Agusta A109E Power, G-TVAA

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Aircraft Type and Registration:	Agusta A109E Power, G-TVAA
No & Type of Engines:	2 Pratt & Whitney PW206C turboshaft engines
Year of Manufacture:	1999
Date & Time (UTC):	17 June 2000 at 0833 hrs
Location:	Arborfield Cross, Berkshire
Type of Flight:	Public Transport (Air Ambulance)
Persons on Board:	Crew - 1 - Passengers - 2
Injuries:	Crew - 1 (Minor) - Passengers - 2 (Minor)
Nature of Damage:	Extensive
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	41 years
Commander's Flying Experience:	4,240 hours (of which 96 were on type)
	Last 90 days - 38 hours
	Last 28 days - 14 hours
Information Source:	AAIB Field Investigation

Synopsis

This report should be read in conjunction with that on Agusta 109E, G-JRSL, which also appears in this bulletin. Two identical types of helicopter suffered a loss of control as a result of the swash plate scissors link attachment bolt fracturing. This was because, in both cases, a very short time before the accidents occurred, the swash plate scissors link had been incorrectly assembled and installed. This report makes recommendations that address the design and maintenance aspects of the rotating scissors link component. The report on G-JRSL describes one of the consequences, which was a total loss of electrical power, possibly due to the left hand pilot's headset moving the battery and generators switches (perhaps with the gang bar) to 'OFF'. Recommendations are made which address this particular feature.

History of the flight

The helicopter departed from White Waltham Airfield at 0829 hrs outbound to Arborfield Cross on an Air Ambulance flight, in order to pick up a patient with a leg injury. It was approaching the pick up point and had entered a gentle right turn in order that the crew may search visually for the patient's location. The helicopter speed was between 60 and 80 kt at this time, at about 300 feet agl.

The three crew members heard a single loud bang, apparently coming from the upper rear of the passenger cabin. Coincident with this noise, the occupants felt the helicopter sink suddenly. This sensation was described as though the helicopter had flown through a vortex wake. The commander instinctively applied additional collective control in order to arrest the sink, but rapidly realised that the helicopter was not responding. The commander noted that the main rotor speed had increased to 105% NR at this stage. Initially assessing the problem as a loss of power, the commander lowered the collective lever to enter autorotation. There were no indications of an engine failure from the helicopter's automated warning system. The right turn was continued in order to position the helicopter towards a suitable landing field and the commander concentrated on keeping the helicopter upright and straight during the final stages of the approach.

The commander lowered the landing gear and issued a Mayday call to White Waltham. Just prior to touchdown, the engines levers were moved to the OFF position. The 'low rotor speed' audio alert sounded during the final stages of the approach, although the occupants could not be certain exactly when this occurred. The pilot had actioned most of the items of the 'Double Engine Failure' drill from memory during the descent, which was estimated to have lasted only about 10 seconds.

Full collective control was applied to arrest the descent. The helicopter then touched down heavily, but with low forward speed. The three landing gears collapsed on impact and the helicopter bounced forward slightly and came to a halt upright with the nose resting against a stock fence of the field adjacent to the intended landing area. The rotor brake was applied and the electrics shut down prior to the three occupants evacuating the helicopter unaided through the normal exits.

The fuel on board on departure for the accident flight was 450 kg. The helicopter's take-off weight was 2,703 kg, and its maximum allowable take-off weight was 2,850 kg.

The Aircraft Flight Manual indicates that the correct speed for the performance of a two engine out autorotation is 70 to 75 kt and that the rotor speed limitations are (Power On) 102% NR below 120 kt, or (Power Off) 90 to 110%, where 100% NR is 384 RPM.

The weather at the time was good, with a surface wind from 160° at 11 kt, visibility 15 km, no significant cloud, temperature +20°C, mean sea level pressure 1027 mb.

Accident site details

The helicopter came to rest on a heading of 300° with its nose in a wire mesh fence bordering a paddock, and with its tail some 13 metres from a garden fence. The nearest part of the associated house was approximately 15 metres beyond the fence.

The approach path of the helicopter was through a narrow gap between the house and a parallel line of trees. To the rear of where the helicopter had come to rest were marks on the ground made by the tail skid and the tail rotor. The landing gear had collapsed on impact. The disposition of the ground marks relative to the helicopter suggested that it had struck the ground in a nose high attitude, with a slow forward speed and a high descent rate. The outer sections of the tail rotor blades had been crushed on contacting the ground and had subsequently been thrown into the base of the fence to the rear of the helicopter. The tail rotor shaft had failed, allowing the main part of the tail rotor assembly to be thrown forward, striking the trailing edge of the left hand stabiliser, through the main rotor disc (although missing the blades) before landing some 10 metres in front of the nose.

The right stabiliser had suffered a compression crease on its underside at the mid span point. It was considered that this occurred as a result of the inertial forces generated by the presence of a tip weight within the stabiliser, and provided additional evidence of a high rate of descent.

Detailed examination of the helicopter

The pilot's report of a loss of lift, together with low torque on both engines initially suggested the possibility of a double engine failure. Accordingly, the engine manufacturer's service engineers were despatched to the accident site to download data from the Engine Data Unit (EDU). Subsequent analysis of the data revealed that the engines had been shutdown normally, with no faults or exceedences being recorded.

During the EDU download, the transmission drive train was examined, with its integrity being confirmed. However, examination of the main rotor head revealed that the rotating scissors linkage had become detached as a result of a failure in the bolt that attached the lower link to the rotating swashplate. The photograph at Figure 1 shows the rotor head and the detached scissors linkage.

The rotating swashplate is shaped in the form of a four-pointed star, with the rotor blade pitch change links attached, via spherical bearings, to lugs at the points. It is driven by the scissors linkage, the upper end of which is attached to the rotor mast. The fixed swashplate, located below the rotating swashplate, is operated by the flying control actuators and controls the vertical position and angle on the mast of the rotating swashplate. It will be appreciated that in the event of the scissors linkage becoming disconnected when the rotor is under power, there will be some loss of synchronisation between the rotor head and the swashplate, such that the latter will tend to lag behind. The pitch links are normally at a near vertical attitude. However the failure of the scissors linkage attachment would result in the swashplate driving loads being taken up by the pitch links, which would tend to lean in the direction of rotation. This change in geometry would result in a reduction of the rotor blade pitch angles without any change in the swashplate position, and probably accounted for the sudden loss of lift reported by the pilot.

The angular displacement by which the swashplate could lead or lag behind the rotor head would be constrained by the freedom of movement of the pitch links. Examination of the rotor head revealed that damage had occurred to the attachment lugs due to deflection, in the direction of rotation, of the pitch links. This can be seen in Figure 1.

Subsequently it was discovered that the lower scissors link had been installed back to front such that the spherical bearing at the base of the link, through which passed the attachment bolt, was restricted in its range of movement. Diagrams of the correct and incorrect installations are shown at Figures 2a and 2b. It can be seen that compression of the scissors (ie increased collective and/or cyclic pitch) with the link fitted incorrectly will cause (a) contact between the cup washer and outer face of the lower link and (b) the spherical bearing to run out of travel. Figure 3a shows evidence of rubbing on the face of the lower link by the cup washer, which had become distorted as a result. Figure 3b shows where the bearing raceway had been distorted due to contact by the cylindrical stub that emanated from each side of the spherical bearing.

Recent maintenance

The helicopter was constructed in 1999 and had achieved 271 flying hours. The technical log showed that on 16 June, ie the day before the accident and 3 hours and 10 minutes flying time earlier, the lower scissors link had been replaced. The reason for this was that during an 'A' check, excessive play had been detected in the scissors link hinge bearing. This necessitated removing the linkage, installing shims in the hinge bearing to remove the free play and reassembling the linkage onto the rotor head. However, the lower link was reportedly difficult to remove from the swashplate bolt, to the extent that some damage occurred to the link bearing. The reason for this difficulty was not clear; corrosion of the bolt was suspected but not confirmed. A new lower link was installed in place of the damaged item. This was the first occasion that the scissors linkage had been disturbed since the helicopter was built. Following the above maintenance activity the helicopter flew on a positioning flight to White Waltham.

The relevant diagram in the Maintenance Manual is reproduced at Figure 4. It can be seen that the representation of the lower link has not been drawn in sufficient detail that could assist an engineer in identifying the correct orientation. One clue to an incorrect installation would be that the flange on the hinge bush would have to be at the opposite end to that shown in order to engage with the machined shoulder on the side of the link. However, this would not preclude fitting the hinge bolt in its correct orientation, ie with the head facing the direction of rotation, as directed in the Maintenance Manual 'Installation Procedure'. This section of the Manual otherwise contains no written guidance as to the correct orientation of the link. There is in fact an error in the instructions, in that the bevelled washer (included in the attachment of the link to the swashplate bolt) is called up as item No 29, when it appears as item 25 in the diagram.

It should be noted that the design of the scissors linkage is unique to the 109E Power. The lower link on earlier versions is asymmetric in planform, and cannot be installed incorrectly. In addition, the Part and Batch numbers are embossed on the inboard side of the link, whereas the equivalent numbers appear on the outboard face of the 109E link. The manufacturer provided confirmation as to the correct orientation of the latter only after reference to production drawings.

The British Civil Airworthiness Requirements (BCARs) Section G4-8, 'Control System Design', paragraph 1.13 states the following: 'Control systems shall be designed so as to minimise the risk of incorrect assembly'. The subject of incorrect assembly is specifically dealt with in Appendix 2 to G4-8. Paragraph 2.3 of the Appendix states that: 'All other controls........should be so designed and constructed as to be mechanically difficult to misconnect or so that misconnection is obvious from the appearance of the system.'

Metallurgical examination of the swashplate bolt

The scissors attachment bolt had failed at the point where it emerged from the swashplate. This left the bolt tail, complete with the nut, cup washer and thin washer, being retained in the spherical bearing. The bolt shank was a sliding fit within the bearing but was prevented from falling out by the shear lip on the edge of the fracture.

It was found that the bolt had failed in fatigue across most of its section, with the final 15% or so failing in overload; see the photograph of the fracture face at Figure 5a. The fatigue initiation area was centred on the 12 o'clock position on the fracture face and was the result of a simple bending mechanism. This was entirely consistent with the loads that would have arisen as a result of installing the lower scissors link in the incorrect orientation. The loads would have been a combination of the spherical bearing running out of travel and the contact between the cup washer and the face of the link; refer once again to Figure 2b. Fretting damage on the link due to contact by the cup washer (which had become distorted as a result), was clearly visible.

The fracture face in Figure 5a shows what appear to be two distinct areas of fatigue. Initial examination suggested that the fatigue process was of a comparatively slow, ie high cycle mechanism over the dark region, changing to low cycle mechanism over the brighter area. However, examination in a scanning electron microscope (SEM) revealed that the fracture surface changed only gradually along the crack length, with no sudden change marking the line between the dark and lighter regions. This suggested that the loading conditions had not changed between the two regions. The observed gradual change would be expected as the stress intensity at the crack tip increased with increasing crack depth. The ductile overload region is shown at the bottom of the photograph.

The sharp colour change on the fracture surface was difficult to explain, but may have been due to staining from grease which seeped into the crack whilst the helicopter was parked overnight at White Waltham. There would have been insufficient time for similar staining in the new crack growth that occurred during the short flight on the day of the accident.

After referring to the Maintenance Manual diagram shown in Figure 4, it was noted that the bevelled washer located between the cup washer and the lower link was missing. In its place was the thin washer noted earlier, that ought to have been installed between the swashplate and the link. A fretting mark on the shank of the bolt inboard of the link was found to be the same width as the bevelled washer (see the photograph at Figure 5b), suggesting that the latter had been installed at this location for a period of time, probably since the helicopter was built. A narrower mark adjacent to it could have been made by the thin washer. This being the case, the thin washer was probably installed underneath the cup washer during the maintenance carried out on the day prior to the accident.

Assuming the bevelled washer had indeed been installed on the inboard side of the link, it would have been lost when the bolt failed in flight. The washer was 4 mm thick; thus the lower link would have been displaced outboard on the bolt by this amount. In addition, the clearance between the underside of the cup washer and the outboard face of the link would have been decreased. Prior to the maintenance of 16 June, the link had been in its correct orientation, although the fretting mark suggested that the bevelled washer had been inboard of the link, as noted above. Examination of the link outer face revealed evidence of a light contact from the rim of the cup washer, which would have imparted a bending load to the bolt. This would have occurred at high collective and/or cyclic pitch settings due to a combination of the reduced clearance noted earlier and the slightly altered geometry.

The fretting marks on the bolt shank suggested that relative movement between the components might have occurred. It was subsequently found that the retaining nut was thread-bound, ie it had been tightened to the end of the bolt's threaded portion. The specified assembly torque in the Maintenance Manual was 8 to 10.2 Nm (5.9 to 7.5 lb ft). However it appeared that some of this had been expended in tightening the nut

against the thread run-out, leaving the component stack-up essentially loose.

Comparison with accident to A109E Power, G-JRSL

This AAIB Bulletin also contains the report on the above accident, which occurred at dusk on 14 January 2000, at Romney Marsh in Kent. The helicopter went nearly out of control following a bang and loss of electrical power. Although flying faster than G-TVAA, the three occupants experienced a sudden sinking sensation and the pilot found the control responses to be abnormal. It is possible that the left seat pilot's head contacted the 'gang bar' thereby switching 'OFF' the battery and generators. The helicopter rolled over on landing, the rotor head components suffering disruption and dislocation in the process.

The same company operated G-TVAA and G-JRSL and the wreckage from the latter helicopter was re-examined after the second accident. It became apparent that the rotating scissors lower link had been installed back to front in an identical manner to that of G-TVAA. Moreover, the technical records indicated that the linkage had been removed and replaced, as part of a combined Annual/100 hour inspection approximately 45 minutes flying time prior to the accident. The swashplate bolt had also failed, although a visual examination found that the fracture face differed from that of the bolt from G-TVAA in that it was inclined at about 45° to the bolt axis, initially suggesting that failure could have resulted from an overload condition as it rolled over following the landing.

The relevant components were removed from G-JRSL and were subjected to a metallurgical examination in parallel with those from G-TVAA. The bolt fracture face was found to have two areas of high cycle fatigue centred on the approximate 12 o'clock and 6 o'clock positions. This was consistent with a reverse bending mechanism, although it was not clear how this could have arisen. As with the lower link from G-TVAA, there was evidence of considerable contact between the underside of the cup washer and the outer face of the link, this giving rise to the *single* bending mechanism that occurred on G-TVAA, with its fatigue initiation at the 12 o'clock position. Whilst a jammed or stiff spherical bearing in the link could have generated reverse bending in the bolt, it was apparent from examination that the bearing operated freely. There was some evidence of an increase in the progression rate of the crack (ie lower cycle) before overload separation took place.

As with the G-TVAA assembly, the bevelled washer was not in its correct location underneath the cup washer. A band of scoring/fretting on the bolt shank suggested that it had been positioned inboard of the link. A faint impression of the rim of the cup washer was found on the side of the link that faced outboard when correctly installed; this was similar to that found on G-TVAA. The retaining nut was found to be thread-bound in the same manner as that from G-TVAA, leading to a slightly loose assembly.

Action by the manufacturer

On 19 June, ie two days after the accident to G-TVAA, the manufacturer issued Information Letter No 109-2000-005, informing operators of the accident, and calling for a precautionary inspection for correct installation of the rotating scissors lower link '...in accordance with Figure 63-34 of the A109E Maintenance Manual'. . The UK CAA drew the attention of the manufacturer to the fact that the Manual does not help to identify the proper installation of this part 'very well'. This resulted in an additional Information Letter, No 109-2000-006, which included a diagram detailing the correct installation of the components.

Examination of intact helicopters

Shortly after the circumstances of the accident to G-TVAA became public, and operators were inspecting their helicopters as per the above Information Letters, it became apparent that three UKbased helicopters had the incorrect stack-up of components assembled onto the swashplate bolts. Although the lower links were correctly orientated, the bevelled washers had been installed inboard of the links. Since no maintenance that required disassembly of the scissors linkage had occurred since any of the helicopters were delivered, it was concluded that all of them had left the factory in this configuration. The same was probably true for G-TVAA and G-JRSL, meaning that five out of eight A109E Power helicopters in the UK were incorrectly assembled. However, the manufacturer has stated that, in a global survey, no other helicopters had been found in a similar condition.

One of the intact helicopters concerned was examined by the AAIB. There was evidence of a light contact between the outer face of the lower scissors link and the cup washer; similar to those found on G-JRSL and G-TVAA. In addition, there were faint marks on the inside face of the lower link where it had apparently contacted the lip of the swashplate above the bolt. This could have occurred at low collective/cyclic pitch settings as a result of the changed geometry caused by the wrongly sited bevelled washer.

It was found that, unlike the two accident helicopters, the scissors link retaining nut was not thread-bound, although there was only one half turn left before this occurred.

Due to the possibility of the swashplate bolt having been subjected to bending loads, the operator of this helicopter decided to replace it. Bolt removal can be achieved only after removing the rotor head and swashplate assembly, and pressing out the swashplate bearing. The head of the bolt is recessed in a machined slot on the inside of the swashplate, the width of the slot being the same as the across-flat dimension of the hexagonal bolt head. This prevents rotation of the bolt, which, during helicopter build, is inserted with the split pin hole orientated vertically.

The bolt was a NAS 1306-28D, in common with the other bolts examined during this investigation (although the Illustrated Parts Catalogue also lists a NAS 6606-D28), and had achieved 317 flying hours since new. This component is not subjected to a finite life. Subsequent magnetic particle inspection did not reveal any cracks. It was noted however, that a bead of sealant under the head of the bolt had not been flattened to the same extent as had occurred with the bolt from G-JRSL. This implied that the bolt had not bedded down to the same degree, although there was a mark under the bolt head where it had contacted the edge of the hole at the base of the slot. The bolt is an interference fit in the hole in the swashplate; thus tightening the retaining nut would tend to be opposed by the friction between the bolt and the bore of the hole. A high assembly torque would thus tend to draw the bolt head further into the hole during service. It was stated by one of the engineers who worked on the helicopter that it was sometimes difficult to achieve the specified assembly torque on the nut. This was because tightening the nut to the specified value would not necessarily result in one of the nut castellations lining up with the split pin hole. Further tightening to the next castellation would then result in a high assembly torque.

Additional information

The Spanish Accident Commission provided details of a fatal accident to Agusta 109E Power, registration EC-GQX, in Spain, which occurred on 26 July 1999. The accident occurred within two flying hours of the helicopter having undergone maintenance that involved removal and replacement of the rotating scissors linkage. It had achieved approximately 300 flying hours in total. Witnesses saw the helicopter perform a violent turn before flying into the ground in a banked attitude and with considerable lateral velocity component. It then rolled over and broke up, killing the pilot, the sole occupant. In the light of information gleaned from investigation of the accident to G-TVAA it was found that the lower scissors link on EC-GQX had been installed the wrong way round. The swashplate bolt had failed, and whilst this initially had been assumed to have occurred as a consequence of the accident, it was later found to have suffered a fatigue failure, similar to that of G-TVAA. Although the fracture had initiated at the 12 o'clock position (the same as for G-TVAA), the fracture face was inclined at an angle of approximately 30° to the bolt when viewed from above. The reason for this was not fully understood, although it was considered that the swashplate driving loads may have had an effect.

As found, there was no bevelled washer between the cup washer and the lower scissors link; however it was not clear if this condition had existed prior to the maintenance activity. An additional similarity to the G-TVAA and G-JRSL accidents was noted in that the nut was close to being thread-bound. After removing the split pin it was possible to rotate the nut approximately half a turn.

The damage to the pitch links indicated extreme deflection in the forward direction. The investigators considered that this damage had occurred whilst airborne, and was consistent with an application of high collective pitch.

Discussion

The common feature in the accidents to G-TVAA, G-JRSL and EC-GQX was that, a short time beforehand, the lower scissors link had been installed in the incorrect orientation. The combined effect of the spherical bearing within the link running out of travel plus contact between the cup washer and the link was to impart a bending load to the swashplate attachment bolt. This resulted in a fatigue crack developing in the bolts of all helicopters and led to the in-flight failure of the bolt in the case of G-TVAA and EC-GQX. The same probably happened to G-JRSL but could not be established beyond doubt; the fatigue cracking was different in nature to that of the bolt from G-TVAA in that it resulted from a reverse bending mechanism, the derivation of which was not determined.

The fact that it was possible to install the lower scissors link incorrectly meant that the design did not comply with BCAR Section G4-8.

Additionally, three intact helicopters were found to have the bevelled washer incorrectly positioned inboard of the link. Since no maintenance had taken reportedly taken place that required disassembly of these components, it was concluded that the helicopters had been manufactured in this configuration. It was found that the change in linkage geometry that resulted from the bevelled washer being positioned inboard of the link caused the upper part of the cup washer rim to be in close proximity to the link outer face. There was physical evidence, which indicated that even when the link was installed in its correct orientation, contact occurred, at high pitch settings, between the cup washer and link. Contact forces would have been light however, and thus probably had little bearing on the accidents investigated here other than perhaps using up the fatigue initiation period.

The link retaining nuts on all the helicopters examined during the investigation were found to be in or close to a thread-bound condition on their respective swashplate bolts. It was thus concluded that an insufficient margin of thread was provided for the installation. It is possible that any tendency for thread binding could result from an adverse accumulation of tolerances within the stack-up of components. Additionally, there could be varying degrees of bedding down of the bolt head within counter-bore on the inner face of the swashplate. It was reported that difficulty was generally encountered in lining up one of the nut castellations with the split pin hole in the bolt, whilst at the same time meeting the Maintenance Manual torque requirement. A high assembly torque could thus result in a progressive bedding down of the bolt head in service, with an associated reduction in clamping force between the components. There would then be an increased possibility of the nut reaching the end of the threads on a subsequent reassembly of the components. A loose component stack-up for any reason in an installation such as this would be undesirable, as it could generate bending loads, as opposed to pure shear loads, with an attendant possibility of a fatigue crack developing.

Safety recommendations

The accidents to G-TVAA, G-JRSL and EC-GQX demonstrated how a failure in the flying controls, much of which is single load-path, can endanger the safety of a helicopter. The investigation concluded that the accidents resulted from a simple, but potentially fatal, incorrect installation of the scissors link. In addition, it subsequently became apparent that a number of helicopters had been manufactured with the incorrect sequence of components assembled onto the swashplate bolt, which would suggest a manufacturing quality problem.

Accordingly, the following Safety Recommendations were addressed to the helicopter manufacturers and the Italian Airworthiness Authorities on 14 July 2000:

Recommendation 2000-40

The Ente Nationazale per L'Aviazione Civile (ENAC) should issue an Emergency Airworthiness Directive to operators of Agusta 109E Power helicopters to inspect the swashplate scissors linkage for correct sequence of assembly of the lower link and associated washers onto the swashplate bolt. In the event of an incorrect configuration being found, the swashplate bolt should be replaced at the earliest opportunity.

Recommendation 2000-41

Agusta S.p.A should urgently consider modifying the attachment of the lower scissors link to the swashplate bolt, with the aim of increasing the margin of available thread, and so reduce the possibility of the retaining nut becoming thread-bound, with a resultant failure to achieve the specified assembly torque.

Recommendation 2000-42

Agusta S.p.A should amend the Aircraft Maintenance Manual to emphasize the crucial nature of correct orientation of the lower link when assembling it onto the swashplate bolt. The amendment should additionally include material that provides unambiguous information as to the correct orientation of the link. In the longer term the design should be modified such that incorrect assembly of the link is impossible.

These recommendations have been accepted, and have led to the issue of Technical Bulletin No 109EP-12. Recommendation 2000-41 has been addressed by adding a thin washer between the cup washer and the bevelled washer, thus preventing the nut from reaching the end of the threaded portion of the bolt.

Recommendation 2000-42 has been met with a temporary revision to the Maintenance Manual.