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HELICOPTER CONDITION MONITORING IN UK MILITARY SERVICE TODAY

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ABSTRACT

This paper sets the UK Military Helicopter scene for the Condition Monitoring papers in the 'Airworthiness' section to be presented at the Forum.

Drawing on in-service experience, the current techniques, equipment and their limitations are described. The environmental problems and operational restrictions are stressed.

Three current techniques are selected and explained in some detail: oil analysis programmes for transmission systems, engine health monitoring, and vibration analysis including tracking and balancing of main rotors. The problems of data analysis and collection for scattered military units are discussed.

Further needs for condition monitoring are propounded: the capability to monitor trends and diagnose faults in a well tuned helicopter, preferably during an operational sortie. The need for quick, accurate and reliable diagnostic aids requiring minimum skill levels is explained.

The ideal aims are stated for future condition monitoring equipments for military helicopters to improve aircraft availability and decrease the overall cost of ownership.

1. INTRODUCTION. Much design and development work is currently in progress to improve the airworthiness of helicopters by using effective health and monitoring systems. To set the scene for the Condition Monitoring papers in this section of the Rotorcraft Forum we take you back to the starting gate: the equipment we in the UK military services use today, the techniques available to us now and the environmental and logistics problems inherent in the way we have to operate. These inevitably differ from civilian operations.

2. ENVIRONMENT. First of all Military helicopters operate to no set patterns and have to be maintained in extremely arduous conditions. These vary from a Royal Naval LYNX in a single ship detachment in the South Atlantic to an Army Gazelle flying 'nap of the earth' in Germany or flying in the jungles of Brunei or Belize; from a Royal Naval anti-submarine Sea King hovering for long periods over the sea to an RAF SAR Sea King operating from remote bases on the coast of Scotland. As well as operating in these conditions, maintenance has to be carried out by very small units where skill levels are minimal and with limited diagnostic equipment. The availability of each aircraft at a moment's notice to fly safely and fight is paramount in the military scenario, hence fault diagnosis must be swift and accurate within the constraints of flight safety. In Germany, the Army and RAF heavy lift helicopters are maintained in the field, mainly by night. All this leads to an ideal where any Health and Usage Monitoring System (HUMS) is part of the aircraft avionics. However the HUMS must be light because the payload, weapons and fuel, is critical in an effective fighting vehicle.

3. THE PARTICULAR. To describe how condition monitoring is used in UK Military Helicopters today three specific areas of the aircraft are chosen: transmission, rotors and engines. The particular methods of condition monitoring used in each area are described and their advantages or disadvantages stressed.

4. TRANSMISSION. The first area in which Condition Monitoring is employed in Service Helicopters is in the Transmission system. This, the mechanical heart of the helicopter is crucial to successful operation and flight safety. It's large components are expensive to maintain, both in cost of overhaul and in aircraft downtime during replacement. Typical costs for overhauling a Sea King main rotor gearbox are £50,000 - £60,000, and during replacement the aircraft could be out of service for up to a week. Good diagnostic aids with the ability to identify a faulty component of the aircraft may make the difference between repairing in situ in a matter of hours (ie lifting a cover and changing seals), to removing and returning to the manufacturer, with the penalty of being out of service for a year or more. Two methods are used to fault diagnose and monitor the condition of transmissions in service Helicopters: the monitoring of component lubrication systems and the analysis of aircraft vibration.

5. LUBRICATION SYSTEM MONITORING. The gearbox lubrication system provides the most straightforward means of assessing the serviceability of this critical transmission component at a given time. Simple monitoring of gearbox lubrication and cooling systems is carried out in flight via cockpit gauges, and on the ground more detailed analysis of debris deposited in gearbox oils enables a measure of component wear rates to be made.

a. Airborne. In the air the aircrew monitor oil temperature and pressure gauges. They will notice fluctuations, and any changes over the period of a flight provide a very basic means of trend monitoring. Chip detectors are fitted to all the Sea King gear boxes which provide an alarm system to warn of debris arising from component damage. In practice these have not proved entirely successful as too many sorties have been aborted for spurious readings caused by build swarf or a build up of harmless microscopic particles or by electrical connector problems. Above all else, airborne monitoring equipment must be accurate and reliable, to remain credible and retain aircrew confidence.

b. Oil System monitoring on the ground. A number of oil analysis techniques are used in service today and their applications are varied depending on the success rates found on each component:

(i) Ferrography is a one-off technique dealing with selected problems, eg to measure the quantity of ferrous metal deposited in some transmission components. By this process trends can be monitored, but testing has to be carried out either in a central laboratory or in dispersed locations. Ferrography is a very expensive process normally of value to particular non-routine investigation into a known defective system. Analysis of Sea King tail gearbox oil is carried out by this method: to date some 19 potential bearing failures have been detected, and thus potential failures averted.

(ii) SOAP, or Spectographic Oil Analysis Programme, is now well established both for transmission components and engines. To keep the programme cost effective, analysis is carried out centrally for each service. Using oil samples taken at regular intervals and posted back from all over the world, the deposits of trace metals such as Iron, Copper, Silver, Aluminium, Manganese and Titanium are measured and monitored. Notwithstanding postal difficulties and the time taken to return samples, increases in wear rates are readily detected and with experience the pattern of the increase of specific elements can be interpreted to give a good indication of the source of increased wear.

(iii) Finally, ad hoc samples of deposits or debris gathered from oil filters and magnetic plugs are analysed to determine possible sources and modes of failure.

c. These 'off aircraft' monitoring techniques can be carried out either locally or at a central Laboratory. Both methods have inherent advantages and drawbacks. Local analysis will give a quick answer, and is particularly useful where the aircraft is operating at a distant or remote location such as on a battlefield in the middle of Germany or from a ship in the South Atlantic. (A debris testing facility was installed in HMS Illustrious in 1982 for just this purpose). However it is rarely cost-effective to provide and operate complex equipment in dispersed locations. The level of expertise at these locations is also lower. By contrast a central laboratory such as the Naval Aircraft Materials Laboratory (NAML) at Fleetlands in Hampshire provides different advantages. Here it is sensible to locate more specialised and very expensive scientific equipment such as Spectographic Oil analysers, and electron microscopes; and to employ more specialised scientific staff. NAML has a wider picture of RN aircraft fleet characteristics and is able to determine the best method of Condition Monitoring for each specific transmission component. NAML is also able to analyse debris from lubrication systems, and today provides a highly respected and widely used service to the Royal Navy in identifying whether material found in oil systems is dangerous or harmless.

d. However although we have had considerable success with them, these processes of oil analysis have too much manual input. This requires high levels of skill, leaving room for error. Before a technical decision can be made using these processes a sample must be taken, sent for analysis, analysed, the results plotted, the trend determined, a diagnosis made and if necessary the advice communicated back to the unit: a laborious and time-consuming sequence of events. Thus it is perhaps not surprising that a 'safe-life' policy based on flying hours is used for service transmission components, with condition monitoring used only to detect alterations from the predicted safe life. We need a reduced and automated Condition monitoring and diagnosis loop which is reliable, cheap and effective to operate before components can be changed 'on condition' which is our clear requirement. Further cost benefits would of course accrue from a lifing policy based on actual fatigue life consumed rather than on flying hours achieved.

6. VIBRATION ANALYSIS (VA). Analysis of a helicopter's vibration signature is carried out in service and gives another indication of the condition of transmission components. A comparison of the frequency of any observed abnormally high levels of vibration with the known rotational speed of transmission components gives an indication of the cause of the high vibration and will possibly detect defective components.

a. Past progress. Considerable improvement has been made in the accuracy of vibration measurement in service helicopters in the last 7 years. During this period equipment has advanced from the first generation clockwork driven Askania vibrograph, which was versatile to operate but with a poor frequency response and very complicated to analyse. In 1978 second generation equipment was introduced in the form of the 2358 Scientific Atlanta vibration signature recorder. This produces a real time card plot of frequency versus amplitude by means of a swift frequency filter looking at the signal from an accelerometer mounted on the airframe. This vastly improved the time required to analyse the vibration signature and is still a good first line GO/NO GO tool.

b. Near future. Entering service now are Multichannel Airborne Casette Tape Recorders which reduce the time taken to record vibration signatures by eliminating the need to sweep slowly through the required frequency band and recording signals simultaneously from the 3 axes of vibration monitored. When combined with electronic frequency spectrum analysers, these give a very accurate and reproduceable picture of the helicopter's vibration signature. The Services have a good diagnostic record of identifying faulty components from Vibration Analysis: incipient failures in such transmission components as Hydraulic pumps, generators, Main Gear Box through - drive - shafts and tail rotor drive shaft bearings are commonly detected in the field by V.A.

c. Test flights. At present however, analysis of vibration from transmission systems is used as a confidence check of performance and airworthiness, or to investigate a specific defect rather than as a continuous trend monitoring programme. Vibration test flights are carried out at periodic intervals (currently 6 monthly) or after major component changes, to check the airworthiness of the helicopter. Additionally a vibration check may be carried out to investigate a specific defect such as a vibration or noise reported by the pilot. These checks are expensive to carry out in that they require a dedicated flight - or portion of a flight - to set the correct height, speed and weight parameters, and because they require the presence of a highly skilled technician to operate the vibration measuring equipment.

d. Because of the cost of these flights, VA is not yet used to its full capacity within the Services as a Condition Monitoring or diagnostic tool. Recording flights are made too infrequently to allow collection of sufficient data to make trend monitoring a viable method of predicting the condition of transmission components. Progress in this area is much complicated by the very 'noisy' vibration environment of every helicopter, and the large number of components rotating at similar speeds, or with near-coincident harmonics appearing throughout the frequency spectrum. This makes detection and isolation of vibrations from specific transmission components a difficult task requiring accurate frequency discrimination and noise elimination which presents a strong challenge to the designers of such a system.

7. ROTORS. Vibration Analysis is also used as a method of Condition Monitoring for the second area of the helicopter - the ROTORS, which is worthy of separate consideration. Considerable condition monitoring attention is focussed on the rotors to tune the system after installation, component changes or major servicing. On these occasions track and, where possible, balance is monitored and adjusted to achieve optimum performance from the Rotors. In service a good rotor track is invariably carried out before doing a full vibration test flight. Not to be forgotton is the need to diagnose faults in the rotor head. A diagnostic system needs to be devised to differentiate between the five common faults: track rods, tabs, chord balance, spanwise balance or dampers.

a. Tracking and balancing today. The primary equipment used in this process is the ageing but well established Chadwick Helmuth track and balance kit. A Stroboscopic light used to monitor blade track requires a degree of skill to operate, but considerable expertise has been built up in service and this is still considered to be a versatile, effective and adaptable method of blade tracking. The same equipment can be used to measure Rotor balance, and where weight adjustment or trim tab facilities are provided within the Rotor system, significant reduction in aircraft vibration has been achieved, with consequent reduction in crew fatigue and damage to structure, and an improvement in avionic reliability.

b. Improvements. This process of tracking and balancing also requires an expensive series of ground runs and flights, involving a time-consuming trial and error process which is open to a degree of subjective operator interpretation limiting its use to inexperienced technicians. The RAF have had success using the ROTORTUNER equipment on the RAF PUMA and CHINOOK helicopters. This kit uses microprocessor technology to automate the tuning procedure, and its use is currently being investigated for other aircraft.

c. Vibration signature. Once the Rotors are tuned, analysis of the aircraft's vibration signature is carried out to give an indication of Rotor condition. Vibration levels at the once per rev (IR) frequency and at the blade passing frequency (here 4 x R) are used to assess rotor trends and performance. Excessive vibration at these frequencies can be caused by a number of Rotor defects. Maintenance and recovery actions are directed by the nature of the vibration and by current experience. We are currently doing work to improve the correlation between vibration signature and rotor system defects. It is hoped that this will reduce the maintenance costs of investigating and overcoming excessive vibration. For example, current documentation lists 24 possible causes of 4R vibration in the Lynx. It is hoped to reduce this to a more manageable number of 'probable' causes. In the process an algorithm of the logical sequence of recovery actions has been written which will form the basis for servicing procedure. This will be updated as experience grows.

d. As with the use of VA for monitoring the condition of Transmission components, the processes used to monitor Rotor condition are expensive and are not carried out with sufficient frequency to permit thorough trend monitoring of Rotors using current VA equipment. Often the first indication that vibration has increased and Rotor deterioration has taken place is literally through the pilot's seat and this may not be reported until for example the missile aimer on a Scout or Wasp reports his sight to be affected by vibration, degrading his aiming accuracy. Future VA systems should ideally be permanently fitted, as with transmission monitoring, and should monitor automatically as far as is practicable, eliminating the need for skilled diagnosticians to be present. The requirement for dedicated test flights, and trial and error diagnostic procedures for adjustments should also be minimised, if not eliminated. It should then be possible to obtain a regular picture of vibration trends at an acceptable cost in time and effort.

8. ENGINES. The third area of the helicopter considered is the engine, of which there are 13 types in UK military Service today. As before, cockpit gauges permit monitoring of lubrication system temperature and presssures, speed, torque and turbine inlet temperature. Magnetic plugs are fitted to aid monitoring the oil system, and Spectrographic Oil Analysis is again used to monitor wear debris on some engines. Diagnosis is still mainly by trial and error methods: laborious and time consuming. Of particular significance for engines is the way power output is monitored.

a. In Service Helicopters we do this by calculating a non-dimensional engine Power Performance Index (PPI). This is produced as two percentage performance figures based on the observed torque for each of the Compressor speed and the Turbine inlet temperature. By plotting successive figures every 25 flying hours, engine trends can be monitored and sudden changes in engine performance can be readily observed.

b. This process is simple in theory but in practice the procedure is laborious. To collect information for the PPI's, specific flight profiles must be set, normally with each engine throttle set in turn to a predetermined high power setting. Conditions must be allowed to stabilise before exact readings of torque, compressor speed, rotor speed, PTiT, Pressure altitude and OAT are recorded by the pilot. Then the fun starts! These figures are plotted on a graph to obtain a percentage PPI figure.

c. Although this may be an acceptable procedure on a test bed, in a Service environment when operating in marginal conditions other priorities are high and there are several possible ways of introducing errors. These include incorrect reading of the gauges, turbulent flight conditions, inaccurate gauges, and mistakes in reading or plotting the figures on the graph: in practice, erroneous results are not infrequent and confuse trend plots.

d. Some improvement has been gained by the recent introduction of hand held programmable calculators to replace the graphs in calculating the percentage PPI figure. These provide a most cost effective measure which enables PPI figures to be calculated in flight and if necessary, repeat readings can be taken to confirm wayward findings. Nevertheless there is much room for improvement in removing many of the sources of error by introducing a fitted aircraft system which takes information direct from the sensors, calculates a PPI (or equivalent) figure, monitors trends, and alerts pilot and ground crew when recovery action may be necessary. In technical terms this is a modest advance we look for in the future.

e. It should be possible, from improved monitoring systems for low PPIs, to diagnose whether the problem is hot end or cold end, eg a burnt out power guide vane, or whether it can be raised by compressor cleaning.

9. SUMMARY. From these simplistic examples it can be seen that the Services have progressed some way from early helicopter days. Much condition monitoring experience has been accumulated, but not without considerable operational and logistic problems. We use a series of well-defined manual techniques using ageing equipments, and our results are reasonably good, but rely too much on operator expertise, 'trial and error' and the postal system.

10. THE FUTURE REQUIREMENT. Many new systems are on the horizon, or even closer. In the services we need any Condition Monitoring system to be simple, cheap, light and accurate. Ideally it should form an integral part of the aircraft system it is monitoring, preferably during normal operational sorties. In the short term, it needs to give immediate and completely reliable flight safety warnings. It also needs to monitor trends: either of vibration or wear, for component changing. Data must be easily interpreted, and able to be signalled or stored for analysis, allowing urgent airworthiness decisions to be actioned fast.

11. THE AIM. The ultimate aim is to improve the availability of the military helicopter by having a well-tuned, low vibration platform whose mechanical health is monitored in flight and during each sortie and for whom fault diagnosis is accurate and far more simple. Each component should be changed 'on condition' only. The technology is available, but to achieve this we would have to assess trade-offs between the cost, weight and reliability of such a vehicle: no budget will stretch to a 100% system, and total 'cost of ownership' or 'through-life costs' nowadays have to be closely addressed. The comprehensive, integrated system available now for a new-build range of helicopters might be too expensive to retrofit into our existing range of SEA KING, LYNX or GAZELLE. However, these aircraft will still be flying into the next century, so that it may be worthwhile to retrofit cheaper and less sophisticated equipments with limited capability to gain a significant proportion of the advantages offered by new technology.