Introduction

In the last update in May 2013, the HSSG reported that Eurocopter had completed its investigation into the causes of the EC225 Main Gearbox (MGB) shaft failures in May 2012 and October 2012, and had identified the root causes and interim and long-term measures to return the EC225 to service over the North Sea.

The HSSG has secured full, independently verified assurance that the root causes of the two EC225 gear box failures has been identified and Eurocopter’s proposed immediate and long terms solutions are valid, enabling a safe return to flight.

Shainin Engineering

Engaged by Eurocopter at the early stages of the investigation, Shainin Engineering has provided oversight of the Root Cause Analysis methodology and close-out. On 28th June, Shainin presented its results to the HSSG in Aberdeen. Its report confirmed that the Eurocopter investigation findings related to the crack initiation and propagation are correct, and detailed enough to allow the determination of corrective actions.

Georgia Tech Research Institute (GTRI)

Georgia Tech Research Institute is a highly-regarded applied research and development organisation retained by the main helicopter operators (Bond Offshore, Bristow Group and CHC Helicopter) to validate Eurocopter’s crack propagation rate test results and the effectiveness of the proposed crack detection methods.

GTRI calculations have verified the results and confirmed the suitability of the in-flight Health and Usage Monitoring System (HUMS).

Professor Burdekin

Professor Michael Burdekin OBE, FREng, FRS is a British civil engineer, emeritus professor at University of Manchester Institute of Science and Technology, England and an expert in the strength of materials, fatigue failures and cracking. He was engaged independently by the HSSG and visited the Eurocopter factory in France where he undertook a review of the processes used by Eurocopter in the investigation and also assessed the work being undertaken by Shainin and GTRI. During his feedback to the HSSG on Friday 28th June 2013, the Professor stated that he had high confidence in the Eurocopter conclusions that Eurocopter had correctly identified the root causes, and expressed high confidence that Eurocopter proposals to return to service were are soundly based.

The investigation, root causes findings and safety barriers were soundly based and noted the thoroughness and professionalism of Eurocopter. Given this independent assurance, the HSSG has confidence that the conclusions are sound, and that the safety barriers are indeed suitable and sufficient to prevent a gearbox shaft failure. Indeed, EASA certified the Eurocopter proposed safety measures which were issued via emergency and Alert Service Bulletins on 7 July 2013.

Causes of Failure

In May, HSSG conducted a survey of workforce confidence in flying. Many respondents were uncertain that the investigations had reached the root of the problem and were sceptical about the interim proposals to return to service in particular. The investigations by Eurocopter were long and thorough, a great deal of understanding was gained, the reasons for the failures are complex and the causes and solutions came to light over an extended period. So it’s important to pull the complete picture together and explain the causes and basis of the safety barriers proposed, so that the workforce can understand and draw its own conclusions and confidence.

Eurocopter attributed both MGB gear shaft failures to fatigue cracks in the vicinity of the electron beam weld joining the bevel gear with the lower vertical shaft driving the gearbox oil pumps. Eurocopter identified that the fatigue life of the shafts was reduced by manufacturing residual stress and stress concentration in the weld area; then, due to further weakening caused by corrosion pits, and active corrosion attack from trapped moisture in the weld area, small cracks formed. With the high shaft rotation speed, the shafts rapidly accumulate millions of number of fatigue cycles, and the cracks grew until the shafts failed, after about 20 hours of flying since crack initiation.
Eurocopter replicated the failure mechanism by corroding metal test samples in the laboratory then fatigue testing the samples on a test rig until small cracks formed in the samples. Importantly, the active corrosion is similar to corrosion fatigue and only occurs when the following three ingredients are present:

1. Stress due to flight loads,
2. Temperature (above ~80 °C) when gearbox is in operation, and
3. Moisture trapped against the shaft as described below.

The exact points at which the cracks started in the two ditching incidents were different, but both started in the high stress area, near the weld. In the May-2012 incident, corrosion was found at the weld stop hole, and the crack grew from this point. The hole is fitted with a plug, and water was held in a gap between the plug and countersink drilled into the hole. The gap was formed due to a detail change in the countersink on a particular batch of gear shafts. This batch of shafts will be remanufactured to the correct specification. See pictures below:

In the October 2012 incident, corrosion pits were found in the weld area and the crack started in this area away from the weld stop hole. Corrosion occurred due to moisture being trapped in a paste (formed by fine metallic powder from the gear splines combining with oil from the lubrication system); the design of the shaft allowed the paste to build in layers and create an environment for active corrosion (see images below).

Corrosion – in a Gearbox?

In most gearboxes, oil coats the metal surfaces protecting from corrosion. So how does water get into the gear shaft and why is there corrosion? The shafts are hollow and ventilated by air laden with water vapour. The MGB is hot with the rotor turning but cools when the engines are shut down. The water vapour condenses on the metal surface as droplets – like condensation on a shower door or dew on a car windscreen.

At full speed the shaft rotates at 2400 rpm, causing high centrifugal force. Oil sprayed into the lower shaft by jets is carried up to the weld area and splines by centrifugal force. Water is denser than oil so the force on the water is higher than on the oil, throwing the water out against the inside of the shaft under the paste.

Water at the weld hole is believed to have been present from when the gear shaft was manufactured.

Fatigue Failure

Metal fatigue is a well-known phenomenon. Professor Burdekin and Shainin Engineering provided a graph explaining metal fatigue and the role of corrosion in the gear shaft failures. The graph below shows how a typical steel component (a steel spring in a car, or the EC225 gear shaft) behaves it is subjected to stress (or force) cycles. The left (Y-axis) is the amount of stress; the bottom (X-axis) is the number of cycles – this number is very large: 1. E+06 is 1 million cycles, 1.E+07 is 10 million; 1.E+08 is 100 million and so on.

The blue and red lines show the number of cycles before the component fails due to fatigue, called the fatigue life. The blue line is for the un-corroded component and the red line for corroded component. At high stress (left of graph) the component fails after relatively few cycles. At low stress (<250MPa in this example)) the fatigue life is infinite – i.e. the component should never fail regardless of the number of times the stress is applied.

The red line shows that the fatigue life is reduced by active corrosion. One reason for this is if there is a combination of stress, temperature and moisture, the local fatigue strength can fall below that necessary to withstand the flight loads and as such a crack initiates. According to Professor Burdekin, the chemical process of active corrosion can also affect the metal surface a microscopic level, causing further localised degradation in strength.
The importance of these curves can be illustrated through the analogy of a car spring. As a car is driven the springs constantly compress and expand as the wheels bounce over bumps in the road. Over the life of the car the springs see millions of compression/expansion cycles. Accordingly, the springs are designed at a level of stress such that the fatigue life is longer than the life of the car. In other words, if the springs are made sufficiently strong, they should never break over the lifetime. However, if their fatigue strength was degraded by corrosion they could break prematurely. The difference with the failure mechanism on the EC225 vertical shaft is that it is active corrosion that significantly reduces the fatigue strength and this active corrosion can only exist in the presence of temperature, stress and moisture. Traditional corrosion associated with moisture is not enough on its own to reduce the fatigue strength to unsafe levels.

The gear shaft in the EC225 MGB is also subjected to stress cycles through shaft rotation; given the high speed of rotation (2400 rpm) the shafts go through many millions of cycles rapidly. Accordingly, Eurocopter designed the shafts with infinite fatigue life, and a large safety margin. However, during the investigation it was discovered that due to hot spots arising from the geometry, and residual stress “locked in” during weld manufacture, the stresses were higher than intended in some areas, reducing the safety margin. Although reduced, there was still a safety margin sufficient to meet the certification requirements. The safety margin was further degraded by corrosion pits and can become negative due to active corrosion at the metal surface causing fatigue cracks.

**Failure Prevention Barriers – Immediate Solution**

The HSSG has secured full, independently verified assurance that the root causes of the two EC225 gear box failures has been identified and Eurocopter’s proposed immediate and long terms solutions are valid, enabling a safe return to flight;

- **Prevent fatigue cracks forming by stopping active corrosion:**
  - Eliminate moisture traps by cleaning and removing the paste; also remove and replace the weld hole plug.
  - Modify the MGB oil jets to spray oil further up inside the shaft, keeping the weld zone clean to prevent moisture traps, also to improve lubrication of the gear splines.

- **Inspect the gear shafts regularly to ensure early detection of very small cracks pre-flight.**

- **Monitor vibration on the aircraft using the HUMS system to detect cracks in flight in time to allow safe landing.**

**Failure Prevention – Long term Solution**

Eurocopter will introduce a new design of shaft which will also retain many of the features of the immediate solution and will minimise stress factors and hot spots and prevent active corrosion. A comparison of the existing and new shafts is shown on the right. The new shafts will take over a year to implement. While the new shafts are stronger than the existing shafts, due to the multiple safety barriers in place under the immediate solution, the existing shafts are considered by Eurocopter, the independent experts and EASA to be safe to operate. Indeed the level of safety of the existing shaft with applied safety measures, or new shaft, is equivalent. The reason for retrofitting the fleet with the new shaft once available, is to reduce the maintenance burden associated with the safety measures.
What happens next?

While the existing shafts are safe with the measures described above, Eurocopter is manufacturing a new shaft to eliminate stress factors and hot spots and prevent corrosion. This will take over a year to design, manufacture, test, certify and fit to the fleet.

Get in touch

For more information on the EC225 situation, visit:
http://www.stepchangeinsafety.net/about/EC225information.cfm

You can get in touch with the HSSG via the dedicated inbox
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You will also find the group’s news at:
http://www.stepchangeinsafety.net/about/HelicopterSafetySteeringGroup.cfm