3 Conclusions

(a) Findings

1 The pilots were properly licensed and trained, medically fit and adequately rested to undertake the flight.

2 The aircraft was properly loaded and maintained, and its documentation was in order.

3 Approximately two thirds of the yellow colour-coded main rotor blade separated as the helicopter was preparing to land.

4 A chordwise fatigue crack in the blade's titanium spar grew through approximately 50% of the spar's circumference prior to a single catastrophic overload failure of the remaining 50%.

5 Almost immediately after the blade failed the centrifugal force imbalance created by the missing blade section tore the main rotor gearbox from the fuselage.

6 Impact of the helicopter's fuselage with the sea surface was not survivable.

7 Search and Rescue assets at sea and ashore were deployed without delay.

8 The origin of the fatigue crack in the yellow colour-coded blade was beneath the malformed tang of the outboard section of the two-piece titanium erosion cover at the scarf joint.

9 The scarf joint tang of the outboard section of erosion cover had been unintentionally distorted during blade manufacture in 1981.

10 The scarf joint malformation was not noticed but it had no effect on the structural integrity of the blade until it was exploited by a lightning strike.

11 An electrical discharge passed between the tang, which was either in contact with the spar or very nearly so, and the spar itself, momentarily creating sufficient heat to change the material properties of the titanium spar (microstructural damage) in a small region less than 2 mm wide.

12 There were no prescribed limits for the size or extent of lightning damage and the decision on whether the blade was repairable was based on engineering judgement exercised by the helicopter manufacturer.

13 The judgement was made that being encased in secondary structure, a spar was unlikely to be damaged in areas where the external secondary structure was undamaged.

14 There was no visible damage in the area of the scarf joint and the blade was assessed as repairable and subsequently repaired by its manufacturer.

15 There was no practical method by which the microstructural damage to the yellow colour-coded blade could have been detected during the damage assessment.

16 The repaired blade was later fitted to G-BJVX as the yellow colour-coded blade. It had been flown for 1,403.25 hours since refurbishment.

17 The fatigue inducing effect of the microstructural damage was either dormant or in slow growth for at least 1,300 flight hours.

18 There was no practical method by which the operator's maintenance staff could have detected the microstructural damage during routine inspections.

19 The fatigue crack probably began during the final 100 flight hours and may have progressed from an embryonic through-crack to 50% of the spar's circumference in as little as 24.4 flight hours.

20 A sympathetic crack formed in the recovered section of the erosion cover not less than 7.3 flight hours before the accident.

21 When the sympathetic crack first appeared, it would have been hidden underneath a black, opaque protective patch that had been fitted to prevent water ingress into the scarf joint.

22 The manufacturer's Composite Materials Manual specified the use of a clear patch material but opaque patches were commonly used.

23 A crack in the blade's upper surface skin aft of the protective patch may have existed 4.3 flight hours before the accident but, if it existed, its location rendered it unlikely to be detectable during a normal pre-flight inspection.

24 There was no existing line maintenance inspection that could realistically have detected the spar crack or revealed symptoms of the eventual blade failure.

25 Routine non-destructive testing of main rotor blades was unlikely to have averted this accident.

26 The helicopter's onboard IHUMS system occasionally recorded spurious data due to signal variability and noise and so the exceedance warning generated by the IHUMS ground station on the day of the accident did not result in an immediate investigation of its cause.

27 Analysis of the Rotor Track and Balance data recorded by the onboard IHUMS system could not have provided a warning in time to avert the accident.

28 The impending blade failure would not have been identified by an onboard HUMS system because detecting such failure modes is beyond current system requirements and capabilities.

29 The only symptom of impending blade failure was an increase in vibration during the cruise which was mentioned by the pilots about seven minutes before the accident.

30 Both pilots attributed the increase in vibration to a main rotor blade being 'out of track'.

31 There was no checklist, advice or previous experience that the pilots could have drawn upon to suspect that a blade might be out of track because of a cracked spar.

32 Apart from the yellow colour-coded blade on G-BJVX, within the 40.8 million flight hours accrued by similar and comparable blades constructed with titanium spars by the same manufacturer, none has failed in flight through spar fatigue. Only one blade has exhibited cracking in the main body of the titanium spar in an area where there was no redundant load path. That cracking was attributable to battle damage.

33 The only practical and currently available method of monitoring the structural integrity of an embedded tubular blade spar is by monitoring the pressure of gas trapped within the spar. The helicopter manufacturer's proprietary method of achieving this is the BIM system.

34 The retrospective fitting of the BIM system to all S-76 main rotor blades is not warranted provided that all such blades struck by lightning remain permanently withdrawn from service.

35 The ADELT beacon and its ejector mechanism were probably serviceable before water impact but the equipment's specification was probably exceeded at water impact.

(b) Causal factors

The following causal factors were identified:

1 A manufacturing anomaly created an area of reduced insulation between a main rotor blade's spar and one section of its two-piece leading edge erosion cover.

2 The affected blade had been struck by lightning.

3 Electrical energy from the lightning strike exploited the manufacturing anomaly and caused microstructural damage that was not detectable when the blade was returned to its manufacturer for assessment.

4 The blade was repaired before being returned to service and a fatigue crack in the spar originated from the microstructural damage.

5 An opaque protective patch applied to the erosion cover's scarf joint hid exterior symptoms of the developing spar crack that appeared before the accident.

6 The helicopter's proprietary onboard Health and Usage Monitoring System (IHUMS) did not provide sufficient warning of impending blade failure in time to avert the accident.

7 There were no in-flight symptoms of impending blade failure that the pilots should have recognised.