Eurocopter AS332-L2, Super Puma, G-JSAR

AAIB Bulletin No: 8/2004	Ref: EW/C2003/02/06	Category: 2.1
INCIDENT		
Aircraft Type and Registration:	Eurocopter AS332-L2, Super Puma, G-JSAR	
No & Type of Engines:	2 Turbomeca Makila 1A2 turboshaft engines	
Year of Manufacture:	2002	
Date & Time (UTC):	22 February 2003	
Location:	1 nm north of Miller Platform, North Sea	
Type of Flight:	Private	
Persons on Board:	Crew - 2	Passengers - 2
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Oil cooler drive shaft and gear wheel fractured. Bearing housing fractured	
Commander's Licence:	N/A	
Commander's Age:	N/A	
Commander's Flying Experience:	N/A	
Information Source:	AAIB Field Investigation	

Synopsis

Whilst engaged on a winching demonstration next to a North Sea platform in the hover the helicopter's main rotor gearbox chip warning light illuminated. An immediate landing was made on the platform. Subsequent inspection revealed metal particles on the chip detector, and that the oil cooler drive shaft had fractured. The aircraft was fitted with a Health and Usage Monitoring System (HUMS) which had earlier detected a potential problem in the main gearbox left hand accessory module. A decision had earlier been made to monitor closely the relevant parameters, and the failure occurred during this monitoring period. The failure was one of a number of similar occurrences to the left-hand accessory module, and was associated with the increased power from the engines in the L2 variant of the Super Puma. It is expected that further service experience will improve the diagnostic skills of the HUMS teams, resulting in earlier decisions to remove components, thereby preventing a component reliability issue from escalating to one of flight safety.

Circumstances

The aircraft was engaged on a winching demonstration next to the Miller Platform in the North Sea, when a main rotor gearbox (MGB) chip warning light illuminated. An immediate landing was made on the platform and the aircraft was shut down. Subsequent inspection revealed metal particles on the chip detector and the oil cooler drive shaft had fractured at the coupling flange on the MGB output drive. A diagram of the gearbox is shown at Figure 1, with a photograph of the partially dismantled gearbox presented at Figure 2.

Figure 1: Details of left hand accessory module

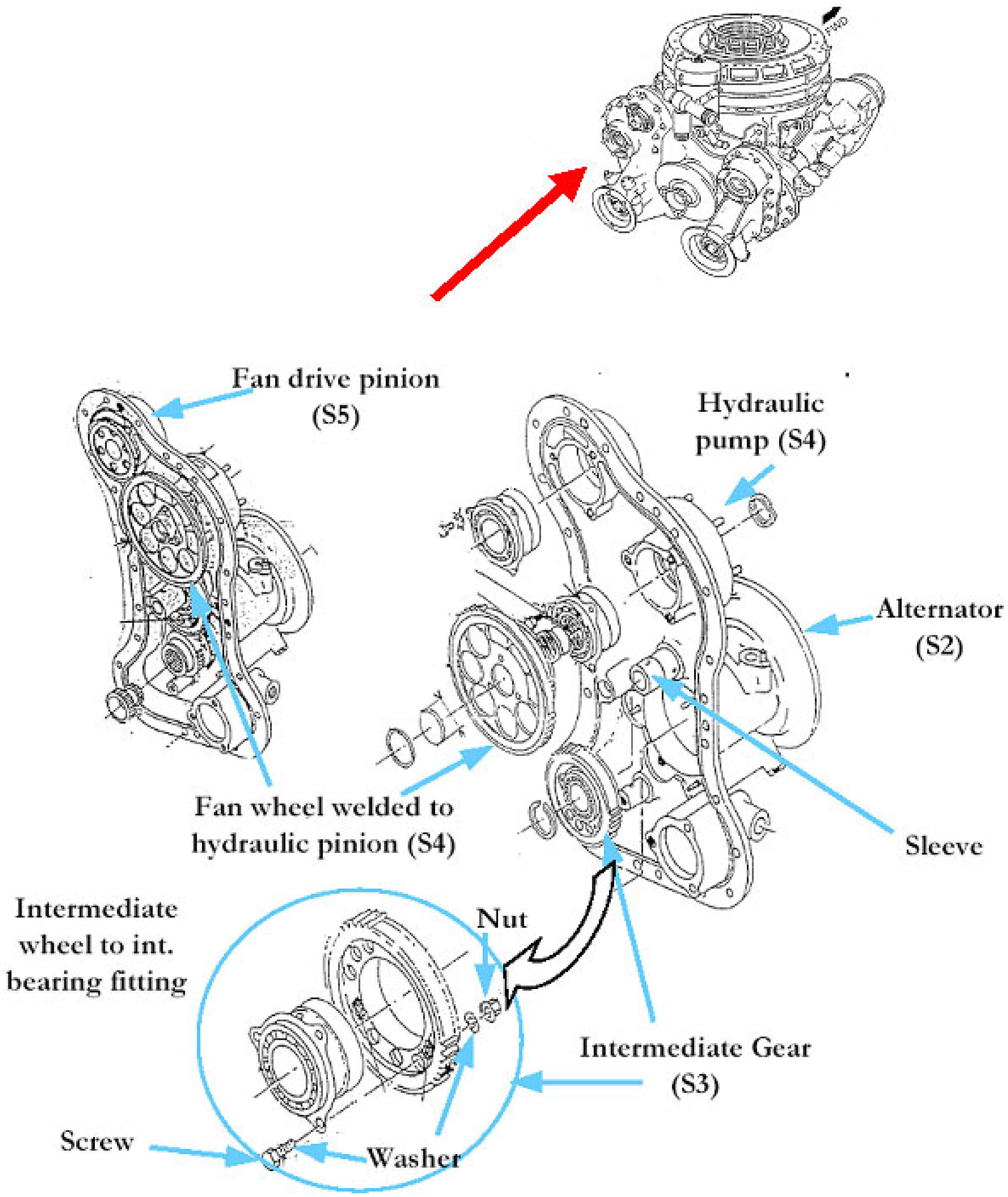


Figure 1 Details of left hand accessory module

Figure 2: LH accessory gearbox module from G-JSAR, showing cracked intermediate gear

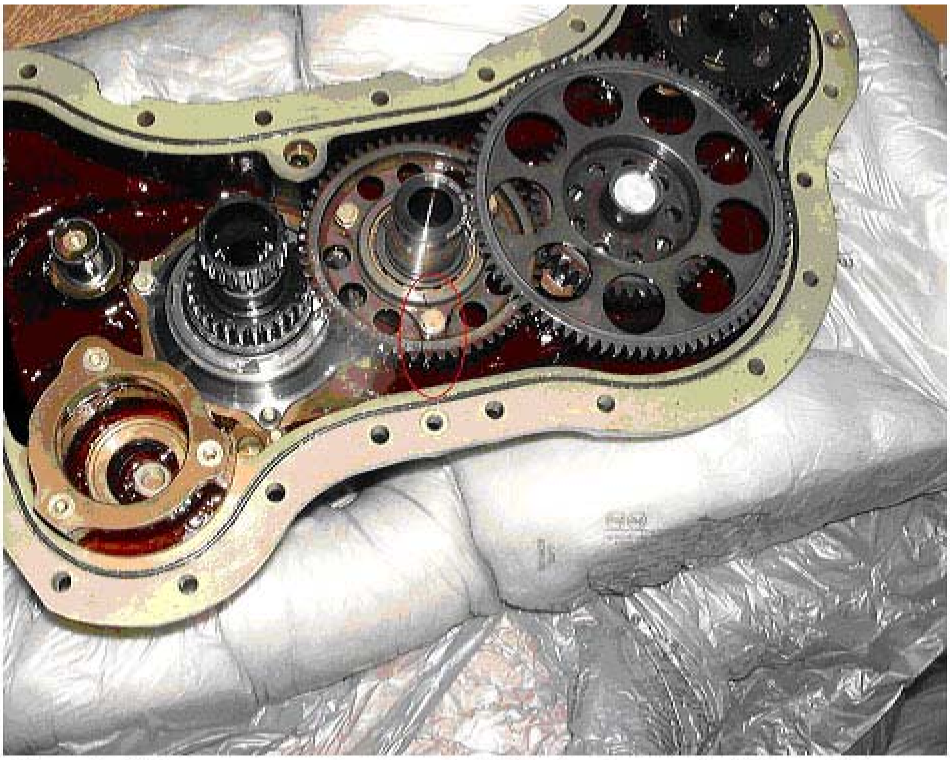


Figure 2 LH accessory gearbox from G-JSAR, showing cracked intermediate gear

The left hand accessory module was removed from the MGB and an internal examination revealed that the intermediate gear wheel had fractured from the bearing at the centre to the outer edge of the gear. Its bearing housing was also fractured through one of the three attachment lugs. The remaining two attachment lug bolts were found fully torque tightened. The detached portion of the failed lug was found lying loose within the module housing.

After fitting a replacement accessory module, oil cooler and its associated drive shaft, the aircraft was returned to service. At the time of the incident the aircraft (and gearbox) had achieved a total of 175 operating hours.

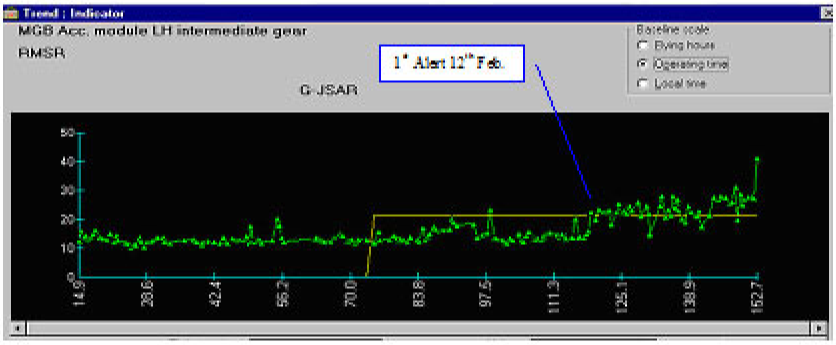
The subsequent investigation centred on the gearbox module, as the oil cooler drive shaft failure was attributed to transient torsional loads arising from 'snatching' in the gear train.

Gearbox health monitoring

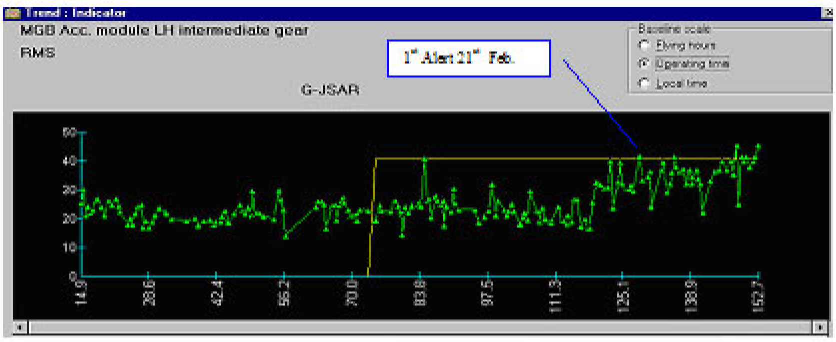
The aircraft was fitted with a Health and Usage Monitoring System (HUMS) that was developed by the manufacturer and referred to as EuroARMS (Eurocopter Aircraft Recording and Monitoring System). The system comprises a number of accelerometers and transducers around the engines, airframe and drivetrain. Vibration signals from a number of major components are monitored and recorded. The data accumulated during aircraft operation is transferred, usually on a daily basis, to the operator's ground-based computer system. The data is then subjected to often-complex algorithms, which establish basic signatures and monitor trends for individual components. With regard to gears, shafts and bearings, two main categories of indicators are used for this process. Energy level indicators measure an absolute or relative energy level. Analysis level indicators search for patterns in the vibration signature. The computer system automatically compares the indicators with pre-determined thresholds and displays warnings when these are exceeded. These enable the operator to identify potential failure conditions and premature wear or deterioration, thus allowing the possibility for timely maintenance. In the event of uncertainty in the interpretation of the data, the operator raises an Engineering Diagnostic Report (EDR) with the manufacturer, who responds with appropriate advice. In any case, the manufacturer has an interest in the process, since the gearboxes are all leased to civil operators on a 'power by the hour' basis.

In this particular case, there was a EuroARMS alert generated on 12 February 2003 concerning the RMSR parameter. This is the Residual Root Mean Square of the signal and represents the residual energy after the gear teeth meshing tones have been removed. The work card associated with this alert called for an EDR to be raised with the manufacturer. This was done on the 13 February, and the manufacturer responded later the same day with the advice to continue flying but with close monitoring for a further 50 flight hours. The RMSR alert was generated on most subsequent flights, as can be seen in Figure 4.

Figure 4: Two EuroARMS data plots, showing threshold breaches



Root Mean Square Residual (RMSR) indicator



Root Mean Square (RMS) indicator

Figure 4 Two EuroARMS data plots, showing threshold breaches.
Note that thresholds are 'learnt' over a period of approximately 50 hours following a transducer change.

On 21 February the RMS parameter threshold was breached, - this is also shown in Figure 4. This is the Root Mean Square of the signal and is a measure of the total energy, the value of which will tend to increase in the event of damage to the component. The EuroARMS Training Manual notes that defect detection using this parameter occurs "at a fairly late stage" in the damage process. Following a review of the thresholds, it was decided to continue monitoring both the RMS and the RMSR parameters. The MGB chip warning and oil cooler drive shaft failure occurred on the following day, some 21 flight hours after the initial alert on 21 February. The final EuroARMS data was sampled only 2 minutes prior to the chip warning.

Other parameters were also examined, including the OM-X and H2FE indicators. The former is the meshing frequency of the gear, which, as the intermediate wheel has 58 teeth, is referred to as the OM-58 indicator. The latter is the second harmonic of the meshing frequency. Both indicators are used to detect gear tooth damage and/or wear. The OM-58 plot (not shown here) revealed a rising trend together with a step change in the trend in the latter stages; however, the threshold was not breached. The H2FE indicator displayed minor trends, but there is currently no threshold set for this parameter.

Finally, there were no meaningful trends in the kurtosis indicators Km (mean) and Kr (residual). Kurtosis is based on the 'tails' of a frequency distribution and is a fourth order term designed to detect an impulsive event in the signal average such as that resulting from tooth damage. This is a highly sensitive indicator that can provide early indication of a defect. The lack of any damage indication from these parameters suggested to the operator that the crack in the intermediate gear probably occurred at around the time of the MGB chip warning.

Previous incident

A similar incident occurred to another operator's AS332-L2, G-PUMS, on 21 November 2002, when an amber MGB oil pressure caption illuminated when the aircraft was on the ground following flight. On the subsequent ground run, the accessory gearbox seized, followed by the shearing of the oil cooling fan drive shaft. A large amount of debris was found on the MGB magnetic plug. Investigation of the left hand accessory module revealed that the intermediate gear had fractured into two pieces. In addition, there was associated damage to the internal surfaces of the casing. A photograph of the internal components of the module is shown at Figure 3.

Figure 3: Failed intermediate gear from G-PUMS

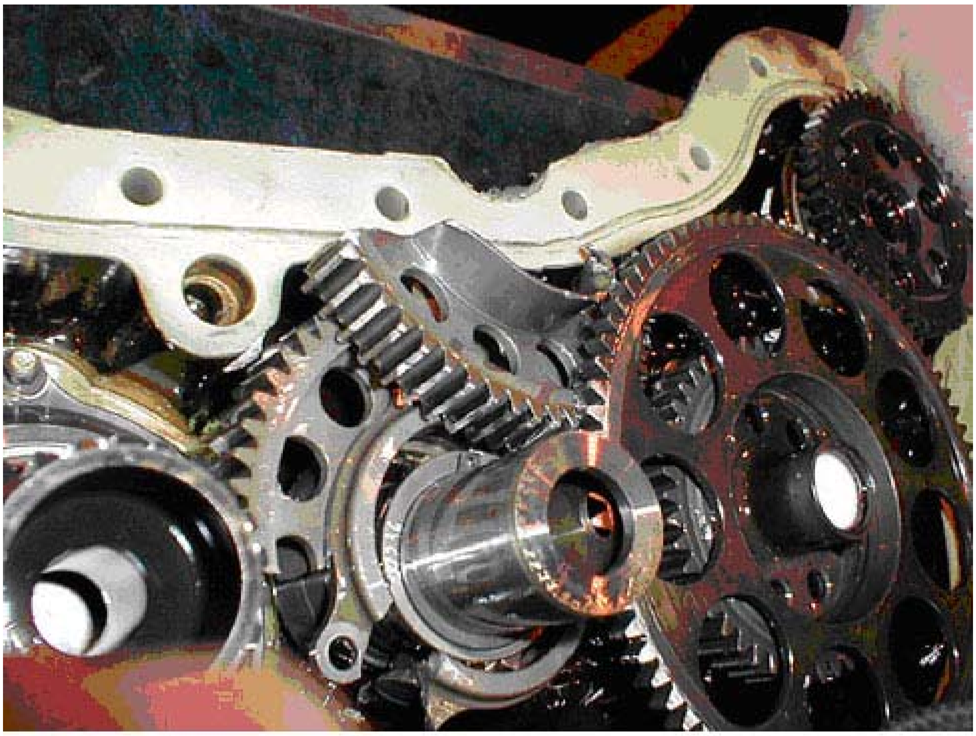


Figure 3 Failed intermediate gear from G-PUMS

This aircraft was equipped with Euro HUMS, as opposed to EuroARMS. A subsequent review of the data revealed that several parameters had been giving potential indications of the impending failure. In particular a "white noise" indicator, which measures background noise after the fundamental and harmonic frequencies have been filtered out, had regularly been exceeding its threshold for the last

190 operating hours. Analysis of the data had led the operator to raise, on 19 November, a diagnostic request on Eurocopter. However there was insufficient time for a response to be received prior to the failure on 21 November.

It should be noted that the daily check of the aircraft includes verifying that there are no HUMS related issues (either failure to acquire data or warning messages). Following the incident, the operator, in conjunction with the manufacturer conducted a review of its engineering procedures, including its internal and external communications. The changes that resulted from the review included extending the distribution of HUMS data, with the aim of making the system less reliant on a few key personnel, which in the past may have led to delays in the assessment of data and associated decision making.

Although this incident was potentially more serious than the one that occurred to G-JSAR, the operator, after consulting the manufacturer, considered that, had it occurred in the air, the ability to continue flight would not have been seriously compromised. Nevertheless, the aircraft would have lost various services, including the oil cooler fan, the No 1 AC generator and the left hand hydraulic pump. In addition, metallic debris arising from the gear failure could have contaminated the MGB oil system, especially if the contamination was sufficient to block the filter, thus opening its associated by-pass valve. The aircraft Flight Manual advises that in the event of the loss of a hydraulic pump and/or an AC generator, a landing should be made as soon as possible. In addition, the loss of the oil cooler fan would result in an increased oil temperature. The manufacturer has indicated that the MGB can operate for 2 hours with the oil temperature in excess of 125°C, although an absolute maximum was not specified. The allowable range, indicated by a green arc on the associated gauge, extends from -10°C to +125°C.

Accessory module history

The AS332-L2 model helicopter, of which there are currently eight examples in the United Kingdom, is equipped with more powerful engines than earlier variants, although the main gearbox is essentially the same. The oil-cooling fan is driven via a shaft from the accessory module and has a higher power requirement due to the up-rated engines.

The aircraft manufacturer was aware of earlier problems affecting both UK and non-UK registered aircraft, concerning the intermediate gear in the accessory module. These had included the gear bearing retaining bolts working loose, leading to fretting. The loss of torque of these retaining bolts had been routinely detected by HUMS; however, rectification could only be achieved by overhauling the gearbox at the manufacturer's facility. It was believed that the loss of torque occurred as a result of an excitation in the adjacent hydraulic pump pinion, and in recent years several modification packages have been introduced, including one that altered the profile of the hydraulic pinion forging in order to change its resonant frequency. The modifications are essentially detail changes and the manufacturer has admitted at operator conferences that some are more successful than others. Whilst overall progress has been made, the intermediate gear continues to be problematical, and the manufacturer is currently conducting trials of a revised bearing attachment. The long-term solution is promised to be an extensive redesign of the accessory module.

The two incidents described above may have contributed to increased sensitivity amongst operators to problems with the left hand accessory module, which may in turn account for a high unscheduled removal rate for this component. Alternatively, further service experience may have resulted in improved diagnostic skills of the HUMS teams. Between January 2001 and March 2003, there were 27 unscheduled removals from a fleet of around 15 aircraft, giving a mean time between unscheduled removals (MTBUR) of 1800 hours. The scheduled overhaul life is 3000 hours.

The perception of the two UK operators of the L2 model is that there has been little recent improvement in the reliability of the module, although there have been no more failures.

Discussion

Although neither of the two incidents described here occurred in the cruise, had they done so, the ability for continued safe flight was considered not to be compromised. Nevertheless, the fact that the MGB and the accessory modules share the same oil system could result in potentially serious contamination problems, thereby constituting a flight safety hazard. The concurrent loss of an AC generator and a hydraulic system represent an additional erosion of safety margins, and this is acknowledged by the Flight Manual requirement that the aircraft land as soon as possible.

The two failure cases together with the large number of premature left hand module removals indicate that the component was introduced into service at an immature stage of development, with problems arising from the increased power requirement for the oil cooler of the L2 variant. The good service record of the module in earlier variants probably contributed to a lack of recognition that significant changes were required. The operators are understandably keen for a resolution to the problems with the module and have been working closely with the manufacturer, who has clearly dedicated considerable resources in attempting to find a remedy. In any case the close liaison between manufacturer and operator was already a necessary consequence of the HUMS systems, and this represents a change from historical relationships in that the manufacturer now plays an increasing part in the day-to-day serviceability and, by extension, the airworthiness of the aircraft. The degree of the manufacturer's involvement will vary from one operator to another. The UK operators have dedicated and experienced HUMS teams, whose experience allow rather more autonomy than the operator of, say, a single aircraft, who may be almost entirely dependant on the manufacturer's specialists for guidance.

The complex nature of HUMS underscores the necessity for effective communications between the operator and manufacturer, as well as the ability to interpret the data. With regard to the latter, the two incidents are illustrative of the learning process. Certainly, in the case of G-JSAR, the advice to continue to 'close monitor' for 50 flight hours following the alert on 12 February 2003 is unlikely to be repeated in the future, given a similar set of data. Similarly, trends and threshold breaches in the G-PUMS data were found to have provided indications that all was not well. Thus the experience gained in these incidents should in future result in earlier decisions to remove a gearbox module before a damage condition progresses to failure, thereby preventing a component reliability issue from escalating to one of flight safety.

HUMS has its origins in a recommendation of the HARP (Helicopter Advisory and Review Panel) report of 1984, which led to the United Kingdom Civil Aviation Authority (CAA) funding trials between 1987 and 1991, culminating in two production standard systems entering service in 1991. The major challenge was to develop systems capable of providing warnings of impending failure of the many critical components in the drivetrain, and the UK AAIB was able to identify six UK accidents in the 1980's that HUMS could have prevented. During the 1990's HUMS systems routinely identified in-service problems and were instrumental in achieving a significant reduction in the number of incidents of serious in-flight vibration. By 1997 the CAA concluded that HUMS were able to provide valid warnings in 60% of all potentially catastrophic failure cases. It is therefore clear that the introduction of HUMS has improved the safety of flight in helicopters.

In the UK, vibration health monitoring systems have been made mandatory on large helicopters certified or validated since certification requirements were tightened by the CAA after the HARP report, by the introduction of the so called 'design assessment requirements' (subsequently incorporated into the JAA and FAA certification requirements). In 1999 an Additional Airworthiness Directive (AAD) was introduced which made vibration health monitoring systems mandatory in the UK on older types carrying more than nine passengers.

Finally, although HUMS is offered as an option by Eurocopter, the United Kingdom remains the only country in the European Union (EU) where such systems are mandatory, although all helicopters operating in the North Sea, regardless of state of registration, currently have them. (The AS332-L2 is slightly different in that HUMS is treated as a condition of Type Certificate validation in the UK). It should be noted that on 28 September 2003, responsibility for the airworthiness standards for most of the civil aircraft registered in the member states of the EU passed to the European Aviation Safety Agency (EASA). This change has resulted in approximately 95% of UK CAA AAD's being cancelled. The AAD concerning HUMS is in the 5% currently retained; however, EASA will ultimately decide whether or not this will also be cancelled.