**ACCIDENT**

| | |
|---|---|
| **Aircraft Type and Registration:** | Agusta A109A, G-DNHI |
| **No & Type of Engines:** | 2 Allison 250-C20B turboshaft engines |
| **Year of Manufacture:** | 1979 |
| **Date & Time (UTC):** | 9 October 2006 at 1431 hrs |
| **Location:** | 2 nm west of Biggin Hill Airport, Kent |
| **Type of Flight:** | Commercial Air Transport (Passenger) |
| **Persons on Board:** | Crew - 1 Passengers - None |
| **Injuries:** | Crew - None Passengers - N/A |
| **Nature of Damage:** | Tail rotor assembly separated from helicopter, severe damage to both vertical stabilisers and aft tailboom |
| **Commander's Licence:** | Commercial Pilot's Licence |
| **Commander's Age:** | 52 years |
| **Commander's Flying Experience:** | 8,465 hours (of which 1,836 were on type)<br>Last 90 days - 68 hours<br>Last 28 days - 16 hours |
| **Information Source:** | AAIB Field Investigation |

**Synopsis**

During cruise flight, an engine exhaust duct separated from the helicopter and struck the tail rotor assembly, causing the tail rotor gearbox to separate. After an initial yaw to the right, the pilot regained limited control. However, a further sudden yaw, possibly associated with a partial structural failure of the upper vertical stabiliser, prompted an immediate autorotative descent, which culminated in a successful forced landing. The investigation established that a clamp attaching an exhaust duct to the left engine had failed, due to stress corrosion cracking, allowing the duct to disconnect from the engine. Two Safety Recommendations are made.

**History of the flight**

The helicopter was being flown by the operating company's Chief Pilot from Redhill Aerodrome to Biggin Hill Airport to collect two passengers and fly them to Battersea Heliport. Prior to the flight, he carried out a pre-flight check of G-DNHI which revealed no anomalies or defects; there were no outstanding defects recorded in the technical log. The helicopter was fuelled to full main tanks and was within centre of gravity (CG) and overall mass limits for the proposed flight.

After a refreshment break, the pilot departed for the short flight to Biggin Hill, 10 nm away. The weather there was fine, with a surface wind from 210° at 8 kt, good visibility and scattered cloud cover at 1,600 ft aal.

The surface temperature was +18ºC. He made contact with Biggin Hill ATC and was instructed to fly to a right-hand downwind position for Runway 21. At this time the helicopter was flying at 1,500 ft amsl and with a cruise power setting of approximately 90% torque, giving an airspeed of 120 kt to 140 kt.

Without warning, the helicopter suddenly yawed to the right, and the pilot thought later that this may have been accompanied by a "bang". He instinctively applied full left anti-torque pedal and left cyclic control, and the helicopter appeared to stabilise with about a 30º angle of bank to the right. Although the pilot was visual with Biggin Hill, he was unable to stop the helicopter from turning away from the airport. Aware that there had been a serious malfunction of the tail rotor, the pilot attempted to regain directional control of the helicopter by reducing the collective setting, and thus the torque being applied to the main rotor. A person on the ground in the area heard the helicopter approaching and then heard two "pops", before seeing the helicopter pass overhead in the direction of Biggin Hill, with what sounded like an altered engine note.

The pilot was aware of a reducing airspeed, possibly to around 100 kt. He reported that having flown the helicopter through about 360º of turn, he was able to fly toward Biggin Hill for a mile or so with crossed controls. There was then was a violent yawing and pitching motion which he described as "wrenching" which he sensed as a significant pitch-up and yaw to the right. It was probably this event that was seen by another witness on the ground who described seeing the helicopter yaw a full 180º (although described as a yaw to the left) before pitching nose-down and yawing back in the direction of flight.

The pilot immediately lowered the collective lever to remove all torque from the main rotor system. He then reduced engine power to idle, lowered the landing gear and the helicopter settled into an autorotative attitude. The pilot sensed that it still wanted to turn to the right and recalled that he was concentrating on maintaining a satisfactory airspeed and main rotor speed, but that he had limited influence on the helicopter's direction of travel. He saw a field ahead of the helicopter which appeared suitable for landing. Being reluctant to flare too harshly, the pilot made a shallow flare before 'cushioning' the touchdown with increasing collective. Consequently, the landing was faster than it would otherwise have been. The pilot lowered the collective lever gently, and the helicopter decelerated satisfactorily without the need to use wheel brakes, and remained upright.

The pilot shut down the engines and attempted to call Biggin Hill or another aircraft on the radio. This was unsuccessful, so the pilot made an 'all-stations' broadcast to inform anyone who might receive his transmission of the situation and his safe landing; this transmission was not acknowledged. The pilot switched off electrical power and vacated the helicopter. He then alerted the emergency services by telephone and ensured that ATC at Biggin Hill were informed of his safe landing. Subsequently, the pilot could neither recall any vibration at any stage of the emergency, nor recall seeing any warning lights or abnormal cockpit indications.

**CG determination**

The manufacturer made a conservative estimate of the effect on the helicopter's CG position after the tail rotor assembly departed. Making the assumption that only 25 kg of fuel was on-board (although it had been refuelled to full tanks prior to flight, fuel weight has a small effect on CG position), that the pilot weighed 80 kg and that the tail rotor assembly weighed 19 kg, they calculated that the CG position remained well inside normal limits.

**Recorded information**

The majority of the helicopter's flight was captured by radar heads at London Heathrow Airport and Pease Pottage in Sussex. Radio communications between G-DNHI and Biggin Hill ATC were also recorded and available for analysis. A plot showing the helicopter's radar-derived track and other relevant information is at Figure 1.

*Radio telephony*

The pilot contacted Biggin Hill Approach Control (129.400 MHz) and reported that he was over the M23/M25 motorway junction at 1,400 ft amsl. Two minutes later he transmitted "MAYDAY MAYDAY (CALLSIGN TWICE) TAIL ROTOR FAILURE JUST WEST OF BIGGIN", and this was acknowledged by the approach controller. The pilot then said "… IN A RIGHT TURN AT FIFTEEN HUNDRED FEET, FIELD IN SIGHT, UNABLE TO MAKE LEFT TURN AT THE MOMENT, AM TRYING TO GET TOWARDS YOUR AIRFIELD". In response the controller cleared the pilot for a landing on any available surface at

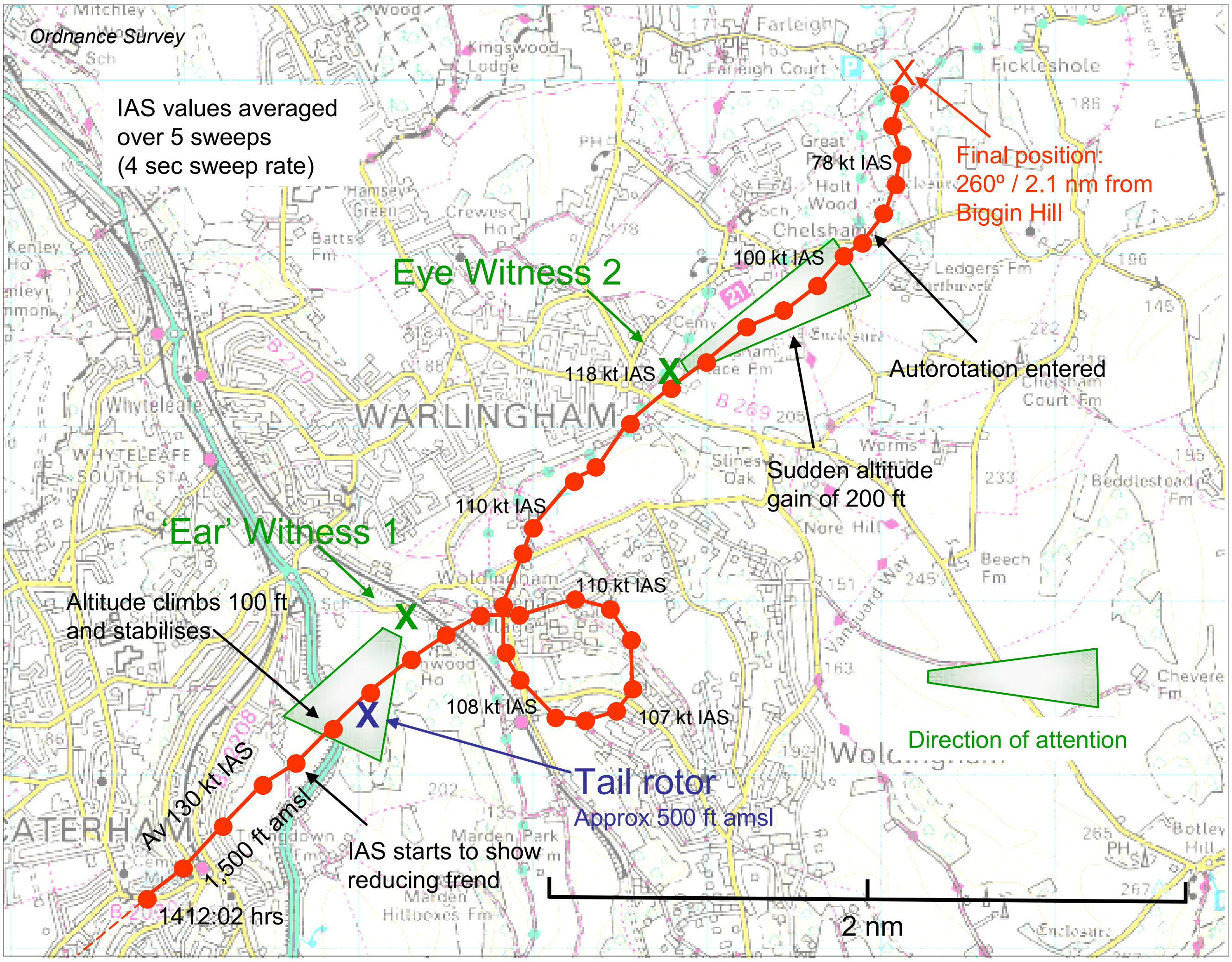



**Figure 1**

Diagram illustrating G-DNHI's track for the last part of the flight, and the location of witnesses the airport. Seventy seconds after his first 'MAYDAY' call, the pilot transmitted that that he was carrying out a forced landing into a field three miles west of the airport. There were further weak and broken transmissions, which were probably from G-DNHI, but which were not readable. An attempt by ATC to use another airborne helicopter to contact G-DNHI was unsuccessful but, by this time, ATC had been informed by telephone that the helicopter had landed safely.

*Radar*

Radar altitude and groundspeed information confirmed the pilot's reported altitude and estimated IAS, based on a south-westerly airflow of 10 kt to 12 kt. When the helicopter was in the vicinity of the first witness, its altitude began to vary, to a maximum of +200 ft /-0 ft. At the same point the instantaneous and averaged IAS began to decay from about 130 kt. Radar returns then showed an orbit to the right before the helicopter resumed its original track. During this time, the IAS continued to decay, until it stabilised between 100 kt and 110 kt. The orbit was flown with an average rate of turn of 6º/sec, although the actual turn rate was highest mid-way through the orbit. The radius of the orbit was approximately 335 m.

The helicopter resumed a track towards Biggin Hill, maintaining a steady altitude and with a reduced IAS, which then began to increase gradually. About 25 seconds after regaining track, the altitude return showed a sudden increase of 200 ft and the IAS began to decay again. About 12 seconds after this event, the altitude information indicated that the helicopter had entered autorotation, with an IAS between 85 kt and 95 kt and an average rate of descent of 2,100 fpm. The last recorded radar position was within 80 m of the landing site, with a calculated height of 300 ft agl.

**Examination of the accident site**

The accident site was a large field that had been unused for sometime which had become overgrown with weeds. Crop furrows formed undulations in the surface. The field was generally surrounded by large areas of woodland interspersed with a few residential buildings and unmade roads. To the east of the field, the ground sloped downwards into a narrow valley that ran in a north-south direction.

Surface marks indicated that the helicopter had initially contacted the ground with its left main wheel, whilst yawed slightly to the right, on a heading of approximately 035º, and with a forward speed in the region of 60 kt. About 2.5 m after the initial contact, the right main wheel contacted the ground; this was quickly followed by the nosewheel. The helicopter, which remained upright, rapidly came to a halt, slewed to the right by about 55º.

**Examination of the helicopter**

Initial examination of the helicopter revealed that the tail rotor assembly, including the gearbox, and left engine outboard exhaust duct were missing, Figure 2. One of the main rotor blades had a deep indentation on its under surface at, approximately, the half-span point. The upper vertical stabiliser was inclined about 25º to the right and its fixture to the tailboom was severely disrupted. The lower vertical stabiliser had suffered severe damage to its trailing edge consistent with being struck by the tail rotor blades.

**Damage to the helicopter**

The tail rotor and its gearbox were found some time after the accident, in the vicinity of the first uncommanded yaw event; the exhaust duct has not been found to date.

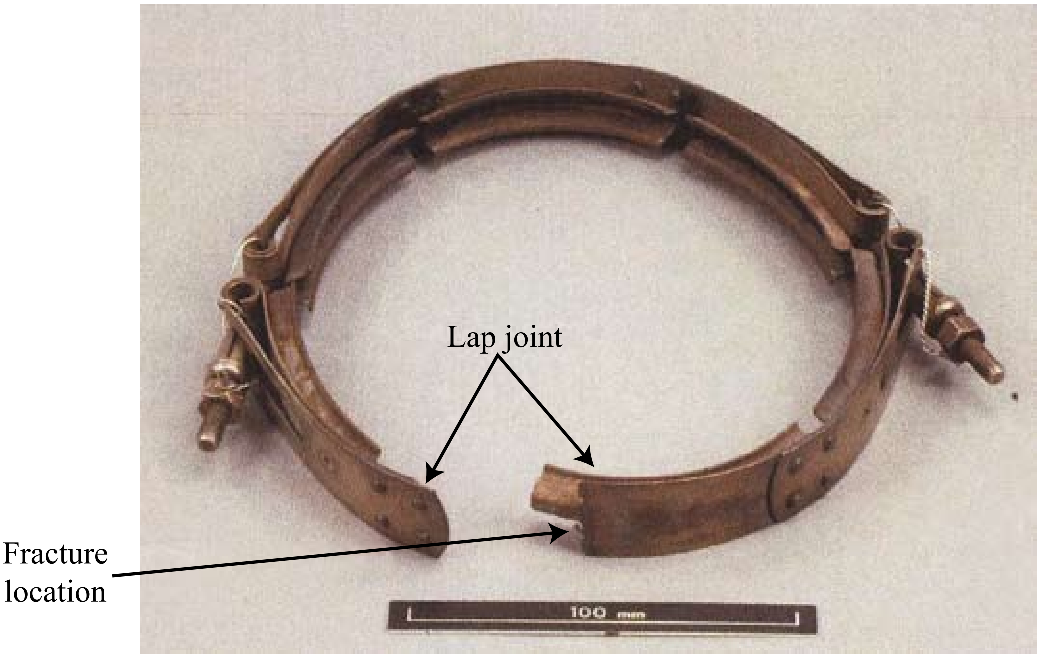
When the left engine cowl was opened, a two-piece

Mormon[1] clamp (part number 4606AC), that had been used to attach the outboard exhaust duct to the left engine, was found loose in the engine bay. This had failed at a position approximately one third of the way around the circumference of one of the two halves of the clamp, Figure 3.

Examination of the inside of the left engine cowl, in the area of the aperture through which the exhaust duct would normally protrude, showed very good evidence that a safety tang on the rear of the duct had very recently been in heavy contact with the cowl, to the extent that it had cut a slot-shaped hole through the metal skin.

Examination of the tail rotor gearbox showed all failures to be consistent with high out-of-balance forces from the tail rotor having induced excessive loads on the gearbox-to-tailboom mounting points, causing these to fail.

**Figure 2**




*Picture courtesy of QinetiQ*

**Figure 3**

Failed exhaust-duct-to-engine Mormon clamp

**Footnote**

1 See paragraph titled Mormon clamp description.

**Exhaust duct description**

The exhaust duct is a stainless steel ovalated tube curved through 45°, 26 cm in length, and with a lip formed at the engine casing interface end, Figure 4. This lip corresponds to a lip on the engine casing which facilitates the use of a Mormon clamp to join the two. A total of four clamps are used to attach two exhaust ducts to each of the engines.

At around the time that the prototype Agusta 109 was being tested, it came to the manufacturer's attention that there had been an event to another helicopter type where a Mormon clamp had failed. This allowed an exhaust duct to separate, which resulted in damage to the helicopter. Following this event, the manufacturer produced a modification whereby two 4 cm long metal tangs were riveted to the lip end of the exhaust duct, to prevent the duct from exiting through the aperture in the engine cowl in the event of a clamp failure, Figure 4. This modification has been applied to all production models of the Agusta 109 helicopter.

**Mormon clamp description**

Mormon clamp is a term applied to a clamp installed around a cylindrical object to connect two halves together. The clamp usually has U or V sections that fit over lips or flanges on the objects to be joined, and serves to pull the two halves together as the clamp is tightened in place. Because the clamp is required to pull the two sections together, it is undersized and, in cases where the sections to be joined are oval, the clamp is not an exact match with the profile of the flanges. This is achieved as the clamp is tightened. The clamp has no position


**Figure 4**

Exhaust Duct arrangement

keyways or orientation markings, but the manufactured shape of the clamps used on G-DNHI approximated to the oval profile of the exhaust ducts.

The inner U section of the clamps used on G-DNHI, comprise six individual sections, three being spot welded to each half section of the clamp. Each half section consists of one strap folded back onto itself at each end, and secured there by four rivets, as illustrated in Figure 3 and 4. The loops formed by the fold-back facilitate the location of T-bolts used to tighten the clamp assembly. The clamps used on G-DNHI, fabricated in the USA by the National Utilities Company (NUCO), are made from AMS 5595 corrosion resistant steel and identified by the manufacturer as 'V-band clamps'.

**Clamps examination**

It was evident that a failure of the strap had occurred on one half of the subject clamp, beneath where it was overlapped by one of its folded back ends. Detailed examination revealed that a crack had formed and that this had initiated in the strap's central region. The crack had then propagated towards the strap's outer edges, running through two rivet holes, before the remaining material failed in overload, Figure 5. Metallurgical examination of the fracture faces indicated that the nature of the crack was consistent with chloride-driven stress corrosion cracking.

The location of the crack on the strap was effectively hidden by the overlap of its end section. This would not have allowed early detection by visual examination or non-destructive testing by, for example, fluorescent dye-penetrant, unless the clamp had been removed. Another area on the failed clamp associated with the strap overlap was found to have surface-breaking cracks which, on further examination, also exhibited characteristics of stress corrosion cracking.

Close examination of the remaining three Mormon clamps from G-DNHI, both visually and by fluorescent dye-penetrant inspection, revealed no evidence of cracking and these appeared to be serviceable.

**Use of Mormon clamps**

The design and manufacture of the exhaust duct and its method of attachment to the engine casing exhaust aperture flange, are the responsibility of the airframe, not the engine, manufacturer. Rolls Royce Allison, one of the main manufacturers of small turbine engines installed in many helicopters and some fixed wing types, provide a flange at the exhaust end of the casing to facilitate the use of a Mormon clamp to attach exhaust ducts. However, the type and manufacturer of these clamps vary between airframe manufacturers. Mormon clamps do not have serial numbers or declared service lives, and are reusable.

**In-service history of the Agusta AB206 and A109 fleets**

The AB206 fleet of about 740 helicopters (first delivery in 1967) and the A109 fleet of about 400 helicopters (first delivery in 1975) use Mormon clamps to attach exhaust ducts, a total of some 3,080 installed clamps. Of these, six are known to have failed in-flight, resulting in the release of only one duct, the event which occurred to G-DNHI.

**Previous occurrences of Mormon clamp failure, UK data**

A search of the UK CAA Occurrence database revealed eight previous recorded incidences of Mormon clamp failure (Table 1), six of which resulted in the exhaust duct departing from the helicopter, including one where the duct struck the tail rotor. All these events involved the Rolls Royce Allison 250 series engine fitted to either the Bell/Agusta Bell 206B, or Bolkow 105 helicopters.

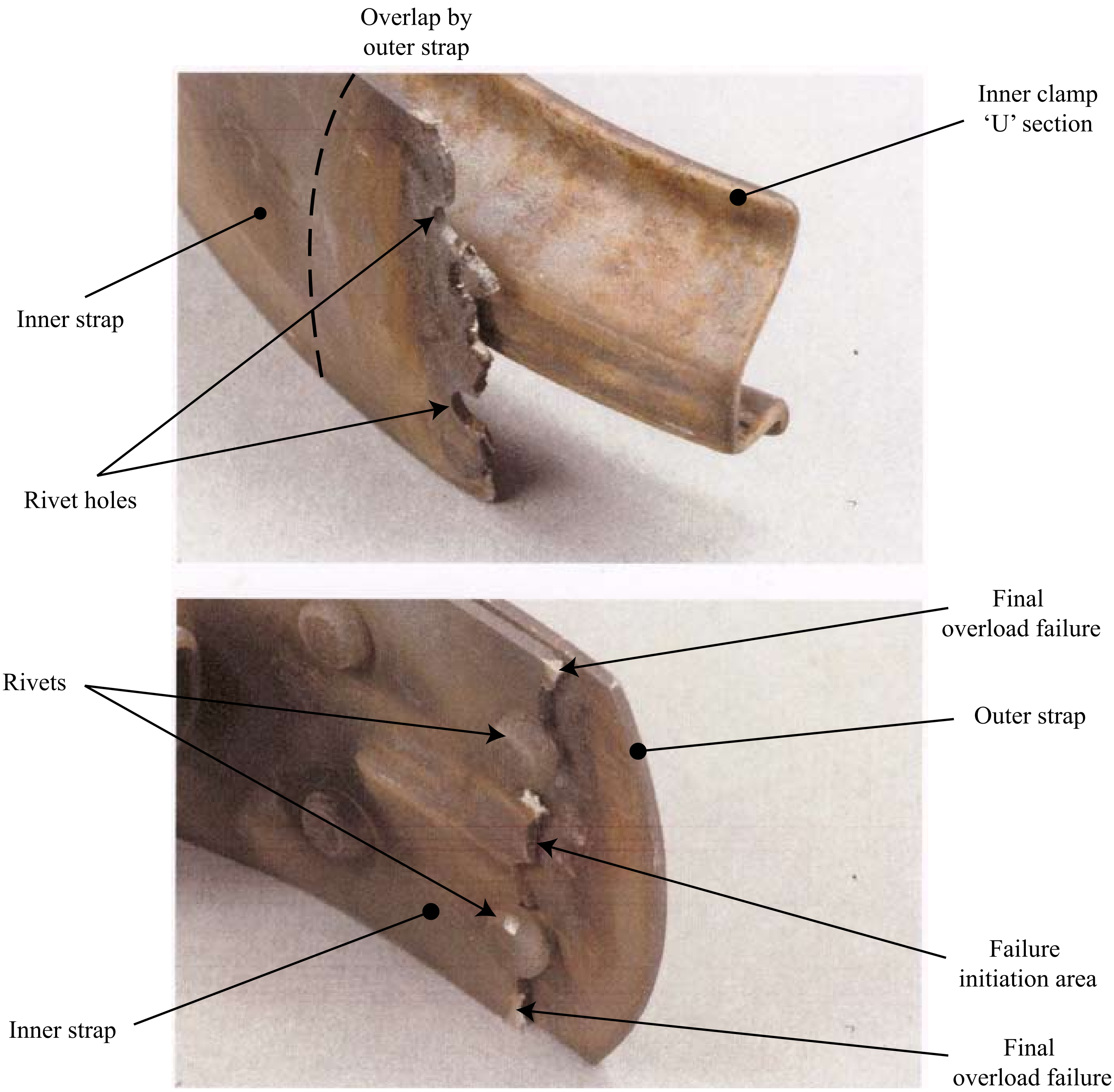



**Figure 5**

The two halves of the fracture of the failed clamp

| Date | Helicopter Type | Engine Type | Details of event |
|---|---|---|---|
| Oct 1978 | Bell 206 B | Allison 250 | Mormon clamp failure allowing exhaust duct to separate and strike tail rotor |
| Feb 1983 | Bell 206 B | Allison 250 | Post flight inspection revealed exhaust duct missing due to Mormon clamp failure |
| Mar 1990 | Bell 206 B | Allison 250 | Mormon clamp failure across width where band is folded back and riveted. Found on pre-flight |
| Jul 1995 | Bolkow 105 | Allison 250 | After shutdown exhaust duct found to be missing |
| Apr 1996 | Bolkow 105 | Allison 250 | Nr 2 engine outboard exhaust duct separated from helicopter during final approach |
| Apr 2000 | Bolkow 105 | Allison 250 | During post-flight inspection RH outboard exhaust duct missing - Mormon clamp cracked through at stud sleeve attachment |
| Apr 2000 | Bolkow 105 | Allison 250 | RH outboard exhaust duct detached due to Mormon clamp failure |
| Sep 2000 | Agusta Bell 206 B | Allison 250 | During post-flight inspection LH exhaust duct Mormon clamp found failed in fatigue across two rivet holes |

**Table 1**

Previous known occurrences of exhaust duct Mormon clamp failures

**UK in-service history of Mormon clamps**

The main UK EASA Part 145 maintenance organisation for Agusta helicopters is frequently required to replace Mormon clamps, Pt No 4606AC, on helicopters fitted with Rolls Royce Allison 250 series turbine engines, due to the presence of cracks in the strap material between the rivets. Thirteen clamps were replaced in 2005, 19 in the first nine months of 2006. Approximately 25% of the cracked clamps are repaired and returned to service, the remaining 75% are scrapped.

There are a number of manufacturers of turbine engines fitted to light helicopters, but only the Rolls Royce Allison engine requires the use of Mormon clamps to attach exhaust ducts, with the exception of early Turbomeca Astazou engines. Other manufacturers generally utilise a nut and bolt attachment method. This type of clamp is also used in some Lycoming and Continental piston engine turbocharger installations and, according to one maintenance organisation, clamp failures are known to occur.

**Relevant Service Bulletins**

In June 1969, the Bell Helicopter Company issued a Service Letter (SL) that introduced tangs on the engine exhaust ducts of model 206A helicopters to retain the exhaust duct in the event of failure of Mormon clamp Pt No 4656AA. In August 1969, Agusta issued a mandatory Service Bulletin (SB), in response to the Bell Service Letter, requiring tangs to be fitted to the engine exhaust ducts of Agusta/Bell 206A helicopters.

In November 2000, Eurocopter issued an Alert Service Bulletin (ASB) applicable to all Bolkow 105 helicopters, titled '*Power Plant – Coupling Clamp – Inspection for Corrosion and Cracking in the Area of the Latches'*. This resulted from the discovery that stress corrosion cracking had occurred in the latches of a Mormon clamp, Pt No 4606AH, resulting in its failure.

In August 2006, Eurocopter issued an ASB titled *'Assembly of the Exhaust Clamps',* again applicable to Bolkow 105 helicopters. This was issued as a result of a reported incident where an exhaust clamp failed during flight. Eurocopter advised that the exhaust clamps must not be secured with wire, as shown in Figure 4, as the lockwire may damage the clamps, due to vibration, causing them to break. Only self-locking nuts should be used to secure the two halves of the clamp.

**Analysis**

*Operational aspects*

From the location of the tail rotor/gearbox on the ground, and information from witness who heard unusual noises, it is likely that the tail rotor assembly separated from the helicopter very soon after being struck by the exhaust duct. The sudden consequent reduction in anti-torque capability, together with a relatively high power setting, caused the helicopter to yaw to the right. When the pilot reduced power, the helicopter's directional stability, aided by the vertical stabiliser, was sufficient to allow a measure of directional control to be regained. The loss of a significant mass so far aft would have moved the CG of the helicopter forward. However, the estimation of the 'new' CG position by the manufacturer indicated that it probably remained within the helicopter's limits, thereby allowing the pilot to retain control in pitch and effect a 'run-on' landing.

The second event, which the pilot described as a "wrench", entailed a further, sudden yaw to the right and a nose-up pitching moment. It is possible that these events involved the failure of the already weakened upper vertical stabiliser at its attachment point to the rear tailboom, in that the stabiliser force vector would have changed, should it have adopted an unusual attitude by canting over to the right. The reduced anti-torque moment was probably only countered by the pilot's immediate reaction of lowering the collective control and reducing engine power to idle.

The terrain beneath the helicopter's flight path, as it descended in autorotation, presented limited opportunities for a safe landing, being quite heavily wooded and undulating. Nevertheless, with limited control available and no other options, the pilot was able to execute a successful run-on forced landing without injury to himself or further damage to the helicopter.

*Engineering aspects*

The failure, due to stress-corrosion cracking, of the Mormon clamp that attached the outboard exhaust duct to the left engine, appeared to have allowed the duct to become loose at the rear of its mounting. With the engine running, forces induced by gasses exhausting from the duct were likely to have pitched the duct forward, until the rear tang contacted the underside of the engine cowl. After a period of time, during which damage was caused to the cowl by the rear tang, the duct fully disconnected from the engine, exited the cowl and, after being struck by a main rotor blade, defected into the tail rotor. In the absence of the duct, it has not been possible to ascertain the process by which the duct was released from the cowling, but the possibility that the safety tang(s) may have deformed or failed cannot be dismissed.

The resulting damage to one or both tail rotor blades was sufficient to induce a severe imbalance within the tail rotor assembly. This precipitated failure of the tail rotor gearbox mounting structure, and partial failure of the vertical stabiliser attachment frames in the rear of the tailboom, allowing the tail rotor gearbox and the rear section of the tailboom structure to depart the airframe.

**Safety action**

As a result of the accident to G-DNHI, Agusta has issued two SBs, 109-123 and 206-242, whose status they regard as mandatory, titled *'Inspection to grooved clamps P/n 4656AA or P/n 4606AC that attach the engine exhaust ducts'*. These SBs apply to Agusta A109A, A109A11 and A109C helicopters (issued 16 November 2006) and Agusta-Bell AB206A/B helicopters (Issued 18 December 2006). They require that a detailed visual inspection for cracks and corrosion of the clamps after removal, using a 10x magnifying glass, within 50 operating hours of the SB's issue date. After this initial inspection, repetitive inspections are required every 200 hours/annually for the A109 fleet and 100 hours/annually for the AB109 fleet. EASA have issued an Airworthiness Directive which mandates these SBs. This inspection regime is regarded as reducing the probability of an in-flight catastrophic clamp failure to an acceptable level.

**Safety Recommendations**

The direct cause of the accident to this helicopter may be attributed to the failure of a Mormon clamp used to secure the outboard engine exhaust duct to the left engine, in combination with the failure of the duct retention system. The clamp failed due to a crack which had developed over a period of time in one of its strap segments. The location of this crack was effectively hidden by the overlap of the strap end section, and would not have allowed detection by visual or non-destructive testing with the clamp installed. The clamps used on G-DNHI, in common with other types of Mormon clamps, were not subject to any proscribed inspection/maintenance regime. Therefore, no documented history of the failed clamp, or any others with identified cracks, was available. However, safety action has already been taken by EASA and Agusta to address the problem with the A109 and AB206 helicopters, the inspection regime being considered appropriate for the early detection of the stress corrosion failure mode.

Since 1978, eight failures of Mormon clamps used to secure exhaust ducts on UK registered Agusta A109, Bell 206 and Bolkow 105 helicopters, are known to have occurred, and it is relatively common for maintenance crews to find that in-service clamps contain cracks. However, although visual inspections of these clamps whenever they are removed from a variety of installations, would seem to identify clamps with developing cracks, the SBs issued by Agusta, and mandated by EASA only relate to their products. Due to different installations on other helicopter types and the nature of these cracks, their early detection would not seem assured on all helicopters which use this method of duct attachment.

Despite the presence of two tangs on the engine exhaust ducts on G-DNHI, designed to retain a duct within the engine cowl in the event of it becoming loose, the left engine outboard duct departed the helicopter following the clamp failure.

The following Safety Recommendations are therefore made:

**Safety Recommendation 2007-114**

It is recommended that the European Aviation Safety Agency require all helicopter manufacturers for whom they have airworthiness responsibility to institute similar Mormon clamp inspection regimes to those detailed in Agusta Service Bulletin Nos 109-123 and 206-242, where they are used to secure exhaust duct components to the turbine engines of helicopters.

**Safety Recommendation 2007-085**

It is recommended that the European Aviation Safety Agency require all helicopter manufacturers for whom they have airworthiness responsibility, to review the design of engine exhaust duct attachment and retention systems, to ensure that no part of the ducting will be released from the helicopter in the event of a failure of the attachment.