The Operational Benefits of Health and Usage Monitoring Systems in UK Military Helicopters

Alan Draper & Cdr James Gourlay RN
HUMS IPT
Defence Logistics Organisation
Ministry of Defence
United Kingdom

ABSTRACT

The potential benefits of HUMS have been lauded for some years. GenHUMS has now been in operational service in the UK Chinook fleet for the last two years and is progressing through its maturity programme. Benefits from the system are being realised and are being exploited by the operators. This paper reviews some of the lessons learnt from the Chinook programme and how they are being incorporated in the Sea King, Puma and Lynx programmes. The paper also outlines the benefits to date and compares against the original claims of the project definition study.

INTRODUCTION

1. The UK military accepted the policy of installing Cockpit Voice / Flight Data Recorders (CV/FDR) as early as 1990. This was to mirror to mandatory civilian airworthiness regulations. CV/FDRs have proven to be extremely beneficial in determining the cause of air incidents. They are however reactive and only prevent incidents of the same type from being repeated. Having undertaken a number of helicopter vibration monitoring trials and having observed developments in the North Sea, it became apparent that the introduction of CV/FDR with full Health and Usage Monitoring System (HUMS) functionality could produce cost benefits as well as proactive improvements in airworthiness.

2. A Project Definition Study (PDS) was commissioned and its results and were incorporated into the Minor Equipment Requirement (MER) documents for the Chinook, Sea King, Puma and Lynx. The positive benefits were used to help secure funding for the project with a return on investment predicted within an average of 6¼ years. Significant benefits were also anticipated from procuring generic HUMS for all legacy aircraft, (hence the term GenHUMS) and a competition was held in 1995 to fulfil the requirement.

GENHUMS PROGRESS

3. Smiths were awarded the contract and work started on the Chinook programme in 1996. The Chinook system entered service in October 2000, embodiment was complete in June 2002. To date the system has amassed some 15,000 hours of operational service.

4. The activity is now centred on the Sea King programme. The Sea King contract placed in July 01 was to install the system to five different marks of aircraft (Mk3 & 3a Search and Rescue, Mk4 Commando, Mk5 Utility and Mk7 Airborne Early Warning). The system has progressed through the preliminary and critical design reviews and the trials installation is expected to commence in early 2003. The first mark will be in service in 2005, all marks will be in service by 2007 and all 90 aircraft will be embodied by late 2008.

5. The Sea King programme draws very heavily on the lessons learnt for the Chinook programme, the most significant of which are discussed in a later section, and will become the baseline standard for the GenHUMS hardware.

6. It has taken time to get the Lynx onto contract. The MoD is currently considering options as to how it is going to replace both Army and Naval variants of Lynx. The Battlefield Light Utility Helicopter (BLUH) and Surface Combatant Maritime Rotorcraft (SCMR) are the titles of the two new staff requirements that have been issued to cover the replacement aircraft. With potential new aircraft being introduced, the MoD has re-examined the value for money of some of the capability upgrades planned for existing Lynx fleets. This has drastically altered the recording requirement of the proposed Lynx HUMS and it has only been possible over the last few months to establish a firm system specification and issue a tender. The Lynx Mk8 contract was placed in November 2002. The Mk8 system will be delivered in 2005. The contract has been designed to provide maximum flexibility should aircraft numbers be affected by BLUH and SCMR procurement decisions. If the BLUH and SCMR requirement is satisfied by a future Lynx derivative then GenHUMS will be directed as the aircraft HUMS.

7. Puma risk reduction activities are now complete, specifications finalised and the company is currently costing the tender. It is the intention to have the contract in place by the end of the fiscal year. The embodiment of HUMS on this aircraft will be part of the Puma Integrated Modification Programme (PIMP). Puma HUMS will be in service by 2006.

LESSONS LEARNT

8. The technical difficulties encountered introducing HUMS into the Chinook are well documented [1,2], most can be attributed to inaccuracies in the Interface Control Document (ICD). To ensure the success of the Sea King, Puma and Lynx programmes, it was essential to learn from the Chinook experience.

9. A significant lesson learnt was to undertake a risk reduction survey on each aircraft type before letting the contract. A draft ICD was prepared for each aircraft from information taken from the aircraft design authorities data pack. The ICD was then scrutinised to identify those signals, which were not fully defined, or there was some issue on the integrity of the signal concerned. Then, at the aircraft, the source, range and definition were established for each parameter. The minimum cost to rectify a discrepancy in the ICD for the Chinook was £350k. At least 7 major discrepancies were identified at each subsequent survey, one survey revealed 20 discrepancies.

10. The surveys also allowed the user community to have an early input as to where the HUMS components should be located. As GenHUMS is being installed into legacy aircraft, some of which have been in service for over 30 years, finding suitable cockpit real estate can be difficult. Having had early visibility of the proposed locations, the user community has been able to comment on their suitability and suggest means for rationalising consoles to make sufficient space. A minor lesson learnt from the Chinook programme was to position the cockpit control unit outside the loci of the restraint belt buckle as a number have been smashed by aircrew eager to leave the aircraft.

11. A painful lesson learnt from the Chinook programme was the importance of the HUMS ground support system design and ensuring it is fully operational as it is introduced into service. In retrospect too much effort was devoted to the implementation of the airborne system at the expense of the ground station. This resulted in the system entering service initially with CV/FDR functionality only.

12. The hardware for the ground support system was specified and procured in 1995. Unix was specified as the operating system as Windows was considered unstable at the time and had not been security accredited. Therefore when the system came in to service it was already antiquated. To prevent this occurring on the follow on programmes, the ground station will be procured as a software application only. When introduced into service the software will be installed onto the latest available hardware.

13. When the HUMS was first considered for installation in UK military aircraft there was a degree of naivety regarding the amount of data that HUMS would produce and how it would be handled through the support infrastructure. HUMS data is downloaded using a 64Mb PCMCIA card (referred to as a Data Transfer Device (DTD)). An hour-long sortie typically generates 4Mb of HUMS data. The ground stations on which the cards are downloaded are very slow due to the limited processing capability and inefficient software. The majority of the processing is undertaken on a central server. The modus operandi is for each aircraft to upload a DTD at the beginning of the day and remove it on cessation of the day's flying. This can cause substantial delays in downloading and processing HUMS data.

14. For future systems (and the planned upgrade of the Chinook Ground station) it is intended that the ground station will have greater processing power and only retain a limited amount of data locally. All data will be sent to a large central data warehouse where it will be available for fleetwide analysis.

Figure 1: Chinook Ruggedised Portable Ground Station

15. Difficulties have also been encountered with supporting HUMS on deployed operations. The original portable ground station specification was to satisfy use in a nuclear, biological or chemical environment. The only Ruggedised Portable Ground Stations (RPGS) qualified to meet such arduous condition were built like brick outhouses and the lengthy qualification process meant the RPGS processors were even more outdated, on entry into service, than the fixed ground stations. The Chinook squadrons have taken the RPGS, shown in Figure 1, with them on deployments and have been able to take advantage of HUMS data. Admittedly ground crews have had to archive the database daily to free up memory. This is clearly unacceptable but gives an indication of the value of HUMS data to the engineers in the field if they were prepared to take on this administrative burden.

16. Means of upgrading the RPGS are currently being investigated. The options being considered are to replace the RPGS processor with one of a higher specification or replace the RPGS entirely with a commercial tough book, compromising ruggedness against cost. For example the current cost of sending the RPGS to a repairer just for an estimate is equal to the cost of buying a commercial tough book with a three-year warranty.

17. Despite the documented problems with the ground support system [3], the Chinook HUMS has remained operational and useful data is being generated and presented to the engineers to act on. This has only really been possible due to the structured maturity programme the MoD has followed. If all of the functionality had been switched-on on the first day of operation,

the ground support system would have collapsed and system credibility would have been lost. The maturity process took each major function in turn, configured it as necessary so that it was working at full efficiency, before that function took precedence over the existing technique. The maturity process now is drawing to a conclusion with the fleet wide implementation of the Rotor Track and Balance (RTB) functionality. A similar maturity period has been scheduled into the programme for the follow on programmes.

AVAILABILITY, RELIABILITY AND MAINTAINABILITY

18. UK military regulation dictates that if an aircraft is fitted with an accident data recorder and if it is unserviceable then the aircraft cannot fly. When the system first became operational, a number of early Chinook sorties were cancelled as the Start-up Built In Test (SBIT) reported that the Data Acquisition & Processing Unit (DAPU) was unserviceable. In every case the DAPU unserviceable caption was generated from missing HUMS components rather than the failure of CV/FDR. A change was made to the SBIT software to differentiate between HUMS functionality failures and CV/FDR functionality failures. Following the implementation of the change no sortie has been cancelled from unserviceability.

19. The reliability requirement for GenHUMS is for the aircraft to have a 99% probability of successfully completing an 8 flying hour working day without experiencing a system failure. This equates to a minimum Mean Time Between System Failure (MTBSF) of 795 flying hours. The Chinook GenHUMS has just completed its In Service Reliability Demonstration (ISRD) [4]. Every HUMS maintenance arising from the selected aircraft was reviewed and assessed against the reliability requirements. A number of the arisings were clearly attributable to physical abuse and were discounted. All Line Replaceable Units (LRUs) satisfied their individual reliability targets, and the demonstrated system reliability was 5149 flying hours.

20. The only item of significance highlighted during the ISRD was reliability of the accelerometers. The accelerometer life was advertised as in excess of 100,000 hours. To date there have been 12 failures in service indicating an accelerometers life of only 19,000 hours. This appears to be a substantial shortfall, however, when taken into the context that each aircraft has 44 accelerometers and there are 40 aircraft in service, the failure rate becomes acceptable. Notwithstanding this acceptability, an investigation is currently underway to determine common factors contributing to accelerometer failures. It is perceived that many of the failures are related to one or two locations that are prone to abuse when exchanging transmission components.

21. The maintainability targets have also been met. The demonstrated average Mean Time To Repair (MTTR) for all HUMS LRUs and Line Replaceable Items (LRIs) is 41 minutes. The target was set at 45 minutes. It was also demonstrated that 95% of HUMS components take less than 2 hours to replace.

OPERATIONAL BENEFITS

22. Operational benefits from operating HUMS are collated by the Chinook HUMS Implementation Group (CHIG). A procedure has been established for squadron engineers to report all incidents where use of HUMS data has aided their diagnosis and rectification of faults. In the early days, the CHIG were able to capture most incidents but now the use of HUMS in fault diagnosis has become so commonplace that only the major or unusual incidents are reported. Examples of how HUMS is benefiting the Chinook fleet are detailed below:

DIRECT PARAMETER DISPLAY

23. HUMS is an advisory system only. The system is configured so that exceedences, cautions and warnings are not displayed in flight. It is however possible to scroll through the pages of the CCU to access vibration data and directly display the values of the flight parameters being recorded. This functionality has been used frequently by aircrew to determine the correct value when left and right hand gauges read significantly different thus also allowing a decision to be made to continue flying. Whilst this does actually create more maintenance activity in recalibrating gauges, the aircrew have increased confidence in the information presented to them.

UNDEMANDED FLYING CONTROL MOVEMENTS

24. An Undemanded Flying Control Movement (UFCM) occurs when a component of the flight control system experiences a glitch or a failure that results in the flight controls being restricted or forced into doing something other than what has been demanded. It is a phenomenon on all rotary wing aircraft (whether publicised or not) and on average there are 4 occurrences in the Chinook fleet each year. The standard procedure for a UFCM on a Chinook is to land and undertake a comprehensive diagnosis routine. The routine essentially starts at one end of the flight control system and works through to the far end. If nothing obvious is found, as is normally the case, flight control components get exchanged until the problem is rectified. It can be a very hit and miss affair and typically the routine takes 2 to 3 days to release the aircraft back to operational service.

25. Following a UFCM on a HUMS aircraft, the routine is very much simplified. The first action is to extract the flight data file from the system. If the pilot pressed the event marker when the UFCM was experienced, 10 seconds of pre and post event flight data will be captured on the DTD. If the event marker is not pressed or the engineers prefer to see data from over a longer period, the full flight data file can be extracted from the Crash Protected Memory (CPM). The flight data trace is then scrutinised to see if it is possible to identify which component initiated the UFCM. In many cases the engineer is simply looking for a change in the normal operating behaviour of a parameter, such as a flat line or a step increase.

26. Use of HUMS has reduced the time to diagnose and rectify UFCMs by 75%. It also prevents unnecessary removal and replacement of serviceable flight control components from the aircraft. The requirement to extract HUMS data now a formal part UFCM procedure.

EXCEEDENCE MONITORING

27. The exceedence monitoring thresholds were initially set to those called up in the Aircraft Maintenance Manuals (AMMs). Through maturity these have been refined to give the engineers the earliest indication of a potential problem. By introducing HUMS, an excursion over the limits of the AMM can be accurately reported rather than relying on the aircrew to observe the exceedence and report it. Accurate reporting of exceedences can add to the maintenance burden as well as reduce it as the following two examples illustrate.

28. A Chinook was operating as part of a four-ship deployment to support a major exercise in the Middle East. It was heavily laden with troops and cargo. The aircrew were concerned that when making a rapid ascent that they over-torqued the rotor system for a considerable time. They were sufficiently concerned that at the next refuelling point they grounded the aircraft for an investigation. The current Chinook over-torque routine takes a minimum of 5 hours to complete properly. This increases if a component is suspected to be damaged and requires replacement. Examination of the exceedence log on the HUMS ground station did show that the aircraft had indeed over-torqued but for a shorter period of time than perceived by the aircrew. The length of time in over-torque conditions was permissible by the AMM and the aircraft was released back on task by the time the refuelling was complete. Subsequent investigation of the full flight data file from the crash protected memory revealed that the aircraft was flying at the edge of the torque envelope for the majority of that sortie, but had only breached the limit the one time.

29. With only 4 aircraft supporting a major exercise the loss of one aircraft (25% reduction in lift capacity), even for a short period of time, can have serious ramifications. Without the HUMS data, the engineers would have had to make a decision based on the verbal description of the incident by the aircrew. The only option available to them would be to take the aircraft off task and conduct the full corrective routine. HUMS provided accurate information to aid the engineer's decision-making process, which resulted in the aircraft being released back on task.

30. A second Chinook was supporting another exercise. On cessation of the day's activities the HUMS data was being downloaded. Whilst waiting for the exceedence report to be generated the aircrew advised that they had an over-temperature caption on one of the engines. The aircrew advised that they had caught it immediately, recovered the engine and kept a close watch on it for the rest of the day whilst they carried on with their tasking.

31. The HUMS report clearly indicated that the engine had exceeded its maximum temperature limit. In fact the incident had raised 3 separate exceedences. The first was that Power Turbine Inlet Temperature (PTIT) was greater than 870°C for longer than 10 minutes, the second that PTIT was greater than 905°C for longer than 10 seconds and finally that PTIT was greater than 938°C. As a result an engineering investigation was carried out.

32. The full flight data file was extracted and scrutinised. The engine temperature was steadily climbing above its normal operating temperature for approximately 27 minutes before the third exceedence was initiated. The logic for the third exceedence replicates the logic used for the caption on the Cautions & Warning Panel (CWP). The data trace showed that the third exceedence was flagged at the same time as the caption illuminated. The trace also indicated that the caption was not acknowledged for 24 seconds and that the engine was recovered shortly thereafter. The maximum temperature reached was 1200°C. The AMM only permits excursions above the maximum temperature for 12 seconds so the engine was replaced. The subsequent strip report from the engine overhaul facility revealed that a number of components, bearings and seals were significantly damaged from the high temperature.

33. Without HUMS and based on the aircrew report, the engineers would have given a cursory look over the engine for signs of damage and then release the aircraft back into service. It is possible that the engine would have failed completely on a later flight and could have caused a catastrophic accident. With HUMS, the engineers were fully able to determine what actually happened to the engine and were able to make the correct decision to replace it. This instigated a expensive and unscheduled engine change and overhaul but increased the airworthiness of the aircraft significantly.

ROTOR TRACK AND BALANCE AND VIBRATION MONITORING

34. There have always been high expectations from the HUMS automated Rotor Track and Balance (RTB) functionality. It has been disappointing that RTB has had to be left until the end of the maturity process particularly as the balance of investment calculations was centred on full RTB functionality from day one. The primary reason behind the delay was the redesign of the nose-mounted camera to avoid potential airflow problems over the pitot static ports. The redesigned nose-mounted camera was not approved until late 2000 and retrofit activities have only just been completed. In addition the RTB functionality has been held back to enable ground station hardware upgrades to be implemented to ensure RTB processing times are acceptable to the user.

35. Currently the existing procedures using the carried on board Rotortuner equipment are still enforced. A complementary set of HUMS RTB data is recorded at the same time and used to prove out the efficiency of the system. The swap over to HUMS RTB is scheduled for early 2003.

36. To gain familiarity and experience with the system, aircraft coming out of maintenance periods are tuned using HUMS RTB directly. Historically it has taken up to 8 flights to tune the aircraft and clear any maintenance arisings. Of the aircraft tuned using HUMS, only one has required more than three flights to bring the rotor system within limits. The design aim for aircraft coming out of maintenance is that tuning the rotor system should take no more than 2 flights. This is considered achievable, once hardware upgrades have been implemented. Squadron requirements for RTB check test flights should also be limited to post major component exchange. Dedicated check test flights to resolve vibration defects will be eliminated as the equipment is permanently carried on board and vibration is monitored every flight.

37. Though the HUMS RTB and vibration monitoring functionality has yet to take precedence over the existing system, the number of call outs for the RAF Odiham vibration specialists to undertake dedicated check test flights on the squadrons has dropped significantly. The specialists have been able to refer to the previous flight's HUMS RTB data, and using their experience, they have been able to look at the vibration characteristic and determine the cause of the reported problem. Previously they would be required to install the carried on board RTB equipment and schedule a dedicated RTB check test flight. Examples of faults rectified in this manner are inactive Self-Tuning Vibration Absorbers and faulty lag dampers. With the introduction of the HUMS rule based reasoning for RTB and vibration monitoring the squadrons will be able to determine the cause of such failures for themselves.

TRANSMISSION BEARING FAILURE

38. One of the most notable benefits from HUMS to date was the use of the system to perform fleet wide health check monitoring following a break up of a combiner transmission bearing [5].

39. During an exercise in Oman, an aircraft was on a sortie when a CWP caption flashed. No other indications of anything untoward were given and after a cursory check of instruments the flight continued. Half hour later the transmission debris light flashed sporadically for 10 seconds, then came on permanently. The aircrew, following the instructions in their flight reference cards, were attempting to land when the left hand transmission warning light came on. This was re-set but immediately latched on again. In the final turn into the landing, the combiner chip and right hand debris warning lights illuminated.

40. Safely on the ground, an investigation was carried out. Oil levels inside the transmission system following the incident were well within limits. The combiner transmission debris screen was removed and large pieces of debris were discovered.

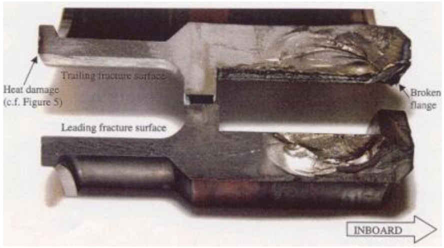

Figure 2: Failed Transmission Inner Bearing Race

41. Due to the serious nature of the incident, the combiner transmission was sent immediately to DARA Almondbank for investigation and overhaul. DARA stripped the transmission and discovered that large quantities of debris had come from the bearing supporting the inner end of the left hand input pinion. The inner race had undergone a complete cross-sectional failure (Figure 2).

42. The aircraft was subject to both Spectrometric Oil Analysis Programme and Wear Debris Sampling but neither had identified the impending failure.

43. The aircraft was fitted with HUMS and though the transmission vibrations threshold and conditions indicators had not yet been matured, raw transmission data was being recorded. The raw HUMS data from that aircraft was evaluated and the failure characteristic was identified. It became apparent from the data that the spalling had initiated at least 95 hours prior to the overload failure. The failure vibration characteristic was converted into a HUMS condition indicator and it was possible to screen all of the other HUMS embodied aircraft within 12 hours.

44. The screening established that no other transmissions displayed similar failure characteristics thus allowing GenHUMS embodied aircraft to remain available for operations. It was necessary for those aircraft not embodied with HUMS to be fitted with dedicated vibration sensors every 25 hours to check and monitor the failed bearing until HUMS was fitted.

45. If HUMS had not been fitted to the aircraft with the failed transmission it would not be possible to identify the failure vibration characteristic. Therefore the only option available to the engineers, to ensure airworthiness, would be to ground the fleet and remove, inspect and replace all combiner transmissions. The last time the fleet was grounded (due to a similar failure) the remove, inspect and replace programme significantly impacted fleet availability for at least 9 weeks.

BENEFITS COMPARISON

46. The original 1993 Project Definition Study (PDS) [6] indicated that, on average, each platform would make a return on investment within 6¼ years. To achieve this return, HUMS would need to generate approximately £13m worth of savings each year. Table 1 illustrates the percentage saving for each user requirement that make up the annual saving.

Table 1: Benefit breakdown per user requirement

Functionality	Percent
Engine Health Monitoring	6%
Transmission Health Monitoring	32%
Rotor Track and Balance and Airframe Health monitoring	45%
Aircraft Usage Monitoring	17%

47. Each element above includes cost savings resulting from HUMS preventing incidents and accidents. In total this equates to approx £4.6m per year. This is a significant amount (36%) and overpowers the other benefits.

48. The savings from accident prevention were determined by an analysis of historical accident records and by assessing whether HUMS would have played a part in preventing the accident from occurring. The PDS analysis indicated that HUMS would have prevented 1 aircraft that required to be repaired on site by specialist personnel, 6 aircraft that required to be returned to works for repair and 7 aircraft that were lost or damaged beyond economical repair. The cost to buy replacement aircraft or to undertake the repairs were averaged and used as an annual HUMS saving.

49. The investment appraisal was reworked in 2000 to support the approval exercise for the Sea King, Puma and Lynx programmes. At this time it was agreed to remove the preventing incidents/accidents factor from the savings equation. Though making a significant contribution to the investment appraisal, it was felt that this factor was impossible to realise. Nobody will give the MoD money back for not crashing an aircraft.

50. The investment appraisal for the 2000 approval focused on the savings identified from the maintenance benefits of HUMS alone that are achievable internally in the MoD. The revised appraisal predicted a total annual saving of £8.84m (£6.85m if deflated to 1993 pricing levels). The breakdown for each user requirement was broadly similar to those shown in Table 1.

51. The indicative implementation costs from the project definition study were approx 50% less than those achieved by the HUMS contract competition. The increased cost along with the reduced annual benefit resulted in the return on investment extending from an average 6¼ years to 19 years. The business case for Sea King, Puma and Lynx was primarily centred on satisfying duty of care and airworthiness requirements.

52. The Chinook element of the revised annual saving is £3.3m. By applying the percentages from Table 1, the MoD should be expecting a saving each year of £200k from engine health monitoring, just under £1.5m for rotor track and balance, £1m for transmission health monitoring and £600k from aircraft usage monitoring.

53. The question is whether the Chinook system is providing the predicted returns. It has proven difficult to ascertain the exact savings for each HUMS arising. The CHIG however has made a financial assessment of the reported arisings and attempted to compare them against the predictions. The word attempted has been used because the predictions were broken down into four distinct key user requirements. In practice it is not so simple to break down the arisings into a single category and the benefit is often shared.

54. Use of HUMS data to resolve defects have prevented engines from being rejected unnecessarily. The unscheduled overhauls cost has been saved so the engine health monitoring element of the annual saving is currently greater than the prediction.

55. The benefits from the RTB functionality is only just being realised due to the redesign of the nose tracker. The consensus from the engineers is that HUMS will significantly reduce the need for dedicated RTB test check flights so the predictions are realistic. The problem is that the majority of the benefit comes from a reduction in flying hours for maintenance activities. Whilst this is may be achieved, it is not a cash benefit to the MoD overall as the saved flying hours are being consumed operationally. The net affect is not a direct cash saving but an increase in operating efficiency and availability.

56. The use of HUMS to check the health of the transmission bearings in the fleet was a good example of how transmission health monitoring benefits can be realised. By itself, this example alone has exceeded the prediction. (The prevention of the accident itself would be recorded as an airworthiness benefit.)

57. Accurate recording of aircraft usage is also identifying benefits. The aircraft maintenance schedule is being driven by the flying hours recorded by the aircrew. The average 20% difference between aircrew and HUMS recorded flying hours will permit a 13-week extension between minor servicing periods. As this will reduce the total number of minor and major servicing periods each year the AUM prediction is most likely to be exceeded. Again with the aircraft in maintenance less frequently there is an increase in operating efficiency and availability.

58. The airworthiness benefits from HUMS have been quite clear even though their potential savings are very subjective. Two instances have been flagged by HUMS, which if left unchecked,

would have resulted in the loss of the aircraft. Assuming a purchase cost of £20m each, it could be argued that HUMS has saved the MoD £40m and that is before the operational impact on the loss of two airframes is taken into account. Admittedly the argument fails the realisable check but gives an insight to the enormous potential of HUMS.

59. In conclusion the Chinook system, once the maturity programme is complete, has every possibility of meeting its predicted savings target. It is very evident that HUMS is saving engineering man-hours and improving the operational availability of the aircraft. These savings will not necessarily result in a realisable cash sum but most likely as a percentage improvement in engineering team productivity and efficient aircraft use. This percentage may be a more accurate indicator of the success of HUMS.

FUTURE ENHANCEMENTS

60. Even though the system has only been in operational use for the last two years, enhancements to the baseline functionality are already being considered:

CV/FDR Replay Station (CRS)

61. The CRS is used to download the full cockpit voice and flight data file from the HUMS CPM. The original HUMS strategy envisioned the use of the CRS after incidents only and not on a regular basis. As such the authority to download the information could only be obtained from the Station Commanding Officer. In operational service the engineers have found the full flight data to be extremely beneficial when diagnosing defects and the authority for download has since been delegated to the squadron senior engineer. (Authority for voice data download remains with the Station CO.) Due to its increased use at the main operating base and during deployments, it has been necessary to increase the numbers of Chinook CRS'S from 3 to 9.

Full FDR download

62. The increased number of CRS's is seen only as a temporary measure. It is the intention to modify the airborne system software such that the full flight data file is downloaded along with the HUMS data each flight. The exact means for download have to be worked out, with the current poor processing performance of the system, the last thing that is required is to slow it down further by trying to process up to 8 hrs of flight data. The initial arrangement will be to have the information on the card and only downloaded to the ground station, if there is a need to, following the maintainers report. If the system is enhanced to include fatigue damage accumulation there will be a need to record flight data continuously. For this the ground station will need to be configured so that it automatically processes the data and archives it correctly to the right tail number without effecting normal HUMS operation.

Fatigue and Usage Management

63. The individual fatigue and usage management system tools developed by MJA Dynamic (Now Smiths Aerospace – Electronic Systems Southampton) for the MoD and presented at HUMS 1999 [7] have now been collated into a single comprehensive toolset referred to now as the Flight Usage Management Software (FUMS) [8]. This name change reflects the change in direction of the tools from direct fatigue calculation to transforming aircraft measurements into diagnostic/prognostic usage information. The aim of FUMS is to provide further improvements in aircraft management, affordability, airworthiness, availability and performance. At the same time FUMS aims to reduce the logistic burden of handling large volumes of data downloaded from individual aeroplanes. Examples of the FUMS toolset are:

Generation and accumulation of Usage indices

64. The usage indices provide concise summaries of aircraft data and at the same time indicate the impact of usage on component condition and life. The usage indices can provide operational management and safety benefits by informing the user about:

- Missions that cause severe usage
- Aircraft configurations that cause severe usage
- Flight conditions that cause high aircrew workloads
- Flight events that cause sever usage; and
- Flying practices that cause severe usage.

By accumulating the usage indices the remaining component life can be assessed.

Monitoring of Operational Exceedences

65. HUMS at present looks at individual parameters and advises when individual physical thresholds have been breached. With FUMS, the software will look across all parameters and identify operational exceedences and significant flight events, by comparing recorded measurements with operationally determined thresholds and flight envelopes. For example, having picked up a heavy underslung load the aircraft might breach its permitted flight envelope whilst trying to navigate through a steep sided valley. FUMS will trigger a warning when the aircraft is flown close to the extreme of its flight envelope.

66. The FUMS prognostic functions can either be implemented as part of the airborne system or as part of the ground station. FUMS will also introduce a prognostics architecture that facilitates the integration of technologies developed by third parties and harmonises their information with the FUMS operational infrastructure. The current FUMS toolset works from the basic data outputs from the installed generic HUMS system and has been developed to enable the technologies to be demonstrated and evaluated quickly and at low cost. As FUMS elements mature they can be introduced into the mainstream HUMS programme.

Improved Data Manipulation & Flight Animation

67. Two elements of FUMS that have already matured and could be introduced into the HUMS programme within a short timescale, are the improved data manipulation and flight animation tools. Trying to reconstruct what is happening with the aircraft from 2 dimensional traces displayed on the CRS can be quite difficult, particularly if during flight the aircrew did not mark the incident you are investigated. The data manipulation tools on the CRS are basic and it can be time consuming to extract the information required.

68. The data manipulation tools developed under FUMS have greater functionality. They will allow the user to design his preferred screens and reports that contain the important FDR information. The enhanced tools have the ability to very quickly translate the data sets onto a graph and correlate the outputs. The tools also permit the user to graphically construct Structured Query Language (SQL) queries on the flight data. By using simple mouse drag/drop actions, fields can be selected, compared and anomalies identified without any typing. In this way the users workload is reduced and complex SQL statements are created without the need to learn SQL. Importantly by using the enhanced data manipulation tools, the ability to write incident/investigation reports will be simplified as it is possible to directly export any resultant data tables and graphs into most word processing documents.

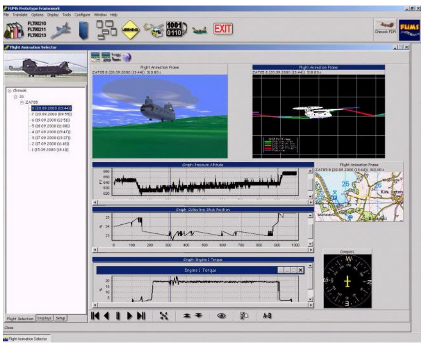

Figure 3: FUMS Flight Animation Screen Shot

69. To complement the data manipulation tools, a flight animation facility is being provided. A typical screen shot is shown in Figure 3. This is to aid the engineer to visualise what is happening to the aircraft at time of the incident. The flight display is correlated directly to the flight data and the display can be used to fast forward to the relevant point in the flight of interest. The animation tool allows multiple views of the aircraft flying, including views from inside the cockpit with real time instrument display and external views from any angle. Side and plan views are also provided and the animation can also be flown against satellite imagery and textured maps. If the FUMS tools are utilised, the fatigue damaging events can also be displayed. The flight animation tool also has a huge potential as a pilot training aid for reviewing sorties particularly if it is combined with the mission planning system and threat data.

Operational Data Recording Exercise

70. To comply with flight safety regulation each helicopter fleet has to conduct an Operational Data Recording Exercise (ODRE) every 5 years. The ODRE requires an aircraft to be fitted with strain gauges so that the structural loads experienced in flight can be measured directly. The measured loads are analysed to assess whether the assumptions made in the aircraft manufacturers fatigue calculations remain valid (i.e. the stresses experienced map the stresses predicted). To complement the strain gauges a full set of flight data is required. The instrumentation for the ODRE is quite extensive, and as the exercise typically last 12 months, therefore the cost of ODRE can be quite large. HUMS can help reduce the cost in two areas

71. The first is to reduce the cost of the ODRE installation by utilising HUMS FDR information to support the data gathered from the strain gauges. A second memory card receptacle will be installed in the Chinook for its ODRE to collect the FDR data. This is to simplify the conduct of the exercise without affecting normal crew operation. It is likely that for future ODRE's the data will be held in a partition of the main memory card.

72. The second means to reduce ODRE cost is to utilise the advanced usage monitoring techniques from FUMS. The techniques can map the actual aircraft usage against the design usage spectrum. Therefore eliminating the need to conduct ODRE every 5 years. The requirement can be satisfied by conducting a load survey on introduction into service, and then continuously monitoring the aircraft against the manufacturers design usage spectrum.

CONCLUSIONS

73. The HUMS programme in UK Military helicopters took a long time to become established and was subject to a number of technical difficulties, all have now been resolved and the lessons learnt from the Chinook programme are benefiting the follow on programmes. The follow-on programmes are now firmly underway.

74. It is still early days for Chinook HUMS but already sizeable benefits are being realised and expectations from the project definition study are broadly being met. Even with the system in its infancy, it is necessary to look forward and start to look at ways the system can be improved and the HUMS data further exploited.

75. The actual cash sum saved by HUMS will always be contentious and difficult to prove. It is however very evident that HUMS is saving engineering man-hours and improving the

operational availability of the aircraft. Similar benefits are eagerly anticipated from the Sea King, Puma and Lynx user communities.

ACKNOWLEDGMENTS

The author would like to acknowledge the support of Cdr James Gourlay, for his assistance in proof reading the paper, and his MoD colleagues in the HUMS IPT and AD/AHMG. The support to the HUMS programme from the team at Smiths Aerospace Electronic Systems Southampton is also acknowledged. Finally the dedication, enthusiasm and perseverance of the staff at RAF Odiham, particularly in the Health and Usage Centre, in making Chinook HUMS a success is also acknowledged and greatly appreciated.

REFERENCES

1. Draper, A. MoD HUMS: Today And Tomorrow, ERA Avionics 2000, London, Nov 2000.

2. Draper, A. An Update On HUMS In UK Military Helicopters, American Helicopter Society Forum 58, Montreal, June 2002.

3. Cook, J. *et al.* Critique Of The Chinook GenHUMS Ground Support System. ES(AIR)(G)/8976.1 AD MM, July 2001 – Unpublished MoD report.

4. Cokayne, I. Chinook HUMS In-Service Reliability Demonstration Final Report, HUMS/76/8/1/3, Nov 2002 – Unpublished MoD report.

5. Cook, J. *et al*. Metallurgical And HUMS Data Evaluation Of Failed Roller Bearing, TM02.216, AD AIM, Aug 2002. – Unpublished MoD report.

6. Larder, B. Project Definition Study for HUMS for MoD Helicopters, SHL1156, Dec 1994 – Unpublished MoD report.

7. Draper, A. Fatigue Usage Monitoring In UK Military Helicopters, HUMS 1999, Melbourne, Feb 1999.

8. Azzam, H. FUMS Software Functionality For Retrofit And Future Prognostics Health Management, 20 Nov 2002 - Unpublished MoD report.