance Log for vibration data

FIGURE 6

Rotor Health Profile

PERFORMANCE	HOVER CONDITIONS
	AOT = xxx
TRK SPD = xxx.x	BLNC MAG = xxx.x
	PHASE = xxx.x

VIBRATION (IPS)

1R	4R	8R	12R
xxx.x xxx.x	xxx	xxx	xxx

FIGURE 7

Transmission Health Profile

USAGE	TORQUE BANDS				TSO xxx HRS
	1	2	3	4	5
LIMIT	XXXX	XXXX	XXXX	XXXX	XXXX
SHAFT 1	xxxx	xxxx	xxxx	xxxx	xxxx
SHAFT 2	xxxx	xxxx	xxxx	xxxx	xxxx
SHAFT 3	xxxx	xxxx	xxxx	xxxx	xxxx

NB *exchange rates would be an alternative display.*

FIGURE 8

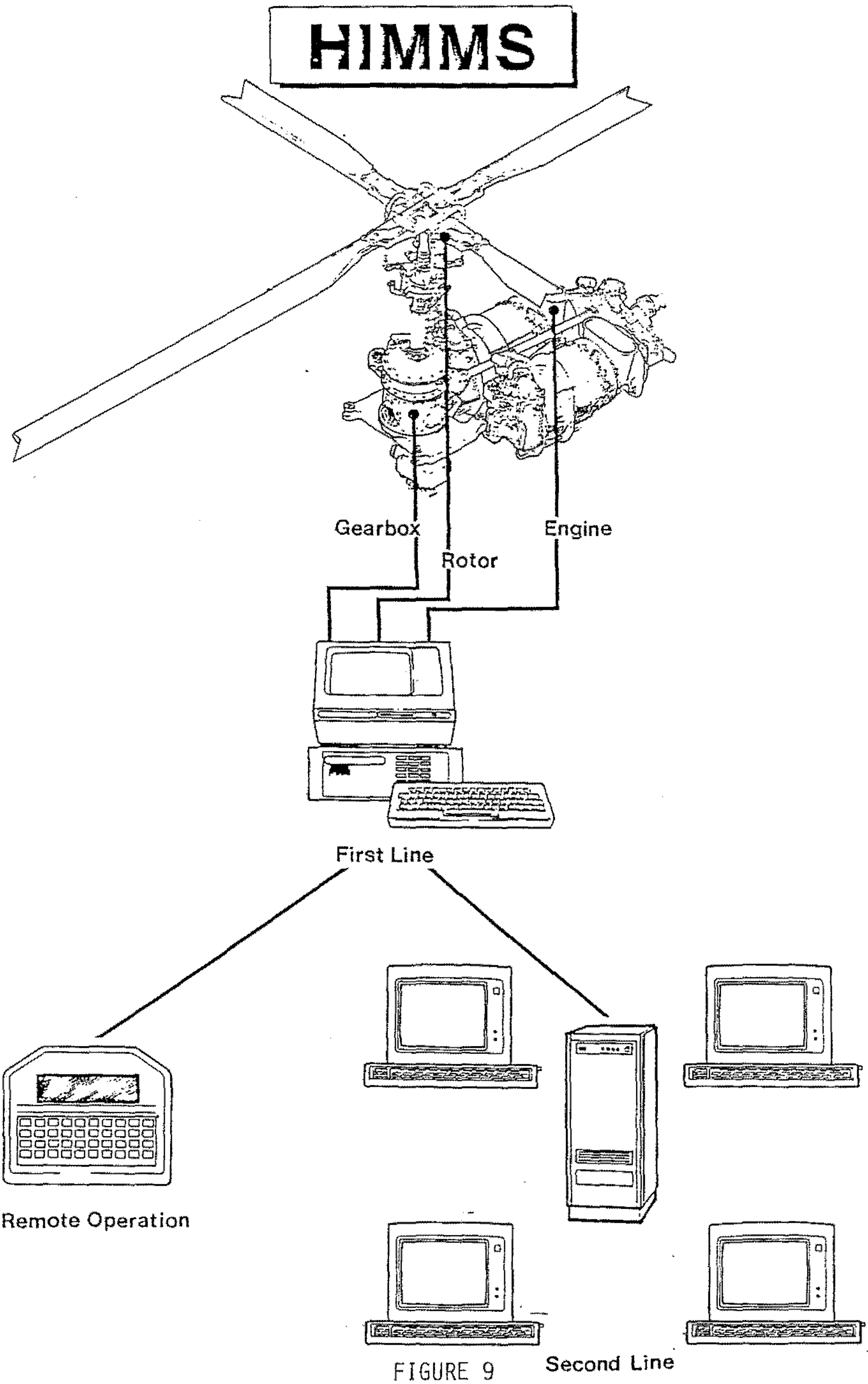

HIMMS
Gearbox
Rotor
Engine
First Line
Remote Operation
Second Line

FIGURE 9