ACCIDENT

Aircraft Type and Registration:	Bell 206B Jet Ranger II, G-WLLY
No & Type of Engines:	1 Allison 250-C20 turboshaft engine
Year of Manufacture:	1969
Date & Time (UTC):	21 December 2005 at 1015 hrs
Location:	3 nm north-east of Coupar Angus, Tayside
Type of Flight:	Aerial Work
Persons on Board:	Crew - 1 Passengers -1
Injuries:	Crew - 1 (Fatal) Passengers - 1 (Fatal)
Nature of Damage:	Helicopter destroyed
Commander's Licence:	Airline Transport Pilot's Licence (Helicopters)
Commander's Age:	48 years
Commander's Flying Experience:	Approximately 15,000 hour (of which at least 2,500 were on type) Last 90 days -126 hours Last 28 days - 42 hours
Information Source:	AAIB Field Investigation

Synopsis

The pilot of the helicopter and an observer were carrying out a pipeline inspection flight between Cumbernauld Airport and Aberdeen. Approximately 45 minutes after takeoff, the helicopter descended to low level where debris was seen to fall from its aft section. Control of the helicopter was lost and it struck the ground, fatally injuring both occupants. The investigation found that the vertical stabiliser had detached from the tail boom and struck the tail rotor. This subsequently caused the tail rotor and associated gearbox to become detached from the tail boom, resulting in the helicopter's centre of gravity moving outside controllable limits.

The cause of the fin detachment was fatigue, in the fin attachment supports. It was concluded that this was the result of insufficient torque in the fin attachment fasteners.

History of the flight

The pilot and observer arrived at Cumbernauld Airport on the morning of the accident in order to carry out a standard pipeline inspection flight. On completion of the task the helicopter was to be delivered to a maintenance organisation near Aberdeen for a scheduled inspection. The pilot was observed starting the helicopter, which lifted off at 0922 hrs. It departed from Runway 26 and turned right to leave the airport boundary heading north-east. There were no further radio transmissions from the helicopter. On board GPS equipment recorded the route which closely followed a gas pipeline heading approximately north-east. The airspeed throughout the flight varied between 100 kt and 120 kt and the short section of the flight captured on radar showed the height to be between 500 ft and 1,000 ft agl. At approximately 1010 hrs a witness on the road between Coupar Angus and Meigle observed the helicopter heading northwards in a gentle descent. As it descended through approximately 100 ft agl, part of the rear section was seen to fall from the helicopter which began a right-hand turn. Another witness observed that it had no tail rotor or vertical stabiliser and that they saw it roll on to its left side before pitching nose-down into the ground. Debris was seen falling from the helicopter before impact with the ground. Both occupants were fatally injured.

Meteorology

An aftercast from the Met Office described a cold front passing through the area during the early morning of 21 December 2006. This left a fresh to strong north-westerly flow established over the accident area with patchy cloud and excellent visibility. The surface wind was estimated at 260º at 15-20 kt gusting 25-30 kt and the wind at 500 ft agl was estimated to be from 290º at 25 kt. The aftercast noted that significant turbulence was likely to have existed over the area and unexpected changes in windspeed and direction could also have been experienced.

Pathology

A pathological examination revealed that both occupants died from severe multiple injuries. No evidence was found of pre-existing disease or medical factors which could have had any influence on the accident.

Accident site details

The helicopter had come down in a freshly ploughed field that sloped gently downwards towards the north-west. The wreckage trail extended for several hundred metres in a generally northerly direction, with the vertical fin, tail rotor assembly and gearbox being among the earliest items found along the flight path. Other debris found in this area included parts of the tail rotor drive shaft and its cover.

The final item in the wreckage trail was the rotor head complete with the rotor blades. The rotor mast had broken immediately below the bump stops and it was apparent that this had occurred in the air. The liberated rotor disc had then sliced off the nose of the helicopter at an angle approximately parallel to the leading edge of the forward doors. The right-hand forward door had been cut in two and it was evident that the nose had been removed by a single rotor strike, in an upwards direction and from right to left, across the floor of the aircraft immediately ahead of the front seats.

The fuselage, minus the nose, had struck the ground in an inverted attitude at an estimated dive angle of 60º, making a shallow crater. It had then rolled out of the crater and come to rest on its left side. The upper cabin area, transmission deck and engine compartment had sustained severe damage as a result of the ground impact.

The aircraft wreckage was recovered to the AAIB's facility at Farnborough, where it was subjected to a detailed examination.

Aircraft history

The helicopter, serial number 405, was built as a 206A model in 1969 and had a United States registration until it was imported to the United Kingdom, where it was registered as G-AXMM. The available records show that it was re-registered as G-RODR from January 1982 to November 1991. In October 1984 the helicopter was damaged as a result of an accident when one of the skids caught on a tree root whilst taking off (AAIB File EW/G84/10/09, report published in Bulletin No 2/85). Repairs, which were of a major nature, were conducted by a company in Canada. In October 1987 the aircraft was damaged after being blown over in a storm. The log book for the period lists the repairs that were carried out, including the fitting of a 'new tail cone'. However, the organisation that conducted the work no longer exists. The work pack associated with the repairs was not available and so details such as part and serial numbers fitted at that time are not known.

In July 1991 the helicopter sustained significant damage during a heavy landing following an engine failure. This accident was the subject of an AAIB Field Investigation (File EW/C91/7/3 and the report was published in Bulletin No 1/92). The helicopter was repaired by the same Canadian company as before, and the work included repairs to the tail boom, which had been cut into three pieces in the accident. The aircraft flew briefly in late 1992 with the registration G-RODY, but was on the ground from September 1993 to July 1996. During this period, it was converted to a 206B model, the principal feature of this being the installation of an up-rated engine. Further ownership changes resulted in the registration changing to G-WLLY in March 1993 and G-OBHH in March 1996, before reverting to G-WLLY in June 1997.

The current owner acquired the helicopter in May 2004 and took it from its base in southern England before placing it with a maintenance organisation close to his home near Aberdeen. It was this company that negotiated the lease with the operator that held the pipeline inspection contract and which conducted most of the subsequent maintenance.

In April 2005 during an annual inspection, corrosion was found in the lower fuselage which necessitated replacing the 'bathtub' section. The rotor assembly, tail boom, vertical fin and horizontal stabiliser were removed and the fuselage was sent away for this work to be carried out. On its return, the helicopter was reassembled. The relevant documentation showed that the vertical fin was refitted on 13 September 2005 and was the subject of a duplicate inspection. The fin supports were, it was reported, inspected visually with the aid of a magnifying glass prior to attaching the fin.

After returning to service the helicopter had a 50 hour inspection on 24 October followed by a 100 hour inspection that was signed off on 14 November. This included an inspection of the vertical fin 'for condition and security', as required by the Maintenance Schedule. A further 50 hour check was carried out on 6 December 2005 at 5,103 flight hours. It had been planned to deliver the helicopter to the maintenance organisation for the next 100 hour check on 21 December, with part of the flight to be spent conducting a pipeline inspection. This would have been approximately 15 flying hours before the inspection was due; however, the operator required the aircraft to be available, with adequate flight hours in hand, between Christmas and New Year, during which period the maintenance organisation had planned to be closed. In the event, the helicopter crashed en-route to Aberdeen, having achieved a total of approximately 5,135 airframe hours.

On inspecting the wreckage at Farnborough it was noted that the tail boom part number was 206-031-004-71B, with the serial number BCJN 5186. According to the aircraft manufacturer, this component left the factory on an unspecified date during the 1970s, on a helicopter with the serial number 1069. This helicopter was damaged in an accident in Guatemala in May 1979, since when nothing more has been heard of it. It is thus not clear how the tail boom from helicopter No 1069 came to be fitted to G-WLLY. The available documentation from the Canadian company that twice rebuilt the helicopter indicates that the tail boom was repaired, as opposed to replaced. Thus, in the absence of any other documentation, it appears that the most likely occasion the subject tail boom was fitted was during the repairs following the 1987 storm damage.

The helicopter was equipped with floats and, as part of this modification, the 'stinger' at the base of the vertical fin was fitted with a triangular alloy plate designed to resist penetration of the tail into water.

Detailed examination of the wreckage

The sequence of the components found in the wreckage trail indicated that the vertical fin, tail rotor assembly and its gearbox had departed the helicopter during flight. Whilst there was a possibility that something fell via an unsecured door from the cabin or baggage compartment into the tail rotor, all the articles that were known to be in the aircraft were accounted for in, or near, the main wreckage. Attention was subsequently focused on the tail rotor (which had remained attached to the gearbox) and vertical fin, with the latter clearly having been struck by a tail rotor blade. One blade tip, including its weights, had been removed as a result of this contact. This left a chamfered edge that matched the profile of the cut in the fin that ran forward from the trailing edge, and which had severed the steel 'stinger' from its mounting in the leading edge. A metallurgical examination of the gearbox mounting bolts indicated they had all failed in bending overload. This was the result of severe out-of-balance forces that occurred following the loss of the tip weights. It was evident that the lower portion of the fin had moved into the tail rotor arc rather than the other way round, indicating that the fin was the first component to become detached.

On all Bell and Agusta-Bell helicopters, the vertical fin is attached to the tail boom by four bolts, which locate into holes in two fin supports positioned at the front and rear of the tail rotor gearbox platform. (See Figure 1.) On G-WLLY this platform is of a fabricated sheet metal construction. The bolts are secured with stiff-nuts. The fin supports are machined forgings; the rear support is riveted in position such that it effectively forms the rearmost frame of the tail boom. The front support is bolted to the structure. Note: There is a later design in which the platform and fin supports are an integral, one-piece forging. According to the manufacturer this was first introduced on the 206L series and then to the 206B model as a way to reduce the spares inventory.

The separated portions of the fin supports had remained attached to the inboard surface of the fin (see Figure 2), which, apart from being struck by the tail rotor, had sustained relatively little damage. Before removing these, the 'breakout' torque for each of the nut and bolt assemblies was measured. These were as follows:

Top aft	30 lbf.in	Top forward	22 lbf.in
Bottom aft	25 lbf.in	Bottom forward	15 lbf.in (but see below)

The Maintenance Manual specifies assembly torque values of 50-70 lbf.in. It should be noted that the bolt in the bottom forward attachment was found to be slightly bent; any structural joint in which plastic deformation has occurred is likely to have lost the torque figure set on assembly, thus the 15 lbf.in value was not considered reliable.

The riveted and bolted attachments of the rear and front supports on the tail boom respectively were found to be secure. The rear support had the number 206-031-418-1

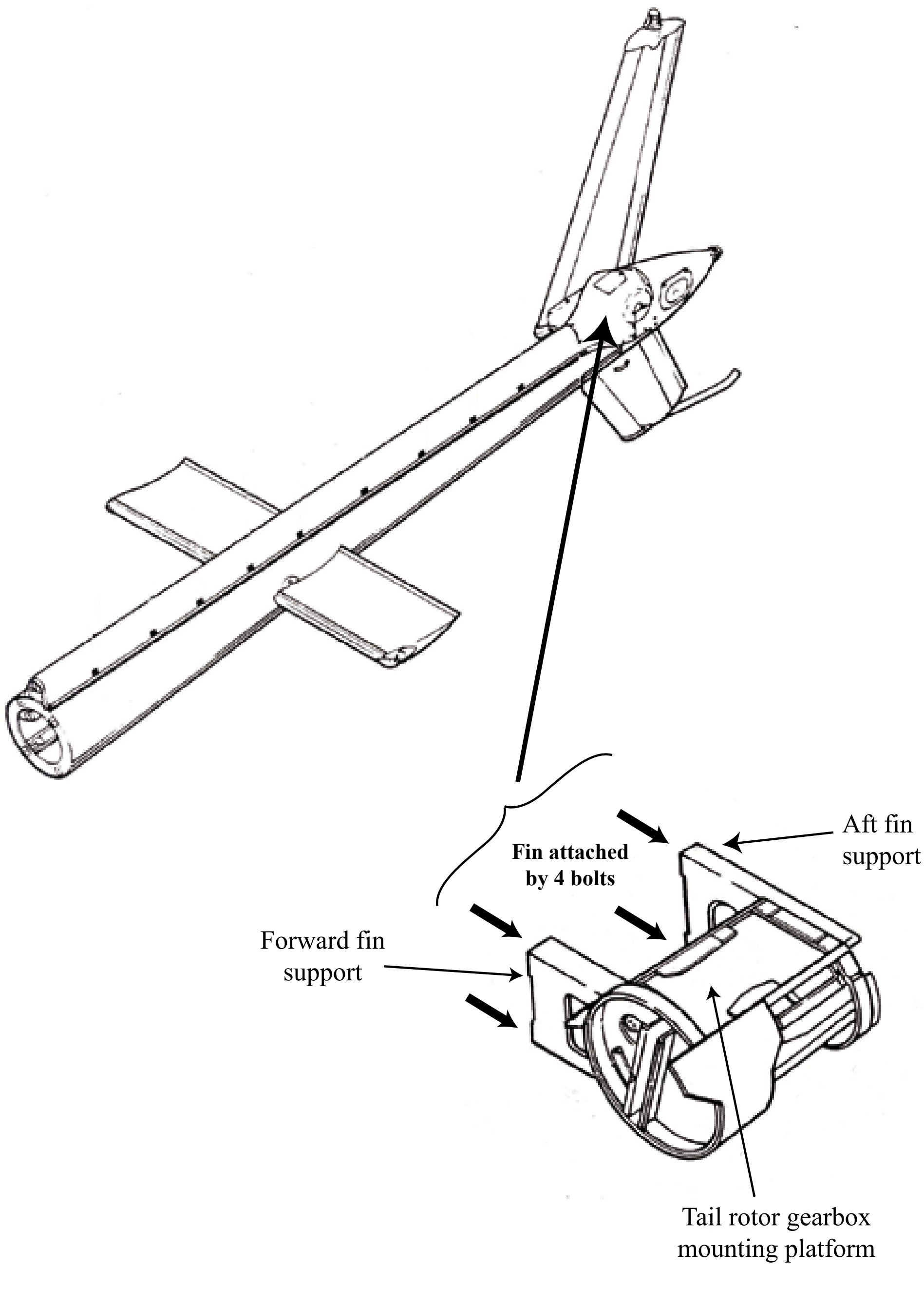


Figure 1

Tail boom and fin support

stamped on it, which was one of several part numbers listed in the Illustrated Parts Breakdown (IPB) for this component. However it was specified for use on tail booms with the part number 206-031-426-001 (as opposed to 206-031-004-71B, the subject tail boom). The front support had no number on it; the appropriate part number in the IPB was 206-031-417-003 or -007.

The vertical fin bore no part number, but there was a log book certificate that stated: '..*unserviceable fin replaced with P/N 206-020-113-011*', dated 3 August 1990. This was found listed in an old IPB, although the current version lists only -005, -007, -009, -107, and -109. It can be seen from Figure 2 that the inboard skin had been reinforced with a doubler. This was the result

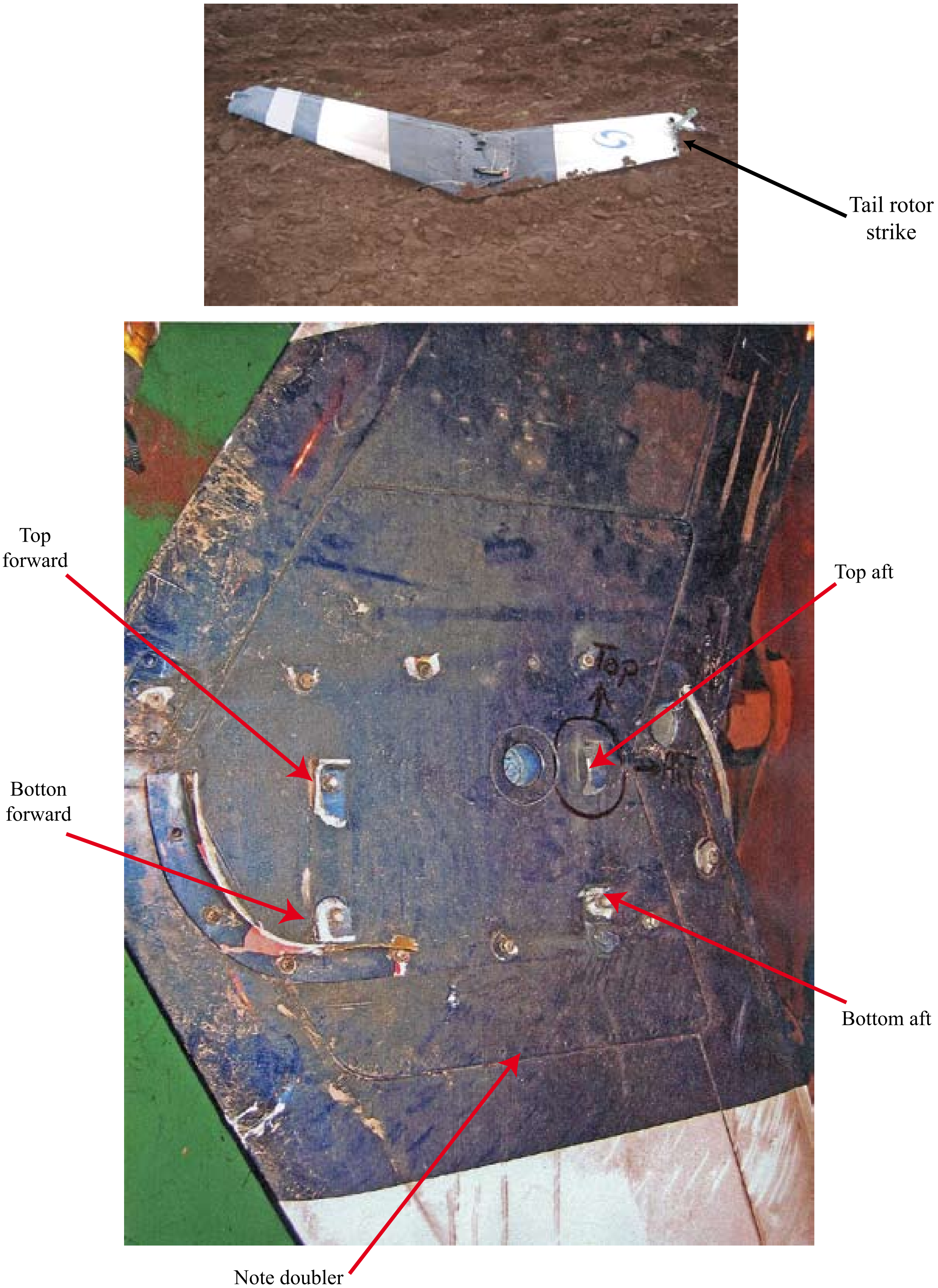


Figure 2

Views of inboard surface fin showing attached portions of fin supports of complying with Bell Service Letter 206-203, dated December 1972, which was introduced following an in-service problem of cracks developing in the fin. Later fins were manufactured with a strengthened central area, dispensing with the need for a doubler.

The fin was of lightweight honeycomb construction and was found to weigh 8.2 kg, including the 'stinger' and alloy plate assembly, which, as noted earlier, had been parted from the fin by the tail rotor. The steel 'stinger' was mounted in a steel block that was embedded in the leading edge at the base of the fin. It was found that this 'stinger', block and alloy plate assembly weighed 1.2 kg. The tail rotor assembly and its associated gearbox weighed 11.3 kg. Thus, together with the pieces of the tail rotor drive shaft and cover that were liberated shortly after the departure of the fin, tail rotor and gearbox, a total mass of approximately 20 kg was lost from the rear of the helicopter. It was calculated that the loss of these components shifted the centre of gravity forward to a point forward of the longitudinal centre of gravity limits.

Metallurgical examination of the fin and supports

The vertical fin and the supports were subjected to a detailed metallurgical examination by QinetiQ at Farnborough. This revealed evidence of fatigue in the fractures that had occurred through and around all four bolt holes in the supports. Figure 2 shows the inboard face of the fin, as found, with the fractured portions of the supports still attached. Figures 3 to 6 show photographs of the supports with the detached portions loosely replaced, and with the cracks highlighted. It can be seen that three cracks were present in the top aft attachment, with two present in each of the other three attachments. In addition to the fastener holes, the photographs show adjacent rivet holes, most with their rivets still in position. These were the result of complying with FAA Airworthiness Directive No 92-09-07, which mandated Bell Alert Service Bulletin No 206-91-60, dated June 1991 (described later), which removed nut plates (anchor nuts) from the supports and filled the holes with plug rivets.

There was no evidence of fretting damage around any of the attachment locations on the fin, although there were rectangular witness marks from the support edges in the painted surface around each of the attachment bolt holes. These took the form of indentations below the lower attachments and indicted the manner of the departure of the fin: the upper attachments failed first, allowing the top of the fin to move outboard as it pivoted about the lower supports. It would have been this sequence which resulted in the bending in the lower forward attachment bolt.

The upper fractures exhibited a considerable degree of corrosion and surface deposits. There was also evidence of post-failure mechanical damage (due to the fracture faces remaining in contact), which masked surface detail, but which indicated that the fatigue cracks had been growing over a period of time. The precise length of time could not be determined. The fracture surfaces from the lower attachments were comparatively clean.

The majority of the undamaged crack lengths in the upper attachments were due to fatigue, whereas the fractures in the bottom sections had smaller fatigue cracks in the bolt and rivet holes and larger areas of overload failure. Significantly, the cracks passed through the bolt holes at all four attachments, with origins visible on opposite sides of the outboard surface of the bore of the top forward attachment. It can also be seen from Figures 3 to 6 that, on the other attachments, the cracks passed through one of the rivet holes in each case, with origins occurring on opposite sides of the bore in the top aft attachment.

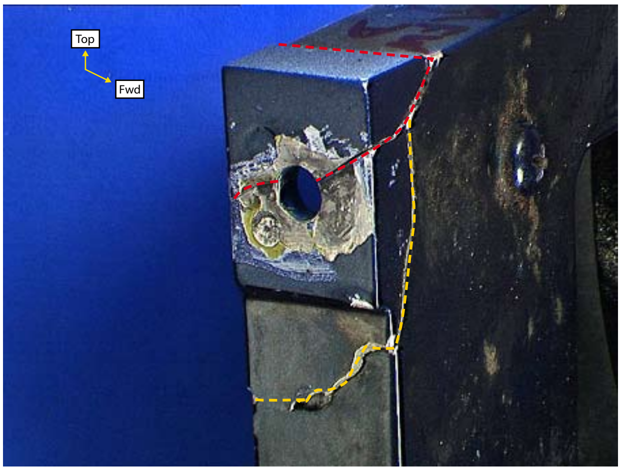


Photo: QinetiQ

Figure 3

Top forward attachment

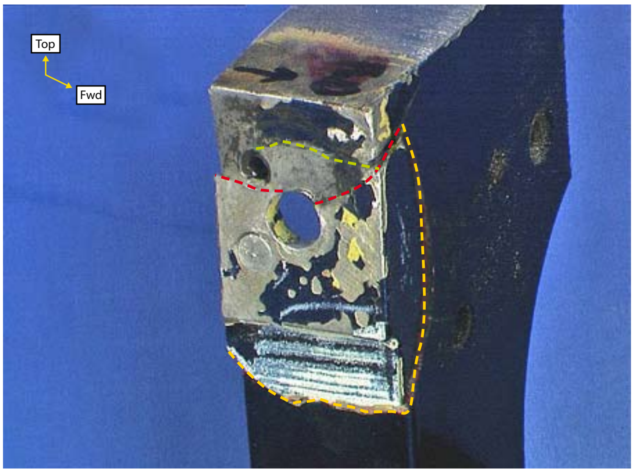


Photo: QinetiQ

Figure 4

Top aft attachment

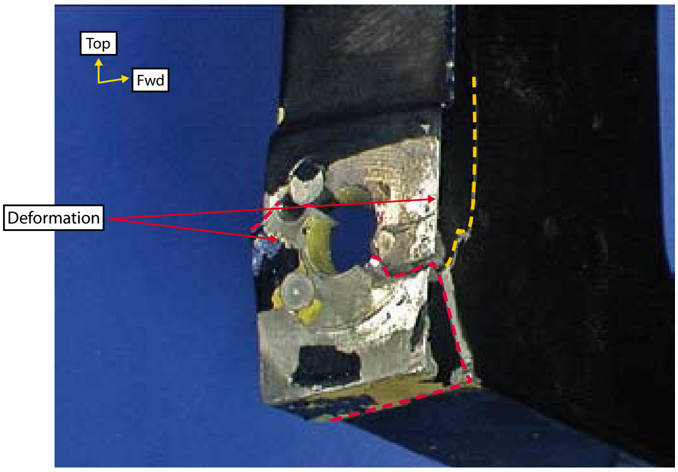


Photo: QinetiQ

Figure 5

Bottom forward attachment

Photo: QinetiQ

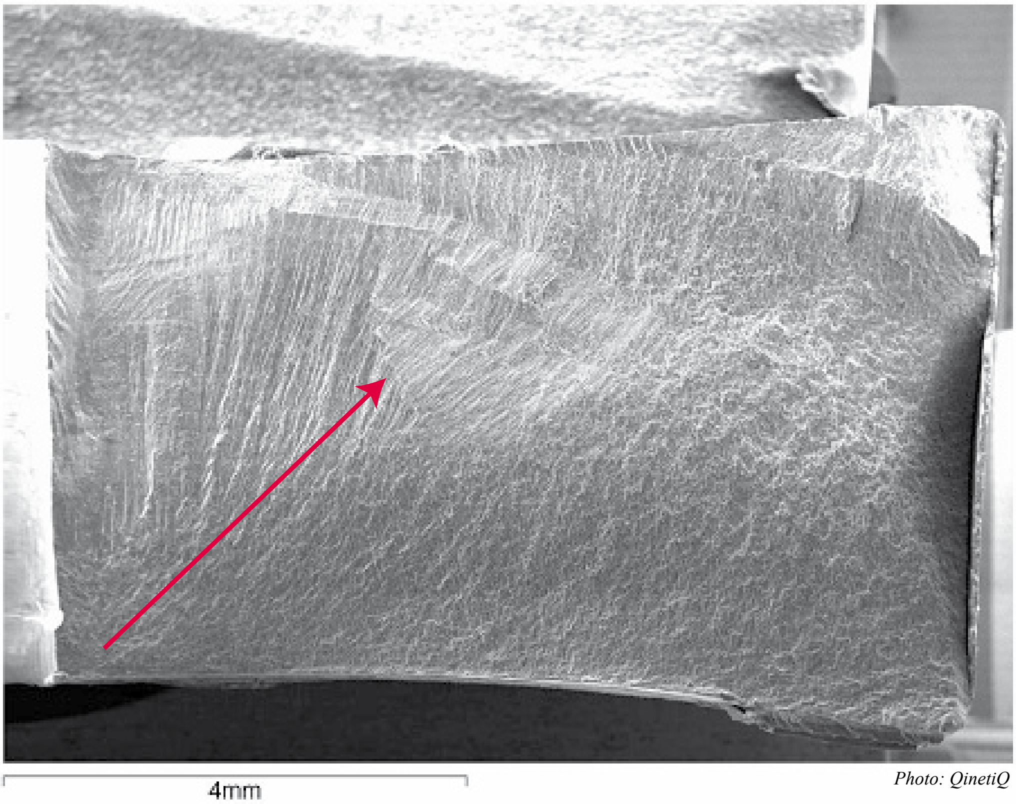
Figure 6

Bottom aft attachment

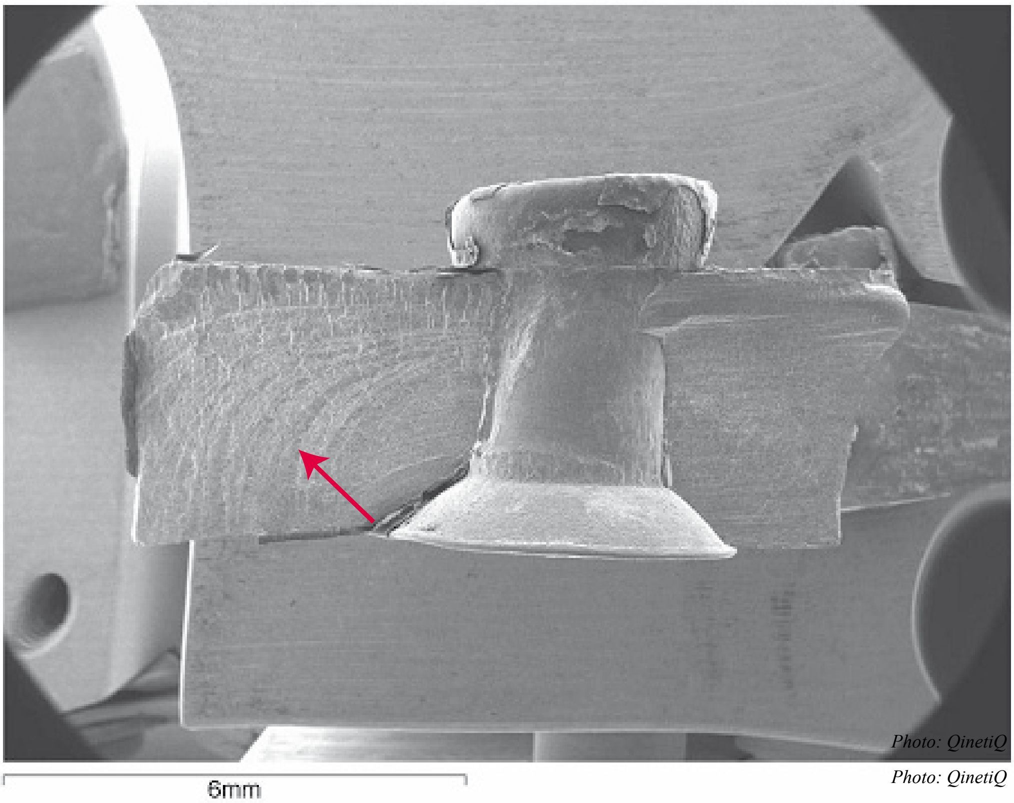
In both lower attachments there were fatigue origins in both the bolt and the rivet holes. The bores of all the holes were otherwise clean, with no significant features such as thread marks or corrosion pits. Figure 7 shows scanning electron microscope (SEM) photographs of a bolt hole and rivet hole, showing how the cracks initiated from the outboard edges of the bores. The cracks have then propagated away from the holes, at the same time extending through the thickness of the material to reach the inboard surface.

It was established that the first cracks to occur were those that passed through the holes, with the others being secondary. For example, in Figure 3, the 'yellow' crack in the top forward attachment can be seen branching off from the primary 'red' crack on the front face of the forging. Consideration of all the fractures led to the sequence of the attachment failures being established as: top aft, top forward, bottom aft and bottom forward.

The material specification was checked and found to conform to the grade of aluminium alloy specified by the manufacturer. Thus in the absence of features such as corrosion pits or mechanical damage sites, there was



Fatigue crack originating from edge at bolt hole on stabiliser side of top forward support



Fatigue crack originating from rivet hole on stabiliser side of bottom aft support

Figure 7

Scanning electron microscope photographs no obvious reason for the onset of fatigue. However, in the light of the low values of the breakout torque that were discovered on the fasteners following the accident, it was considered that insufficient torque may have been responsible. In support of this scenario, the metallurgical report contained the following comment:

'Specifying a torque setting for a mechanical fastening is a simple way to ensure that the joint is at a sufficient pre-load or clamping force (although not a particularly accurate way to measure it due to numerous variables in the torque-load relationship). It is known that increasing the clamping force increases the fatigue resistance of the bolt and mating surfaces of structure by establishing compressive stresses in critical areas. It also produces a more rigid structure thus reducing the likelihood of fatigue due to flexing.'

Also visible in Figures 3 to 6 are the remains of a paint finish on the outboard surfaces of the supports. Although most of the surfaces surrounding the bolt holes were bare metal, it was clear that originally, both yellow primer and dark blue gloss paint had been applied. Similarly, the shims on the fin inserts, against which the supports abutted, were also painted, although the paint had remained largely intact. Although no instruction to the contrary existed in the Maintenance Manual, it was considered unusual for the mating surfaces of a structural joint to be coated with gloss paint.

Maintenance information

The Helicopter Maintenance Schedule requires that the fin supports be inspected every 100 hours. This takes the form of a visual inspection only. A dye penetrant process would not normally be used; neither would the fin be removed. Thus a typical inspection would require the removal of the tail rotor gearbox fairing, allowing access to the inboard faces of the fin supports. These would then be cleaned and visually inspected for cracks. There is no requirement for a periodic inspection of the outboard faces, which would of course necessitate fin removal. Thus the fin is only removed for reasons other than inspection of the supports, such as repairs or re-sprays. Access to the supports with the fin removed is excellent and, as a consequence, a visual inspection of the inboard and outboard faces of the supports can be accomplished with ease.

In the case of G-WLLY, the fin was most recently removed in the summer of 2005 in order to facilitate the storage of major components whilst the fuselage was away being repaired. A qualified engineer, with 25 years experience of helicopter maintenance, and who was familiar with Bell and Agusta-Bell 206 helicopters, was employed by the maintenance organisation to take charge of the subsequent rebuild. The engineer stated that he and a colleague installed the fin in "about an hour", using the same nut/bolt/washer stack-ups that came off the helicopter; part of the process included checking that the stiff-nuts were fit for re-use. It should be noted that the Maintenance Manual details three slightly different procedures (in terms of the nut/bolt/washer stack-up) according to the serial number of the helicopter. The 'as-found' stack-up consisted of a plain aluminium washer under the bolt head and a radius washer next to the nut; this was appropriate to the helicopter serial number, but it was noted that the Manual took no account of the possibility that the tail boom might have been changed for one of an earlier or later production standard.

Although the maintenance company generated the work packs, the engineer instigated a process of dual inspections at various points during assembly. This included the fin installation, with the appropriate entry in the Duplicate Inspection Sheet calling up a "vital point inspection" in accordance with BCAR (British Civil Airworthiness Requirements) Section A6-2/B6-2. In fact the duplicate inspections described in these documents refer to flight, engine and propeller control systems, rather than structure. Vital points are defined in Section A5-3/B-5-3 and include aircraft structure; however, listings of vital points are not required for aircraft manufactured in accordance with a Type Certificate issued prior to 1 January 1986. In the event, the co-signatory checked the fastener stack-up, although he did not physically check the torque on the fin attachment bolts other than to confirm with the engineer as to the values he had used.

It was established that no re-painting occurred on any part of the helicopter during this reassembly. The most recent re-painting activity was carried out in December 2000, according to the log books, in which one of the certificates notes '*...vertical stabiliser removed for re-spray, refitted post re-spray*'. The helicopter had achieved 4,330 flight hours at this time, which was approximately 800 hours prior to the accident.

Previous occurrences

The manufacturer stated that they were aware of one fatal accident to a Bell 206 involving the in-flight detachment of the vertical fin. This occurred in April 1991; the helicopter crashed into the sea shortly after departing an offshore platform. The United States National Transportation Safety Board (NTSB) report noted that the fin supports had:

> *'...separated as a result of corrosion and corrosion pitting. The examination also revealed that the operator had attempted to combat the corrosion during a refurbishment of the airframe. All the fatigue fractures appeared old and one had paint in the fracture'.*

The United Kingdom CAA Safety Regulation Group database contained only one record on Bell 206 fin supports; this referred to a crack in a rear support that was found on a visual inspection and occurred in March 1977.

Transport Canada supplied a listing from a 'Service Difficulty Report Review', containing 12 records pertaining to the vertical fin. One of these, occurring in October 1980, involved the in-flight detachment of the fin and was the result of washers being omitted when complying with Service Letter 206-203. Over time, tension in the attachment bolts had pulled the fin-mounted inserts through the fin; thus this incident was apparently unconnected with the fin supports. Most of the other records were concerned with corrosion or cracks in the fin. There was one event in which, during an inspection, the top aft fin attachment bolt was found to be broken. The other three bolts were found to be below the minimum torque value.

Federal Aviation Administration Airworthiness Directives (FAA ADs)

During the service life of the Bell 206 the manufacturer has issued a number of Alert Service Bulletins (ASBs) concerning the vertical fin and its attachment to the tail boom. For the Agusta-Bell 206, there was invariably, for each ASB, a corresponding *Bolletino Tecnico* from the Italian company, although there were small differences in the content and issue dates.

The first relevant ASB was 206-26, dated 18 December 1972. This was superseded on 9 January 1973 by ASB No 206-01-73-1. Both of these required a repetitive inspection of the fin for cracks until Service Letter 206-203 was complied with (ie fitting a doubler). On 1 July 1973 the FAA made ASB 206-01-73-1 mandatory with the issue of AD No 73-12-01.

On 27 June 1973, Bell issued ASB No 206-01-73-5, which required inspection of the fin supports for cracks in the fin attachment bolt holes. Part I of the Bulletin called for the removal of the fin prior to conducting a dye penetrant inspection of the supports, which had to be replaced if cracks were found. In addition, the bolt holes had to be inspected for thread marks. Any marks had to be removed with a straight reamer, although this required prior removal of the nut plates on the inboard faces of the supports, into which the fin attachment bolts were located. If the nut plates had chafed into the radius of the forging, the marks had to be burnished. After cleaning up the holes the nut plates were replaced. The fin supports had to be replaced if any cracks were discovered; this was dealt with in Part II of the Bulletin. The replacement forgings were supplied without nut plates, the attachment bolts being secured with stiff-nuts. ASB No 206-01-73-5 was mandated on 15 November 1973 by FAA AD No 73-21-03.

On 28 June 1991 Bell issued ASB No 206-91-60 which applied to all 206A and B models with serial numbers between 4 and 1163 and which were equipped with a vertical fin assembly with a doubler installed on the inboard side. The reason for issue was that:

> *'[The manufacturer]has determined that installation of an external doubler on the fin may require spacing washers or shims between the fin and the tail boom to preclude unacceptable fatigue stresses on certain fin support forgings'.*

Part I of this Bulletin called for inspection of the supports in a similar manner to ASB 206-01-73-5, although the nut plates, if present, were not reinstalled; the nut plate attachment holes were filled with plug rivets. The supports were to be replaced in the event of any cracks being found. Part II called for inspection of the gaps between the fin-mounted inserts and the faces of the supports. Washers were used to fill any gaps so that the resulting stack was flush, -0 to +0.010 inches, with the surface of the external doubler. The washers were bonded in position. Both this ASB and 206-01-73-5 required that bare aluminium (ie on the supports) was to be coated with anti-corrosion primer. Gloss paint was not specified.

ASB No 206-91-60 was mandated on 29 June 1992 by FAA AD No 92-09-07. Operators were given 30 days or 100 flying hours, whichever occurred first, to accomplish this work.

With regard to G-WLLY, the Modification Statements in the log books show that all the above ASBs had been complied with. In addition, physical evidence, in the form of the plugged nut plate attachment holes and washers were found during the examination. It was not clear from the records when ASB 206-91-60 was embodied on the helicopter, although it is probable that it was accomplished during the second rebuild in Canada.

Examination of the components by the manufacturer

Following examination by the AAIB, the components were delivered to the manufacturer's facility at Fort Worth, Texas, where they conducted their own examination. Their findings were in broad agreement with those of the AAIB, with some additional comments concerning the washers that were used to fill the gaps between the fin supports and the inserts, as per ASB No 206-91-60. They noted that the washers appeared to be "homemade", in that they were out-of-round and that the holes were not centred; in addition some of them appeared ground down and had rough edges. However, they had been manufactured from the correct material.

On loosely assembling the components (with the exception of the bottom forward attachment, which was deformed), it was noted that the washer in the top aft attachment did not stand proud of the surface of the doubler and thus did not meet the ASB requirement. As, the washers were not disturbed during the disassembly and reassembly of summer 2005 they were likely to have been in this state for a while. It was noted that the washers had been bonded to the fin inserts on top of the finish paint, which, as it appeared to be same blue colour as the rest of the fin, suggested that they may have been reattached when the fin was re-sprayed in December 2000.

Analysis

Handling characteristics

The investigation established that the vertical fin had suffered an in-flight detachment from the helicopter. The manner of its departure was such that the lower part of the fin entered the tail rotor arc; the resulting contact removed the 'stinger' at the base of the fin and damaged the rotor blades. The tail rotor and its gearbox were torn from their mountings shortly after the loss of the fin. Apart from the effect on directional stability, there would have been the consequences of the loss of approximately 20 kg of mass from the rear of the helicopter.

The vertical stabiliser provides directional stability and also has an outboard inclined leading edge. The aerodynamic load that this generates reduces the tail rotor thrust required during forward flight. It would be at its most effective during high speed flight when it would be subjected to the greatest lateral loading. Although the Met Office aftercast noted the probability of turbulence in the area, this is not thought likely to have affected materially the loading on the fin.

The loss of the tail rotor, associated gearbox, vertical stabiliser and 'stinger' would have had a major effect on the helicopter's handling characteristics at any speed. It was calculated that the loss of these components shifted the centre of gravity forward to a point forward of the longitudinal centre of gravity limit. This would have occurred rapidly and is likely to have led to a loss of control even with full aft cyclic control applied. Handling difficulties would have been compounded by the loss of the lateral thrust from the tail rotor causing the helicopter to rotate to the right. It is probable that the pilot would have applied full aft cyclic control in an attempt to arrest the nose down pitch, resulting in the main rotor blades contacting the top of the tail boom. In fact this was confirmed by the presence of tail rotor drive shaft components early in the wreckage trail. What happened after this is conjecture, but it is possible that the blade contact on the tail boom resulted initially in the failure of at least one of the main rotor pitch control links. This could have resulted in a large increase in lift on one blade such that it tilted the rotor disc, causing a bending overload failure of the mast. The separated rotor disc then sliced off the nose of the helicopter.

Whilst mast failure is not necessarily an inevitable consequence of fin detachment (as illustrated by one of the Canadian incident reports), the loss of the tail rotor and gearbox in this case severely reduced any possibility of the crew surviving the accident.

History of the aircraft

The aircraft was constructed in 1969 and had experienced a chequered history, being involved in a number of incidents and two major rebuilds. At some stage it had gained a tail boom of uncertain provenance, which served to highlight a potentially confusing situation with the Maintenance Manual, in that the method used to attach the vertical fin varied according to the serial number of the airframe, as opposed to that of the tail boom.

The log books indicated that more than 5,100 flying hours had been achieved at the time of this accident, which is not exceptional for a helicopter of this age. However, it is questionable as to how much of the original airframe remained following the two rebuilds; the recorded figure is probably irrelevant. Despite this, the log books indicated that the helicopter had been maintained in accordance with its schedule and that all the necessary Airworthiness Directives relating to the fin and its attachment had been complied with. There was thus no evidence to suggest that the cause of the accident was rooted in the distant past. This view was reinforced by the fact that the fin supports were reportedly in good condition at the time the tail was reassembled in September 2005. As a thorough examination of the area is easily accomplished with the fin removed, a reasonable level of confidence can be placed in this assessment. It was therefore concluded that the fatigue cracks most probably initiated *after* September 2005, with the main issues being the cause of the crack initiations and the failure to detect them before they progressed to a critical condition.

The failure

The QinetiQ metallurgical examination of the supports noted that the fatigue cracks had originated in the attachment bolt holes and/or the nut plate rivet holes. More specifically, the initiation points were on the outboard edge of the bores (ie the interface with the inboard side of the fin). Bearing in mind the fin exerts an aerodynamically generated force to the right during the cruise, it follows that the resulting tension in the bolts tends to reduce the compression in the fin supports. It is possible that certain vibration modes of the fin could have a similar effect. The crack progression was therefore likely to have been along the outboard surfaces of the supports, at the same time propagating through the material to the inboard surface. The effect of this would be that at any one time, the cracks would be longer on the outboard surface of the supports than on the inboard. This would not have assisted the discovery of the cracks during the 100 hour inspection in November 2005 (assuming they had developed by that time), as the fin was not required to be removed. Also, the cracks would not have been visible on the forging inner faces until their length exceeded the diameter of the washers under the stiff-nuts. Finally, the visibility of the cracks, if present, would not have been aided in this case by the dark blue paint scheme of the aircraft.

The sequence of the attachment failures was established as: top aft, top forward, lower aft and lower forward. It is probable that the top aft attachment had completely failed some time before the accident, thus increasing the load on the remaining attachments and consequently accelerating the crack progression.

The lack of torque

The mating surfaces of a structural joint are normally held in compression by the fastener components. Compression is generally regarded as beneficial in conferring fatigue resistance, and in this case the support forgings would be clamped between the nut and washer on the inboard faces and the fin (or, to be more precise, the shim) on the outboard faces. On fins without doublers, the forging outer faces abut directly against the fin inserts and are therefore placed in compression when the bolts are tightened. The addition of the doubler (which has cut-outs to allow access to the inserts) thus creates a gap between the forging and the insert, and a consequent loss of compression in the area of the forging immediately surrounding the bolt hole. It seems probable that this was the cause of the in-service fatigue crack problems that led to the issue of ASB No 206-91-60 and FAA AD No 92-09-07 (which introduced the shims), although the likely fatigue mechanism was not actually explained in either publication. The fact that the washer in the top aft attachment did not stand proud of the doubler surface when the components were loosely reassembled would have served to reduce the compression applied around the fastener hole.

The cause of the crack initiation was not obvious. However in the absence of observable defects such as thread marks or corrosion pits, it is considered that insufficient assembly torque or an in-service torque loss may have been responsible. Corroborative evidence was provided by the low torque settings found on the fin attachment fasteners after the accident. The stiff-nuts were found to be in good condition and were not thought likely to have backed off in service. The fact that the fatigue cracks had progressed to failure of the attachments suggests that the loss of torque must have existed for a considerable time. It thus seems reasonable to suppose that this condition may have been present at the time of the last 100 hour inspection, irrespective of whether the cracks were present or visible. Whilst the fin may not have appeared physically 'loose' at this time (the lack of any obvious fretting damage suggested that this was the case), a torque check on the fasteners could have revealed the problem and hence potentially averted the accident. However, such a check was not required by the Maintenance Manual.

Regardless of the cause of the torque loss, the immediate consequence would be a loss of rigidity, or stiffness, of the structural joint, which could render it vulnerable to the effects of vibration. In particular, the 'stinger' and its associated alloy plate represented a significant mass concentration at the base of the fin, effectively on an approximately one metre moment arm from the attachment area. Whilst it is considered that this was not responsible for crack initiation (the 'stinger'/plate assembly is, after all, common to most float-equipped helicopters and has not resulted in any reported problems) it is possible that the vibration amplitude would increase with crack progression, which in turn could accelerate the process.

The 'stinger' assembly on this type of helicopter presents itself as an accessible 'handle' for such purposes as manoeuvring the helicopter in a hangar, or for the application of a downwards load in order to assist mounting the jockey wheels on the skids. Any aggressive ground handling could result in excessive lateral loads being applied to the fin, with the attendant possibility of causing strain in the structural joint. However, any loss of rigidity, or even cracks caused in this way, might be expected to affect the lower attachments, as they are closer to the applied load, whereas the complete failure of the top aft attachment suggested that this was where the first crack initiated.

Finally, there is the matter of the remains of the gloss paint on the faces of the support forgings. A corrosion inhibitor/primer is all that is specified in the manufacturer's ASBs and it is not standard practice to apply gloss paint to the mating surfaces of structural joints. Since no painting was carried out during the reassembly in September 2005, it is likely that the paint was applied in December 2000. Paint has a finite thickness, and in the event that the paint film deteriorated or disintegrated (perhaps as a result of excessive loads applied to the fin during ground handling) and was lost from the stack-up, there would be a corresponding loss of assembly torque. However, it was not possible to determine if the amount of paint found adhering to the support faces was different from that present at the time the fin was reattached to the aircraft. As a consequence, it was impossible to assess how much of a contribution, if any, the presence of the paint made to the cause of the lack of torque.

Summary and Safety Recommendations

This was the second fatal accident to a Bell 206 involving failure of the fin supports. Earlier concerns about their structural integrity had been addressed by a number of Alert Service Bulletins and Airworthiness Directives. This investigation did not reveal any defects in what is manifestly a mature design. The failure was attributed to a lack of assembly torque in the attachment of the fin to the support forgings. The fin became detached when the helicopter was within an hour of landing at its maintenance base for its planned 100 hour inspection, where the extensive cracks in the fin supports would certainly have been discovered.

Whilst the lack of assembly torque in the fin attachments could not be accounted for, there were a number of possible explanations. Regardless of the reasons for the lack of torque, a torque check on the fasteners could have revealed the condition and hence prevented the accident. No such check was required in any of the periodic inspections.

In March 2006 the AAIB published Special Bulletin S1/2006 in which Safety Recommendations 2006-039 and -040 were made to the United Kingdom Civil Aviation Authority (CAA), the European Aviation Safety Agency (EASA) and also, since the design authority and manufacture of the Bell 206 series is now based in Canada, to Transport Canada. The Recommendations are reproduced here:

Safety Recommendation 2006-039

It is recommended that the United Kingdom Civil Aviation Authority require a one-off inspection, within a reasonable timescale, of the vertical fin supports of all Bell and Agusta-Bell 206 series helicopters on the UK register. The inspection should be conducted with the fin removed in order to obtain adequate access.

Safety Recommendation 2006-040

It is recommended that Transport Canada, the European Aviation Safety Agency and the US Federal Aviation Administration each consider requiring a one-off inspection, within a reasonable timescale, of the vertical fin supports of all Bell and Agusta-Bell 206 series helicopters within their jurisdictions.

Subsequent safety action

On 6 June 2006, in response to these Safety Recommendations, the CAA issued a Letter to Operators (LTO) detailing an inspection to be completed at the next 100 hour maintenance input. However, the LTO left compliance with this inspection to the operator's discretion by requesting rather than requiring compliance.

On 26 April 2006 Bell Helicopter Textron (BHT) issued ASB 206-06-107, which called for an inspection of helicopters equipped with the older type of supports, together with a Maintenance Manual amendment that included, among other requirements, a recurrent torque check of the fasteners at each 100 hour/annual inspection. The ASB was mandated by Transport Canada on 5 June 2006 with the issue of Airworthiness Directive CF-2006-12.

In addition, the ASB called for an increase of the torque values to 75-95 in lbs. Reference was also made to BHT-ALL-SPM (Standard Practices Manual), which provides guidance on paint finish applied to faying surfaces, which are defined as 'face-to-face areas of adjoining (contacting) parts'. However the ASB did not require the fin to be removed unless low torque values were recorded, paint was found on mating surfaces, or if cracks were suspected following an external examination. The text of ASB 206-06-107 was extensively amended at Revision A on 15 June 2006, but there was still no requirement to remove the fin unless some anomaly existed.

In addition to the ASB, on 17 April 2006, BHT also issued Operations Safety Notice (OSN) GEN-06-36, which reminded owners/operators to adhere to the original paint finishes, especially in the area of faying surfaces.

In Europe, on 5 July 2006, Agusta issued Bollettino Tecnico No 206-240, in respect of Agusta-Bell 206 series helicopters. This is a shorter, simpler version of ASB 206-06-07 which, significantly, does require removal of the vertical fin in order to inspect the supports. On 20 July 2006 the European Aviation Safety Agency (EASA) issued a Proposed Airworthiness Directive (PAD) No 06-192, in preparation for mandating the Bollettino Tecnico.

Finally, although this investigation has been concerned with a helicopter equipped with an older type of tail boom, ie on which the tail rotor gearbox platform was of a fabricated sheet metal construction, there is no suggestion that the one-piece fittings on later helicopters would be any less vulnerable to the effects of low torque. Thus the Safety Recommendations 2006-039 and 2006-040 contained in the Special Bulletin were intended to apply to all Bell and Agusta-Bell 206 helicopters, and the AAIB notes that while ASB 206-06-107 applies only to the older type of tail boom, the BHT Maintenance Manual amendment also applies to the later design.