AIRCRAFT ACCIDENT REPORT 4/96

Air Accidents Investigation Branch

Department of Transport

Report on the accident to AS 350B Squirrel, G-PLMA Near Lochgilphead, Argyll, Scotland on 5 May 1995

This investigation was carried out in accordance with
The Civil Aviation (Investigation of Air Accidents) Regulations 1989

London: HMSO

This report contains facts which have been determined up to the time of publication. This information is published to inform the aviation industry and the public of the general circumstances of accidents and serious incidnets.

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Department of Transport
Air Accidents Investigation Branch
Defence Research Agency
Farnborough
Hampshire GU14 6TD

1 August 1996

The Right Honourable Sir George Young
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr MM Charles, an Inspector of Air Accidents, on the circumstances of the accident to an AS 350B Squirrel, G-PLMA, near Lochgilphead, Argyll, Scotland on 5 May 1995.

I have the honour to be
Sir
Your obedient servant

K P R Smart
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch
AAR	Air Accident Reports
ANO	Air Navigation Order
ARB	Airworthiness Requirement Board
ATC	Air Traffic Control
BCAR	British Civil Airworthiness Requirements
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CG	Centre of Gravity
cm	centimetres
CVR	Cockpit Voice Recorder
DGAC	Direction Generale de L'Aviation
FAA	Federal Aviation Administration (USA)
FAR	Federal Aviation Requirements
FDR	Flight Data Recorder
FTL	Flight Time Limitaion
g	gram(s)
GRP	Glassfibre Reinforced Plastic
hrs	Time (24 hour clock)
kg(s)	kilogram(s)
km	kilometres
kN	kilonewtons
kt(s)	knot(s)
mm	millimetres
MOR	Mandatory Occurrence Report
NAS	National Aircraft Standards
nm	nautical mile
PN	Part Number
rpm	Revolutions Per Minute
SB	Service Bulletin
RTF	Radiotelephony
TSO	Technical Standing Order
UTC	Universal Time Co-ordinated
V_{NE}	Never-exceed Speed

Air Accidents Investigation Branch

Aircraft Accident Report No: 4/96 (EW/C95/5/2)

Registered Owner	PLM Helicopters Ltd
Operator	PLM Helicopters Ltd
Aircraft Type	AS 350B Squirrel (Ecureuil)
Nationality	British
Registration	G-PLMA
Place of Accident	Near Lochgilphead, Argyll, Scotland Latitude: 56° 01' N Longitude: 005° 25' W
Date and Time	5 May 1995 at 2015 hrs All times in this report are Local (UTC + 1 hour)

Synopsis

The accident was notified to the Air Accidents Investigation Branch (AAIB) at 2100 hrs on 5 May 1995 and an investigation began the same day. The investigation was conducted by Mr M M Charles (Investigator-in-Charge), Mr J J Barnett (Operations), Mr R W Shimmons (Operations) and Mr A N Cable (Engineering).

The accident occurred when the helicopter was involved in the aerial transfer of farmed salmon in Scotland. The pilot was transiting at low-level over a sea loch with a sling and hook underslung below the helicopter. It was concluded that the end of the sling probably contacted the surface of the loch and rebounded into the tail rotor causing separation of the tip of one tail rotor blade. The severe out of balance forces on the tail rotor then caused the separation of the tail rotor gearbox from the tail boom. The helicopter was seen to crash on the shore of the loch. The pilot was killed and the aircraft was destroyed.

The investigation identified the following causal factors:

(i) The commander unwisely decided to low-fly over Loch Fyne with a sling attached to the belly of the helicopter.

(ii) The commander's judgement of height may have been adversely affected by the calm sea and weather conditions.

(iii) The commander may have been suffering from a degree of fatigue because he had worked in excess of the permitted duty and flying hours.

(iv) The inaccurate estimation of the task resulted in increased pressure on the commander to complete the work.

Eleven safety recommendations were made during the course of the investigation.

1 Factual Information

1.1 History of Flight

1.1.1 Background

The helicopter operator specialises in underslung load work. In the Spring of each year the company undertakes the aerial transfer of farmed smolts (small salmon reared in fresh water) to sea water 'cages' where they grow to maturity. The fish farmers estimate the number of transfers required and the operator's management then determine the flying programme and assets required to accomplish the task. Often, to minimise flying time, fish are transported in tanks on board a lorry to a suitable helicopter landing site near the sea cage.

The smolts are transported by air in purpose-designed 'buckets' which, when immersed in the sea water, automatically discharge their contents. The helicopter then returns to the loading site with the empty bucket still attached to its sling. The type of bucket in use at the time was comparable in size and shape to a large oil drum and, when loaded, had a nominal weight of 500 kg. It takes several minutes to load the bucket with water and fish; consequently more than one bucket is used at each site to enable quick turn arounds to be made. When transferring fish the helicopter is occupied by the pilot alone but the operation requires support from ground staff who assist in refuelling the helicopter, filling the buckets and attaching them to the sling. Typically on any one day, the helicopter together with its pilot and ground support staff from the operator (the crew) will operate from more than one loading site and at each site it will carry out multiple bucket transfers. When a task at one loading site is almost complete, the helicopter sometimes takes an empty bucket onward from the sea cage to the next loading site and leaves it there before returning to complete the task at the original loading site. When a task is complete, the helicopter usually leaves the last empty bucket at the next loading site and returns to collect the ground crew.

On 3 May, two days before the accident, the commander had a rest day. On the day before the accident he was programmed to start at 0430 hrs for a departure at 0500 hrs from his employer's main base at Inverness. The company's operations manager expected him to finish work at about 1530 hrs and to spend the night at Dallalea, which is about 55nm north of Jura. However, he started work late at 0555 hrs and so was not expected to finish work until 1700 hrs. In fact, that day he completed multiple fish transfers during 7 hours and 50 minutes of flying and finished the tasks at Dallalea at 1730 hrs. He then decided to spend the night on the Island of Mull (a 12 minute flight and nearer the next task than Dallalea) where he finished duty at 1815 hrs. At about 1900 hrs he spoke to the company operations manager by telephone regarding the work schedule; he did not mention that he had exceeded his duty and flying hours limits for the day. After eating a meal in a hotel, the commander and the ground handler spent the night in a guest house. They went to bed at about 2200 hrs.

1.1.2 The day of the accident

On 5 May, the day of the accident, the operations officer had planned for the commander to start duty at 0530 hrs and take-off at 0600 hrs. He was then expected to fly until 1100 hrs when he would be relieved by another pilot until 1630 hours. At that time he would resume flying and complete the final task which was expected to take one hour.

The commander and the ground handler rose early and ate breakfast at about 0445 hrs. At 0535 hrs they took-off to fly to Jura where they landed at 0610 hrs. After disembarking the ground handler, the pilot flew to Ormsary on the mainland (see Appendix A) to collect four fish workers. Subsequently, between 0750 hrs and 1100 hrs in the vicinity of Jura, the commander carried out his flying tasks involving the transport of fish. On completion, he transported the fish workers back to Ormsary and then came back to collect his ground handler. At about this time the commander received a facsimile message confirming the allocation of work for the rest of the day. The two men then flew to Tayinloan where they arrived at 1200 hrs. The commander handed over to the relief pilot and, with the latter's agreement, the commander took the relief pilot's car to drive 32 miles to Lochgilphead to buy food. From there he drove 10 miles to Loch Glashen (see Appendix A) to await the arrival of G-PLMA.

The commander arrived at about 1400 hrs and after eating a sandwich, he walked the relief pilot's dog and sat down in a shed. While he was awaiting the arrival of G-PLMA, the commander spoke with another company ground handler who had driven from Glasgow with fuel supplies; the ground handler later stated that the commander was in good form and didn't appear tired. Just before the aircraft arrived one of the ground handlers contacted the company to ask where the helicopter was. He was informed that the plan was behind schedule. After carrying out multiple fish transfers during the afternoon the relief pilot arrived at Loch Glashen at 1630 hrs. As the two ground handlers were then preparing the refuelling equipment, the pilots discussed the programme for the rest of the day. There were two more tasks to be completed which were expected to take approximately two hours and one hour respectively. The company plan was for the relief pilot to do the first; however the pilots agreed between themselves that both tasks would be done by the commander.

1.1.3 The accident flight

The penultimate task was to transfer fish from Loch Glashen to some sea cages off the western shore of Loch Fyne near Tarbert (see Appendix A). Before the first transfer, G-PLMA was refuelled to 45% fuel; the commander then picked up a loaded bucket and flew to the sea cages near Tarbert where he discharged the fish. Bringing back the empty bucket, he left this bucket at the fish containers and flew to the refuelling area to replenish again to 45%. This was the procedure for each run and each took between 25 and 40 minutes. The task was expected to take four lifts but seven were required to complete it which resulted in the task taking about one and half hours longer than planned. The commander started this task at approximately 1645 hrs and completed the first six lifts uneventfully. Part way through this task, at about 1900 hrs, the commander telephoned one of the company managers to say that he had not started the final task and that he would be spending the night in the local area.

On the sixth lift, after unloading the fish at Tarbert, the commander flew to Meall Mhor where the empty bucket was released from the sling by a farm worker. He was seen to fly off with the unloaded sling hanging below the helicopter and to arrive at Loch Glashen with the sling still attached. For the seventh lift, the commander left Loch Glashen at 1955 hrs and was instructed by radio to unload the fish at Portavadie (see Appendix A); this was done and he then flew to Meall Mhor to drop his second empty bucket. However, on this occasion he landed on the lawn in front of the house and, without shutting down the engine, got out of the helicopter to talk to a group of people who were waiting with a lorry load of fish for transfer. Whilst he did so, a bystander took photographs of the helicopter. The bystander had worked on offshore oil rigs for 18 years and was familiar with helicopters; he noticed a strange noise coming from the helicopter which he likened to a knife being sharpened on a grindstone.

The commander informed the fish workers that he would return in five minutes and flew off with the unloaded and unrestrained sling below the helicopter to fetch his ground crewman. The assembled group watched the helicopter depart and soon after crossing the shore line it turned to the east and then to the north to continue up Loch Fyne.

Witnesses in cars driving along the A83 road which runs alongside the western shores of Loch Fyne and Loch Gilp saw the helicopter as it made its way northwards over the water. The first witness was driving with her young sons from her home near Tarbert along the main road towards Lochgilphead. As they drove northwards past Meall Mhor, they saw the helicopter coast in over the road with a bucket underslung and it came to the hover near a lorry. About five minutes later, in the vicinity of Stronachullin (see Appendix A), she saw the helicopter once more. It was over the Loch but without the bucket. She noticed that the helicopter was flying at a low height and thought it had something else attached to the sling. She likened the helicopter's height to other helicopters she had seen a year or so before when they were filling containers with sea water to fight fires on the hills. The second witness was also near Stronachullin when she saw the helicopter as she was being driven southwards. She also reported that it was flying quite low, probably just above tree level but over the Loch with what she took to be a rope hanging below it. She thought the rope was about 20 to 30 metres long and had a loop at its lower end which was about 10 metres above the water. As her car and the helicopter passed, the helicopter appeared to turn away from the road and set off across the sea towards the land on the other side of the Loch.

A few minutes later, as the first witness reached the southern end of Ardrishaig (see Appendix A), her sons reported that the helicopter was spinning. She stopped the car and saw the helicopter obviously out of control near the rubbish dump on the opposite shore of Loch Gilp. The helicopter was yawing rapidly to the left and right without completing a revolution, and at the same time rolling and pitching. These multiple motions took place in two to three seconds and within a small volume of airspace. Next she saw a long black object fly off the helicopter and it then spun around through at least two complete revolutions without losing height. When the spinning stopped, the helicopter dropped nose first to the ground.

Many other witnesses were aware of the last moments of the helicopter's flight. Several in Ardrishaig reported that it was flying particularly low over Loch Gilp near the eastern shore line and that it entered a steep climb as it approached the coastline near Castleton (see Appendix A). One witness stated that he normally took little notice of passing helicopters because they were a common sight but his attention was drawn to this helicopter by its unusually low height. It was not going very fast and did not appear to be in trouble until it got near the rubbish dump. He saw it climb and then it appeared to go out of control in extreme attitudes. Seconds later he saw what he took to be the tail rotor detach before the helicopter descended to the ground in a nose-down attitude.

Other witnesses in the vicinity of the crash site also saw the helicopter flying low over the sea near the coastline and then low over the land near the crash site. It crossed the coast near the crash site but flew inland beyond it before commencing a left turn, crossing briefly to the north of the A83 road near Castleton, before returning to the shoreline where it crashed. Witnesses reported that the engine noise was normal until a few seconds before the crash when the whining noise faded and was replaced by a beating sound; several also saw black smoke issuing from the helicopter at about this time. Significantly, no one in Ardrishaig or

Castleton saw anything hanging from G-PLMA during its final stages of flight and two witnesses reported that a door appeared to be open. One of these witnesses who was very close to the helicopter's final flight path stated that she could see papers coming out of an open door.

The helicopter crashed a few metres inland of the shore to the south of Castleton. The crash position was close to the direct route between Meall Mhor and Loch Glashen and close to open fields.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	1	-	-
Serious	-	-	-
Minor / None	-	-	-

1.3 Damage to aircraft

The aircraft was destroyed.

1.4 Other damage

None.

1.5 Personnel information

1.5.1	Commander:	Male, aged 52 years
	Licence:	Airline Transport Pilot's Licence (Helicopters and Gyroplanes)
	Type Ratings:	AS355F Squirrel 2 AS350B Squirrel AS332L Super Puma Bell 206 JetRanger Hiller UH12 Hughes 269 Bolkow 105 Robinson R22
	Instrument rating:	None
	Base check	2 March 1995

Line check	2 March 1995
Underslung load check	3 April 1995
Medical	Unconditional Class One renewed on 16 March 1995 .

Flying experience:

Total all types	7,682 hours
Total on type	98 hours*
Last 90 days	98 hours
Last 28 days	83 hours

*The commander had also acquired significant experience in the AS355 Twin Squirrel between March 1989 and September 1994.

1.5.2 Duty time

The commander began a planned three day period of duty on 4 May. On that day, the day before the accident, he commenced duty at 0555 hrs and ceased duty at 1815 hrs after a duty period of 12 hours 20 minutes which included 7 hours 28 minutes flying. His subsequent rest period was 10 hours 40 minutes. He came on duty on 5 May at 0505 hrs and he flew for 4 hours 04 minutes during a period of 7 hours 10 minutes duty which finished at 1215 hrs. He was then free to rest until 1615 hrs when he started the second part of a planned 'split duty'. Thereafter, he completed another period of 4 hours duty up to the time of the accident which included 3 hours 30 minutes flying.

1.5.3 Commander's background

The commander had been a helicopter pilot in military service. His flying logbook showed that since 1982 he had spent five years of alternate crop spraying in the summer and electricity line patrol in the winter. In 1987 his work pattern altered to one of passenger transport until 1990 when he became a police aviation support pilot. In October 1993 he returned to passenger transport flying and remained active in this role until January 1995. In his application to PLM helicopters for the temporary contract, the commander had included amongst his qualifications, 400 hours experience of underslung load operations.

The commander first flew with PLM on 16 February 1995 when he underwent a handling check. He flew again in March to complete the training and commenced productive employment on 1 April 1995 on a two month contract, mainly to transport smolts within Scotland. His training records provided by the company revealed that his technical and procedural knowledge was excellent and that he had been assessed as competent to carry out external load operations.

1.6 Aircraft information

1.6.1 General

The AS350B Ecureuil was a conventional helicopter with a three-bladed main rotor rotating clockwise as viewed from above. Directional control was effected by a two-bladed tail rotor situated on the right side of the tail boom. The cabin housed two forward seats and a three-place bench seat. The instrument and avionics equipment provided for the crew was typical of a helicopter of this size but did not include a radio altimeter. Appendix B, Figure B-1 shows the general arrangement together with the positions of the various cabin and baggage bay doors. Details of the cabin floor structure and tail rotor gearbox mounts are shown at Figures B-3 and B-4.

1.6.2 Weight and centre of gravity

Maximum authorised weight	2,100 kg (when carrying an external load)

Before the tail rotor damage was incurred, the helicopter's weight and balance details were as follows:

Weight	1,444 kg
CG Position	3.40 metres aft of datum
CG Limits	3.17 metres to 3.52 metres aft of datum

The estimated weight and CG position of the helicopter after the tail and tail rotor gear box separated in flight were:

Weight	1,404 kg
CG position	3.21 metres aft of datum

1.6.3 External load carriage

The aircraft flight manual was entitled AS350B. It contained two supplements regarding the external load carrying installation and the additional flight limitations. Two load release mechanisms were installed: an electrical mechanism fitted to the underbelly hook operated by a switch for normal release, and a mechanical lever mounted underneath the collective control grip for emergency jettison. Operation of either mechanism should release the load and the sling. An external rear view mirror was fitted in a position which enabled the pilot to see beneath the aircraft to assist him with underslung load tasks. Attached to this mirror was a smaller convex mirror in which a sling would have been visible at all times.

The flight limitations were an increase in maximum weight of 150 kg to 2,100 kg and an absolute maximum airspeed of 80 kt with 'a load on the hook'.

The underslung load sling seen being carried by G-PLMA on its departure for the last flight was approximately 6 metres long. It comprised a steel hook and a 5 kg steel ball weight carried on a 13 mm diameter steel cable, 4.6 metres long, which was attached via a swivel assembly to a 0.85 metres long woven nylon springer rope (Appendix B, Figure B-2); the latter being shackled to the underbelly cargo hook. The hook and the ball weight were painted orange. The sling, while attached to the cargo hook, was long enough for the hook to enter the tail rotor disc when swung to the rear.

1.6.4 Certification

Initial application for certification of the helicopter type was made by the manufacturer to the French Direction Generale de L'Aviation Civile (DGAC) on 17 June 1974. DGAC certification of the original version, the AS350C, was granted on 2 September 1977. This was extended to the AS350B on 27 October 1977. Certification was based on USA Federal Aviation Requirements (FAR) 27.1-27.10 (ie FAR 27, Amendments 1-10), together with DGAC complementary and special conditions.

British type certification in the Transport Category was granted by the UK Civil Aviation Authority (CAA) in May 1978, on the basis of the DGAC certification together with CAA UK Additional Requirements (Ref 9/31/RY2201). For this certification, the CAA considered the British Civil Airworthiness Requirement (BCAR) issue applicable at the date of the initial application for French type certification to be relevant, in accordance with their normal practice.

Air Registration Board Notice No 15, 'United Kingdom Certification of Foreign Aircraft of Weights not Exceeding 12,500 lb', Issue 2 of 1 April 1971, notes in effect that aircraft of foreign design and construction presented for UK certification would be investigated to establish an equivalent standard of airworthiness to that provided by UK airworthiness standards. The Notice was current at the time of AS350 UK certification and at the time of the original application for DGAC certification. The CAA has reported that this notice was not relevant as it was intended to apply to fixed-wing piston engined aircraft only.

1.6.5 Pilots' seats

The pilot occupied the right hand of two forward seats, Aerospatiale Part Number (PN) 360A76 11721 01. Each consisted of a glassfibre reinforced plastic (GRP) moulding, with an integral high back (73 cm, measured from the seat pan), fitted with cushions and a removable plastic material cover. Two channel section steel seat rails were bolted to the base for attachment to the floor (Appendix B, Figure B-5). Each seat was retained vertically and laterally by four turnbuckles screwed into the captive nuts in the cabin floor and located in longitudinal slots in the seat rails. The two slots in the 5 mm thick lower flange of each seat rail were 130 mm long and 10 mm wide; the turnbuckle heads were 9x16 mm wide. The turnbuckles were prevented from rotating to their release position by a locking pin which passed through a hole and a groove in the head of each turnbuckle and bore against the seat rail vertical web. Features of the seat included an oval cut-out in the forward web of the base, to provide access to the seat rail bolts, and a substantial single vertical corrugation in the left side of the base to accommodate the plunger mechanism for fore and aft seat retention. A plastic fitting attached to the top of the seat back provided two fairleads for the harness shoulder straps.

1.6.6 Pilot's harness

The pilot's harness (Appendix B, Figure B-6) consisted of two lap straps, each shackled to a floor fitting adjacent to the side of the rear of the seat, and two shoulder straps which passed through the seatback fairleads and were anchored by an inertial reel bolted to the seat back (Appendix B, Figure B-5). At their forward ends the four straps each terminated in a steel tongue fitting retained in a quick release box when the harness was fastened. The straps were of 2 inch wide 8-bar webbing. Each lap strap consisted of two parts, a long strap which connected the tongue to a length adjustment fitting and a short strap which connected the latter to a triangular steel shackle. The connection of the short strap to the fitting at either end was by means of a stitched loop in the webbing, formed by a single turnback of material retained by 6 rows of lateral stitching, which provided a stitched overlap over an approximately 0.9 inch length of belt. With the lap strap fastened around a seat occupant, the angle between the cabin floor and the projected line of each side of the lap strap at the respective floor attachment, measured in a vertical plane parallel to the helicopter longitudinal axis, was approximately 55° with the seat at the forward end of its adjustment and 60° with it at the aft end.

The remains of data plate labels stitched to the straps indicated that the webbing of both lap straps had been replaced by a CAA authorised repairer, in the case of the right strap in 1980. The time at which the left straps had been repaired was unknown as the label had been worn away but the condition of the left harness appeared to be similar to that of the right harness. Inquiries indicated that the repairer ceased operations in 1995. The pattern and spacing of the stitching on the replaced straps appeared to reproduce closely that on similar original manufactured straps of the same type. The aircraft maintenance schedule required visual inspection of the harnesses at intervals to assess their continued airworthiness.

1.6.7 Pilot's helmet and headset

The pilot wore a helmet, retained by a velcro fastened chinstrap, with a compatible headset attached inside by means of a fastening kit. The electrical lead for the headset terminated in a standard single plug which located in a socket mounted rigidly on the side of the collective lever quadrant, just above cabin floor level. The socket faced forwards, ie parallel to the aircraft centreline in plan view, but angled upwards at approximately 35° relative to the floor.

1.7 Meteorological information

Witnesses in the vicinity of the accident site stated that it was a very clear evening with no cloud and no wind. The police helicopter pilot who attended the scene arrived there less than an hour after the accident. He stated that the weather was very good with visibility in excess of 200 km; there was little or no cloud cover and a light westerly wind.

1.8 Aids to navigation

Not applicable.

1.9 Communications

There was no record of any RTF messages between the helicopter and a ground agency. Moreover, at its normal operating altitude, the helicopter would have been below the coverage of ATC radars and beyond the reception range of receivers at the nearest major airfield which was Glasgow airport.

1.10 Aerodrome and approved facilities

Not applicable.

1.11 Flight recorders

There was no requirement to carry a Flight Data Recorder (FDR) or a Cockpit Voice Recorder (CVR) and neither was fitted.

1.12 Aircraft Examination

1.12.1 Crash site

The helicopter crashed on the eastern shore of Loch Gilp, 2 nm south of Lochgilphead. The ground in the area of the crash site sloped gently upwards from the shoreline, towards the east, generally smoothly but locally somewhat uneven and rocky in parts.

Crash site and wreckage examination indicated that the helicopter impacted the ground while rolled right, pitched nose down and yawing to the left, on an easterly heading, with a moderately high descent rate and little forward speed. Initial ground contact was onto a rocky area, causing detachment of the right landing gear skid. The aircraft then rolled right, contacting the ground with the main rotor blades and the right horizontal stabiliser, before inverting. It came to rest on its left side 7 metres from the initial ground impact point.

Portions of the helicopter were not located with the main wreckage, indicating that they had detached before the main part of the aircraft had struck the ground (Appendix B, Figure B-7). The tail rotor gearbox cover, the aft 1.5 metres of the tailboom with the vertical fins attached, electrical cables from within the tailboom, the tail rotor long drive shaft and the window from the cabin right door were found 55 to 85 metres from the initial impact point on the beach of the loch to the west of the main crash site, between high and low tide levels. The tail rotor gearbox with tail rotor attached was found embedded in the ground 35 metres to the north of the initial impact point. Parts from the tip portion of one tail rotor blade were absent. The underslung load sling, part of the small tailcone fairing from the aft end of the tailboom and the detached parts of tail rotor blade were not recovered, in spite of extensive searching of the shoreline and the shallow water in the area.

1.12.2 General aircraft damage

The helicopter sustained moderately severe damage on ground impact, including detachment of most of the above-floor skin panels from the cabin, partial separation of the remains of the tailboom from the fuselage rear structure and gross damage to the main rotor head.

1.12.3 Tailboom

Examination showed that the tailboom fracture approximately 1.5 metres from its aft end had resulted from combined rearwards tension and lateral bending, aft end to the left. Markings and damage showed that both upper and lower fins had been struck by a tail rotor blade, forcibly in the case of the lower fin. A number of damage features around the tail rotor gearbox location showed that the gearbox had been in violent motion in the region for a period. The signs included the characteristics of the damage to the gearbox mount components (para 1.12.5), markings on the tailboom and the tunnel covers from repeated forcible contact by parts of the gearbox and by its output rotor shaft, and heavy battering and machining of the tail rotor control rod by the gearbox input drive coupling and the associated flexible coupling, to the point where the rod had been flattened and severed. The markings showed that the gearbox had gyrated both in a predominately pitching sense around both aft mounts and in a pitching, rolling and yawing sense around the right aft mount.

The bearings mounting the tail rotor long driveshaft had all separated from the tailboom, generally by virtue of the bearings having pulled out of the hangars but in the case of the aft hangar because of forcible detachment of the hangar from the boom. The long driveshaft had pulled out its splined connection to the short shaft, translated rearwards through the tunnel and then separated from the helicopter. This could not have occurred before the detachment of the tail rotor gearbox. Separation of the long shaft would have removed the bearing location for the aft end of the short shaft and severe damage to the tunnel components showed that the short shaft had flailed while restrained by its forward flexible coupling. This, together with other extensive signs of rotational damage to the shafting and the tunnel made it clear that the tail rotor drivetrain had been rotating at appreciable speed at the time that the disruption occurred.

The tailcone had partially detached from its fastenings to the tailboom structure and the aft part of the tailcone had fractured and was not recovered. The characteristics of both effects indicated that the aft end of the tailcone had been overloaded in a downwards direction. Markings on the forward portion of the tailcone suggested that this may have been contacted by a tail rotor blade, but the evidence was limited because the aft part of the cone was not recovered.

1.12.4 Tail rotor

The tail rotor gearbox together with the rotor drive shaft remained intact, little damaged externally and with no appreciable internal damage. The drive train between the input coupling and the tail rotor blade yoke turned freely and smoothly with little backlash and the blade pitch change mechanism associated with the gearbox and rotor showed no sign of defect or appreciable damage.

The tail rotor blades remained attached to the yoke, with one blade having survived virtually undamaged. The other blade had sustained considerable leading edge impact damage, with flattening and local deformation of the leading edge over its outboard 35 cm. The effect was progressively more severe towards the tip and over the outboard 10 cm the leading edge had been severely flattened and the outboard 3 cm of the titanium leading edge strip had fractured off, consistent with a heavy leading edge strike near the tip. The outer 30 cm of the spar had delaminated, consistent with the effects of the leading edge damage, and this had released both tip weights. The tip closure rib and the outboard 24 cm of the foam wedge had detached from the blade together with an approximately triangular portion of skin, 15x15x15 cm, from the left surface of the blade in the tip region. On the opposite side of the blade near the tip an area of skin approximately 16x15x7 cm had detached. None of the separated parts of the blade was recovered. Paint smudges on most of the blade leading edge and markings on both upper and lower fins provided clear evidence that the blade had struck the fins while rotating. Some evidence suggested that the tailcone fairing also may have received a blade strike.

In addition, a number of orange smudges were apparent on the damaged blade; several were situated on the outer part of the leading edge and one was on the right surface of the blade (as installed) approximately 8 cm from the tip. The latter mark consisted of a linear smudge, 3 cm long, commencing near the position of the spar and travelling towards the trailing edge and somewhat outboard, with associated local damage to the blade surface. Analysis of the deposits by Mass Spectrometry and Infrared Spectroscopy indicated that they were nitrile rubber. Further analysis, to compare the chemical composition of the deposits with that of the orange paint on a sample sling hook which had reportedly been painted with the same paint as the sling hook in use during the accident flight, showed that the materials were quite unlike each other. It was also found that the deposits were unlike any of the other orange coloured materials used for the aircraft or its equipment, including the fish buckets and the equipment carried in the baggage and cargo compartments, except for a sample of a PRC sealant from the pivot bolt mounting the tail rotor pitch change bellcrank to the tail rotor gearbox. The analysis results were consistent with the smudge deposits having originated from contact with this type of sealant. It was geometrically impossible for the blade to have contacted the bellcrank pivot bolt sealant, but the operator reported that this type of sealant (normally PRC compound PR1422B) is used in a number of areas such as gearbox joints, main rotor blade tip caps and fuselage skin joints. Examination to determine the part of the helicopter that had contacted the damaged tail rotor blade and left the deposits was hampered by damage in some areas and the exact origin of the marks could not be established.

1.12.5 Tail rotor gearbox mounts

Severe localised damage in the area of the tail rotor gearbox aft mounts had occurred. Both captive nuts for the mount bolts had forcibly pulled out of the tailboom fitting. The left mount bolt and nut were not recovered, although the gearbox lug remained intact, with the steel bush in place. Overload features on the tailboom reinforcing structure associated with the left nut, including localised damage around the nut hole, demonstrated that the bolt had been present and engaged with the nut. The retaining plate for the nut remained in place but forcibly detached from one of its attachment rivets. The evidence indicated that loading on the gearbox had loosened the nut and destroyed its axial restraint and subsequently failed the mount bolt.

The right mount bolt and nut remained threaded together, retained in the gearbox lug hole, with the bolt somewhat bent. Severe localised damage to the nut retaining structure indicated that the nut had been forcibly pulled upwards through the structure by overload forces. The nut retaining plate had been severely distorted and had forcibly detached from one of its attachment rivets. The evidence indicated that the bolt hole in this pad not been bushed; it had suffered severe battering against the bolt and had enlarged to around 14.5 mm diameter.

Severe hammering type damage was apparent on both rear mounting pads and on the mating areas of the tailboom skin, particularly in the case of the right aft mount. The damage to the left pad components was consistent with hammering contact with the gearbox pitched nose down. That to the right pad was more extensive and severe and signified hammering contact with the gearbox pitched nose up and down and rolled to the right.

Both lugs of the forward attachment bracket had fractured. Detailed specialist fracture examination found clear evidence of a high-strain, relatively low cycle fatigue mechanism. Blistering of the bracket paint adjacent to one of the fractures was also indicative of localised high temperature caused by rapid high-strain bending. No signs of long term fretting damage were present. The time period over which the failure had occurred could not be closely quantified but was considered likely to have been less than two minutes.

The evidence was consistent with the effects of gross abnormal loading on the tail rotor gearbox over a limited period and suggested that the forward mount lugs had failed first, followed by failure of the left aft mount and finally by failure of the right aft mount. The evidence did not indicate that any pre-existing defect in the mounting arrangements had contributed to the failure.

1.12.6 Cabin

The bottom structure of the cabin remained intact, with localised deformation at the right side of the forward end that showed that it had received an appreciable impact in this region. The remainder of the bottom structure, including the floor panels, had not deformed appreciably, apart from moderate local buckling in the area beneath both front seats. The left aft turnbuckle nut for the left forward seat had pulled forcibly upwards through the floor structure; the other seven turnbuckle nuts for the forward seats remained in place, with turnbuckles in situ.

Most of the above-floor cabin skin panels had detached, but no signs were found that gross loading had been applied to them to cause failure of the relatively lightweight plastic structure. In particular the evidence did not suggest heavy ground contact by the above-floor structure during the roll-over and there were no indications of major incursion into the cabin space during the impact sequence.

The four cabin doors were found with the main wreckage, apart from the window transparency and beading from the right door which were found on the littoral. Both these items were intact and the evidence suggested that they had separated from the door shortly before ground impact of the helicopter because of abnormal loads on the transparency and/or the door that had caused the beading to deform and disengage from the edge of the door cut-out. Both bolts for both aft doors were found gated in the latched position. The positions of the forward door latch mechanisms at impact could not be positively established; no evidence was found to suggest pre-accident failure. Markings suggested that before the accident the engagement between each latch rod and its latch plate with the door handle closed had been approximately 8 mm.

1.12.7 Baggage bays

Both side baggage bay doors were found with the main wreckage, substantially intact. In the case of both doors, markings suggested that the main latch had been fastened at the time of ground impact and clearly indicated that the pins for both safety latches on the left door and the single safety latch on the right door had been engaged.

Available signs suggested that the aft baggage bay door latch had been engaged at the time of ground impact, but was not positive. No evidence was found to suggest that the latch or its warning light system microswitch had been defective or maladjusted.

1.12.8 Pilots' seats

The pilot's seat was found detached from the floor, lying on the ground adjacent to the remains of the cabin and loosely retained to the aircraft by the remains of the pilot's harness (Para 1.12.9). It had separated from the aircraft as the result of a different type of failure on either side. On the right side the GRP seat base moulding had fractured around the periphery of the attachment rail, leaving the rail and the mating small portion of the seat base still attached to the floor. On the left side, distortion of the outer part of the attachment rail had grossly widened the central part of the slot and released the rail from both turnbuckles. The distortion comprised a generally lateral and downward deformation of the portion of the rail forming the outer edge of the slot and had clearly resulted from loads reacted by the respective turnbuckle. Similar distortion was present on the right hand rail slots. At the front end of the left rail forward slot, an overload fracture of the outer part of the rail had also occurred, allowing additional slot widening.

Other seat damage consisted of substantial fractures of the seat base forward web around the cut-out and a localised fracture of the left side of the seat back 44 cm above the pan. No signs were found to suggest heavy contact on the seat by parts of the aircraft or by the ground during the break-up and roll-over following ground impact. The damage was consistent with the effects of moderate downward and rightward loading on the seat pan, particularly on the right side, and moderate forward loading on the top of the seat back, together with predominately outward loading (relative to the seat) on the seat rails from the turnbuckles. The aft slot of the left rail had also been subjected to downward loading. Moderate localised floor distortion had reduced the lateral separation of the left and right turnbuckles from the normal 263 mm by approximately 20 mm in the case of the forward pair and by 10 mm in the case of the aft pair.

The unoccupied left forward seat was also found detached from the cabin floor. Three of the four slots in the attachment rails had been grossly widened by outward lateral and downward distortion of the outer part of the rail, similar to the effects on the right seat. This had released the rails from three of the turnbuckles and the left aft turnbuckle nut had pulled out from its attachment in the floor. The seat back exhibited two localised fractures on each side and a minor degree of distress on the fairlead block. With these exceptions the seat appeared to be undamaged. Again, no signs were found to suggest heavy contact on the seat by parts of the aircraft or the ground. The damage was indicative of some forward loading applied to the seat back near the top, with outward lateral loading applied to the rails by the turnbuckles. In this case there had again been a moderate amount of localised floor distortion; this had reduced the lateral separation of the left and right turnbuckles by 8 mm in the case of the forward pair and by 11 mm in the case of the aft pair.

1.12.9 Pilot's harness

The pilot's harness release fitting remained fastened but the left lap strap released from its floor attachment shackle as a result of failure of the stitching through the turnback that formed the end loop of the short strap (Appendix B, Figure B-6). No signs suggestive of extreme loading were apparent elsewhere on the harness.

1.12.10 Pilot's helmet and headset

The pilot's helmet showed signs of having received a number of minor blows and scrapes but remained intact and without significant damage. The headset, together with its lead and plug, and the helicopter headset socket also remained intact and little damaged.

1.13 Medical and pathological information

The autopsy indicated that the pilot had not been subjected to extreme reaction loads from either lap straps or shoulder straps. The commander suffered multiple bone fractures, lacerations and bruises arising from the crash, including a heavy blow to his forehead. No pre-existing medical condition likely to have contributed to the accident was discovered during the autopsy.

A doctor who had been nearby at the time of the accident arrived at the site very shortly after the accident and attempted to render aid to the pilot. He was found adjacent to his seat, next to the remains of the cabin. The doctor reported that the pilot initially had been found with his helmet on and fastened and with part of his weight forcibly restrained by the helmet chinstrap by virtue of tension in the headset lead, which remained plugged into the aircraft socket.

The autopsy found that the cause of death was asphyxiation. In the opinion of the aviation pathologist the injuries were severe, but not necessarily fatal. The severity of the blow to his head made it highly likely that, immediately after the crash, the commander was unconscious and unable to make any effort to release his helmet.

1.14 Fire

There was no fire

1.15 Survival aspects

1.15.1 Crash loads

Aircraft structures, including crew and passenger seats and harnesses, are required by UK and USA certification requirements to withstand specified load factors intended to relate to crash landing accelerations. These were specified in FAR 27.561, Amendment 10 for original AS350C type certification by DGAC. The requirements considered applicable by the CAA for AS350B UK type certification were BCAR Section G, Issue 3, dated 15 June 1966; relevant requirements were in BCARs G3-8, dated 1 February 1963 and G4-4, dated 1 January 1954.

BCAR G4-4, 'Seats, Safety Belts and Harnesses' defined the occupant design weight as 170 lb (77 kg). It noted that "The requirements of this Chapter are intended to ensure that the occupants of a rotorcraft are provided with reliable and adequate facilities for resisting dangerous movement when subjected to the forces appropriate to normal and emergency conditions." The requirement also specified that "Seats and berths shall be of a form such as to fulfil the duty for which they are installed and to provide the maximum safety in emergency conditions to the occupants and other persons thrown against them."

Suitable methods of testing seats were contained in ARB Specification No 3, 'Tests for Seats with Safety Belts Attached'. Issue 2 required the BCAR static load factors to be multiplied by a factor of 1.2 for testing 'to allow for the fact that a limited number of seats will be tested' and noted that 'when more than one seat is to be tested this factor may be reduced after consultation with the Board.' Issue 2 of the Specification (of 10 July 1953) was current in the 1970s. The CAA has reported that it was not applicable to AS350B type certification (granted by DGAC in 1977 and by the CAA in 1978) as it was not referenced in Issue 3 (1966) of the BCARs which was the issue applicable at the time of initial application to DGAC (1974). The Specification was referenced in the subsequent issue of BCAR G4-4, revised 7 November 1975. This BCAR also specified "The seat local attachments shall achieve a factor of 1.33 on the accelerations prescribed in G3-8,2."

BCAR G3-8 'Crash Landing Conditions' specified the accelerations to be considered. Issue 3 noted that "the requirements of this Chapter are intended to ensure that in the event of the rotorcraft having to crash-land then the safety of the occupants has been fully considered." An Appendix notes that 'It is recommended that inertia forces corresponding to higher accelerations than those prescribed should be used for the design of seat and equipment attachments, etc.'

CAA Specification No 1 dealt with seat belts. A copy of the issue applicable at the time of certification was not obtainable from CAA but it was understood that test loads specified for certification remained unchanged in the subsequent issue, Issue 5 of 24 September 1979. This specified a unit load of 150 lb/g for forward static load factors as the basis for certification and also required safety belt attachment fittings to have an additional strength factor of 1.33. Testing of at least one prototype belt to the above unit load factored by 1.2 (ie 180 lb/g) was required. For series belts, complete or sample testing to half the rated strength (ie 75 lb/g) and possibly sample testing to 180 lb/g was specified; reconditioned belt requirements were similar. Thus, for the BCARs applicable at the time of certification, the basic factored test load for the forward static load factor of 4g appeared to be 720 lb (3.2 kN). However, the Specification required that the lap strap lie in a plane approximately at 45° to the plane containing the longitudinal and lateral axes of the aircraft and that accurate representation for testing could be necessary where unusual geometry could affect the ultimate load. The term 'unusual geometry' was not defined; if taken to apply to the AS350 where the lap strap angle could be approximately 60° rather than the 45° specified above, geometric considerations could imply an additional factor of 1.414 (cosine 45°/cosine 60°), giving a required test load of 1018 lb (4.5 kN).

FAA Technical Standard Order TSO-C22f defined the minimum performance standards for seat belts and required that they meet the standards set out in National Aircraft Standards (NAS) Specification 802, with exceptions. The NAS required a minimum rated strength for a belt assembly of 3000 lb, but TSO-C22f specified that this be reduced to 1500 lb. NAS 802 specified that the rated minimum breaking strength of the webbing shall be at least 150% of the assembly rated minimum strength, ie 2250 lb (10 kN). It also defined qualification tests for both complete assembly and webbing rated minimum breaking strengths, in both cases by tensioning three samples at a maximum rate of 4 inch/sec. For the assembly test no signs of failure, permanent deformation or weakening after load removal were allowed; for the webbing test the material was required to withstand the load for at least three seconds without failure.

Historically, the FAR crash condition load factors were lower than those required by BCARs. However, studies in the 1980s by the USA Federal Aviation Administration (FAA) and the helicopter industry led to revised requirements in 1989 which included a major upward revision of static load factors and introduced dynamic testing as well as static testing (Amendment 25). They also included a requirement to simulate the effects of cabin floor deformation by misaligning parallel floor rails or fittings by at least 10° in pitch and roll before the dynamic tests.

The various loading requirements were:

DIRECTION	STATIC LOAD FACTOR - g				
	BCARs 1966	BCARs 1975* x1.2	BCARs 1975** x1.33	FARs Amdt 10	FARs Amdt 25
Down	6	7.2	8	4	20
Up	3	3.6	4	1.5	4
Sideways	3	3.6	4	2	8
Backwards	3	3.6	4		
Forwards	4	4.8	5.3	4	16

* BCAR G3-8 basic load factors factored by 1.2 for testing, in accordance with CAA Specification No 3, as referenced by BCAR G4-4, 1975.

** BCAR G3-8 basic load factors factored by 1.33 for seat and harness attachments, in accordance with BCAR G4-4, 1975.

Specialist opinion indicated that crash accelerations very much greater than those specified by FAR Amdt 10 and BCAR Issue 3 (1966) are likely to be experienced in many potentially survivable aircraft accidents. The CAA reported that none of the subsequent upgraded requirements above have been applied to the AS350 because of the normal policy of airworthiness authorities not to require the application of such improvements where they occurred after the date of application for type certification in the country of origin. In the course of the investigation the CAA stated that for this reason no requirement for improved AS350 seat or harness crashworthiness was envisaged.

1.15.2 Pilots' seats

Static load testing of a sample high-back seat of the type fitted to G-PLMA was described in SICMA Report No 215 of 22 February 1978. The report did not describe the test set-up but the manufacturer reported that it had been similar to that used for testing the original type of low-back seat, Aerospatiale Report No 350.A.06.2065 of 31 May 1977. For this testing the seat was mounted on a floor structure representative of the undeformed cabin bottom structure and loads were applied to a wooden mannequin retained by the floor mounted lap strap. For the high-back seat test the shoulder straps were reportedly included and for the forward loading tests the load was applied at a height of 8.5 inches (21.5-cm) above the seat pan, corresponding to a share of the reactive load of 70% by the lap strap and 30% by the shoulder straps. Loads were applied to the mannequin in four directions sequentially, equivalent to the following load factors, without major seat or harness failure resulting; the various static load factors required (para 1.15.1) are also included:

DIRECTION	STATIC LOAD FACTOR - g					
	AS350 Seat Tests	BCARs 1966	BCARs 1975 x1.2	BCARs 1975 x1.33	FARs Amdt 10	FARs Amdt 25
Down	6	6	7.2	8	4	20
Up	3	3	3.6	4	1.5	4
Sideways	3 (right)	3	3.6	4	2	8
Backwards	-	3	3.6	4		
Forwards	6	4	4.8	5.3	4	16

A final forward overload test on the seat resulted in significant failure of the seat with a forward load on the mannequin equivalent to 9.5g and was stopped at 10g, without harness failure. The seat test loads thus exceeded the FARs applicable at the time of DGAC certification and met or exceeded the BCARs considered by the CAA to be applicable to UK certification. The testing did not include principal axes, or the simulation of dynamic effects or of cabin floor deformation.

The manufacturer reported that it was unaware of cases of failure of this type of seat in normal service or in survivable accidents. The CAA database listed the following Mandatory Occurrence Reports (MORs) concerning the seat type:

1. MOR 93/03178, AS350, Accident to G-PLME on 9 September 1993. Damage included collapse of floor structure and seat structure failure. The accident was reported in AAIB Bulletin 2/94.

2. MOR 94/01781, AS355. Co-pilot's seat back. 3 inch crack found during annual inspection.

3. MOR 94/02472, AS365. Pilot's seat fractured at junction of seat retention mechanism and the seat base. Found during major inspection.

No further details were available on Cases 2 and 3. The limited information available suggested that the failures had occurred during normal usage.

Additional information on Case 1 showed that following an engine failure the helicopter had struck the ground with a high rate of descent and little forward speed, causing the skid gear to collapse and the bottom structure to contact the ground. The floor had distorted around the bottom structure right longeron and the pilot's seat base had fractured on both sides, generally around the edges of the seat rails, releasing the seat from the floor. The seat made heavy contact with the distorted floor, loads had been transmitted upward by documents packed in the seat base and the pilot had suffered a severe back injury. The operator informed the CAA in 1993 of reservations about the crashworthiness of the seat type in a detailed CAA Mandatory Occurrence Report. The operator also reported having discussed its concern with the manufacturer's agent and subsequently with the manufacturer.

Information from an operator indicated that cracking of the seat base material at the profile of the back end of the seat rails as a result of normal service had been found on a considerable number of seats. This was believed to be due to loads applied by rear seat occupants pulling on the back of the front seat to pull themselves up. Inspection of a random example showed that the base had cracked at this location on both sides, to the extent of having produced a hole right through the material across the width of the mating seat rail.

A qualitative assessment of G-PLMA's seat by a composite specialist noted that the through-thickness strength of the horizontal portions of the laminate at the bottom of the base to which the seat rails attached would have been relatively poor compared to the in-plane properties of the material. The only method of preventing the through-thickness shearing that occurred would have been to considerably increase the laminate thickness in the area where the rail attached. The specialist also noted that static testing might not necessarily simulate the true behaviour of the seat during impact where a dynamic response might be expected.

Modifications aimed at strengthening the seat and its attachments were published in Aerospatiale Service Bulletin (SB) AS350 No 25.24, first issued on 2 August 1984. Revision 2 of the SB, issued 2 April 1987, included the addition of bonded reinforcement strips at the bucket/base junction and the installation of rail reinforcements. The latter consisted of the addition of an angled bracket bolted to the seat rail web at the centre of each slot and overlapping the outer edge of the rail (Appendix B, Figure B-5). The SB effectivity was listed as all pilot and co-pilot seats fitted on AS350 helicopters, all versions. It noted that the rail reinforcement modification was incorporated on the production line from aircraft SN 1774 or 1875, depending on the detailed standard. Similar SBs had reportedly been issued for other Eurocopter types with this type of seat. The reason for the modification was given as 'Prevent incipient cracking between back and bucket and improve attachment of seats'. No classification was entered on the SB, reportedly signifying that the manufacturer had classified it as Optional. The modifications had not been classified as Mandatory by the CAA and had not been incorporated on either forward seat of G-PLMA (SN 1049).

1.15.3 Pilot's harness

Enquiries revealed that the type of loop stitching used on G-PLMA's lap strap was similar to that on other belts of the type but that on older belts of the same type a gate stitching pattern had been used, extending over a greater length of the belt (approximate 1.4 inch (3.6 cm) compared to 0.9 inches (2.3 cm) for the lateral stitching). No evidence was found to indicate why the stitching pattern had been changed by the manufacturer who continued to use this type of stitching. The opinion of a harness stitching specialist was that the preferred method of forming a loop of this type would be to mutually overlap the turnback from both loops (Appendix B, Figure B-5) and to stitch through the three layers of material with either a Gate Stitch or WW Stitch pattern extending over 3 inches (7.6 cm) of the strap length. The lateral stitching pattern used was not considered suitable.

Testing to measure the breaking load of the type of strap that failed on G-PLMA was carried out using the two parts of the apparently undamaged left seat lap strap from G-PLMA. In each case tension was applied between the tongue fitting and the floor shackle at an extension rate of 10 mm/min. The aircraft manufacturer also conducted tests on two unused straps, manufactured in 1995 and believed to have the lateral loop stitching pattern. The failure loads and the required test loads were:

STRAP		FAILURE		
		LOAD		MODE
		lb	kN	
G-PLMA Left Seat:	Left Strap	2039	9.07	Webbing Breakage
	Right Strap	2239	9.96	Loop Stitching Failure
1995 Unused Strap:	Strap 1	3232	14.66	Webbing Breakage
	Strap 2	2845	12.90	Webbing Breakage
TEST LOAD REQUIREMENTS				
BCAR Factored Test Load		1018	4.5	
FAA TSO-C22f Test Load		2250	10	

A chemical analysis by the manufacturer revealed no significant difference between the thread used on the failed right seat lap strap and a sample from an unrepaired strap.

1.15.4 Pilot's headset lead

Tests were conducted on a headset lead assembly and aircraft socket combination similar to that used by G-PLMA's pilot. Measurements were made of the force required to pull the lead plug from the socket as a function of the angular deviation of the pull from the socket forward axis. Forces of well over 100 lb applied during testing did not cause the assembly to fail. Results were as follows:

ANGLE °	FORCE lb
0	8
10	8
20	9
30	11
40	12
60	50
90	In excess of 100

1.16 Tests and research

Nil.

1.17 Organisational and management information

1.17.1 Regulatory framework

The accident occurred 11 days before The Air Navigation Order 1995 came into force on 16 May 1995 and so, at the time, the operator and his staff were subject to the provisions of the Air Navigation Order 1989.

The words 'air transport undertaking' are defined in both Orders as meaning 'an undertaking whose business includes the carriage by air of passengers or cargo for valuable consideration.'

1.17.2 Flight category

The terms 'public transport' and 'aerial work' were defined in Article 107 of the 1989 Air Navigation Order. Either category could apply if valuable consideration was given or promised in respect of a flight or the purpose of a flight. There were many provisions within the Articles which applied to flights not carried out by an air transport undertaking. However, for an air transport undertaking, the flight was categorised as public transport if:

a. valuable consideration was given or promised for the carriage of passengers or cargo in the aircraft on that flight.

b. any passengers or cargo were carried gratuitously in the aircraft on that flight, not being persons in the employment of the undertaking.

1.17.3 Crew fatigue regulations

The Regulations pertaining to Crew Fatigue contained in Articles 57 to 60 of the 1989 Order were applicable to any aircraft registered in the UK which was either:

a. engaged on a flight for the purpose of public transport; or

b. operated by an air transport undertaking.

The regulations applicable to 'an air transport undertaking' placed a duty on operators to establish a scheme for the regulation of flight times and stated that the scheme was to be approved by the Authority (the CAA) subject to such conditions as it thought fit. To assist operators in devising a company scheme for public transport operations, the Authority issued Civil Aviation Publication (CAP) 371 entitled 'The Avoidance of Fatigue in Aircrews - Guide to Requirements'. Edition 3 of this document effective May 1990 provided guidance on the requirements, content and scope of a flight time limitation scheme. There was no mention in this document of a suitable scheme for aerial work operations conducted by an air transport undertaking; individual company schemes were approved by the CAA. It was also noted during the investigation that there were a number of other operators, engaged in underslung load work, who were air transport undertakings, and who had not been required to produce a flight time limitations scheme in accordance with the ANO. This was a generally accepted practice which it is understood originally came about some 15 years ago as a result of legal advice to the CAA. No documentation was provided in support of this practice and there were no exemptions or permissions available to allow such companies to operate without a FTL scheme.

1.17.4 Operating company's flight time limitation scheme

At the CAA's request, the Operating Company had provided instructions to its flight crew regarding flight time limitations in its Operations Manual which was carried in the helicopter. The company FTL scheme was split between two sections of the Operations Manual. The instructions in Section 5 of the Manual were applicable to public transport operations, followed the requirements contained in CAP 371, and were comprehensive. They stipulated minimum rest periods and procedures to be followed for extending a flying duty period by split shifts or commander's discretion.

The instructions in Section 3 were applicable to aerial work operations and did not follow the requirements contained in CAP 371 because the CAA had authorised a flight time limitation scheme less rigorous than that required for public transport operations. An extract of these instructions is reproduced at Appendix C.

1.17.5 Company instructions to pilots

Periodically the operating company issued instructions and information to its pilots in the form of 'Notices to Pilots' and other documents such as 'Smolt Transfer'. Freelance pilots were provided with personal copies of these notices.

Notice to Pilots 1/95 reminded pilots that the Company Operations Manual states that the pilot is to remain at the controls whilst rotors running. Notices 2 to 8 of 95 addressed topics not directly related to flight safety. Notice 09/95 *(issued after the accident)* on the subject of slings stated:

'In the light of the accidents to PLMG and PLMA pilots SHALL ensure that, whenever possible, the aircraft does not transit with an unballasted sling attached to the cargo hook. Whenever the aircraft has a sling attached the V_{NE} will be reduced to 80 kts and the "DANGER SLING" flag must be upright and clearly visible. A sling attached to the aircraft hook means that the aircraft is carrying an underslung load. Pilots must be aware that the sling, especially slings of the length currently used for fish operations, when in transit hang up to 4 meters below the aircraft. The hook can easily be propelled into the tail or tail rotor if it contacts an external object (ground, water etc). This applies even at low ground speeds.'

The 'Smolt Transfer' document contained numerous instructions regarding the approved procedures but it did not contain a prohibition on flight with an unballasted sling.

Before the Commander started work with the operator, the Chief Pilot discussed with him the circumstances of a previous accident involving G-PLMG (see paragraph 1.18.4) and the importance of maintaining an awareness of an underslung hook and of flying at a sufficient height to avoid ground contact with the sling or hook.

1.17.6 CAA exemptions

The CAA had granted the operating company a number of exemptions from the provisions of the ANO provided certain conditions were met. The exemption pertinent to this accident gave permission to fly over water for more than three minutes for the purpose of public transport provided that (inter alia): each occupant wore a lifejacket; the helicopter carried liferaft(s) capable of carrying all the occupants; and a search and rescue beacon was carried on board.

1.18 Additional Information

1.18.1 Distances, speeds and times

By road the distance from Tayinloan to Loch Glashan was estimated to be 42 statute miles. By road the time taken to drive at a reasonable speed from Meall Mhor to Stronachullin was 4 minutes 15 seconds and from there to the southern outskirts of Ardrishaig took another 4 minutes 38 seconds.

The direct flying distance between Meall Mhor and abeam Stronachullin was approximately 3 nm (nautical miles) and from there to the crash site was a further 3 nm. Allowing for the probable distance flown by G-PLMA after it coasted in near the crash site and then returned to it, the total distance flown from Meall Mhor to the crash site was approximately 7 nm.

The normal fast cruise speed in the Squirrel is achieved by setting the maximum continuous engine rating which results in a level flight speed of approximately 110 kt.

1.18.2 Tail rotor problems

The helicopter manufacturer reported that they knew of no previous cases of AS350 tail rotor blade fatigue failures or debonding, except as a result of a tail rotor strike on an obstruction, and knew of no previous cases of tail rotor gearbox mount failure, except as a result of excessive tail rotor imbalance.

It was reported by the manufacturer and the operator that the AS350 is highly sensitive to tail rotor blade abnormalities and that the aerodynamic and/or imbalance effects of even minor blade damage cause substantial vibrational changes that should be readily noticeable by the pilot. With a rotor radius of 3.05 ft (0.93 m) and a speed of 2,088 rpm the tangential speed of the tip is 652 ft/sec (199 m/sec). Calculation showed, for example, that the loss of the tip balance weight and its mounting components, a weight of 0.30 lb (138 gm), would generate a rotating radial imbalance force of 1,342 lb (5.97 kN).

1.18.3 Baggage bay door problems

Reports showed that there had been a number of cases of AS350 side and aft baggage bay door opening in flight, including two concerning G-PLMA's aft baggage bay door. In the first of these, on 14 August 1986, the door was seen to be open after take-off. In the second, on 6 January 1992, the door was reported to have opened in flight during severe turbulence. The operator believed that in both cases the door may have been incompletely latched and examination showed that it could perhaps be possible for the door to be closed, and initially remain so, with the bolt not fully engaged in the hole in the latch plate.

Examination of other similar aircraft suggested that the ability to achieve such a partially latched condition possibly could have been dependent to some extent on the detailed damage and deterioration of the latch components that had occurred in normal usage. Following these cases Service Bulletin 52-07, required by CAA Airworthiness Directive AD 006-03-92 of 1 July 1992, was incorporated on G-PLMA on 2 April 1992 to add a door warning light system.

1.18.4 Previous accidents

A previous accident occurred on 28 March 1988 to a similar helicopter operated by the same company whilst it was transiting with an unloaded cargo sling. The helicopter experienced severe turbulence and the sling contacted the tail rotor but the pilot was able to land safely. Following this accident, the operating company modified its procedures, fitted ballast weights to all company slings and instituted a maximum recommended airspeed of 80 kt when flying with an unloaded cargo sling. The intention of these changes was to prevent the sling from flying up into the tail rotor.

The accident to G-PLMG of 7 December 1994 which was reported in AAIB Bulletin 3/95 concerned another helicopter of the AS350 series during an overland transit flight with an unloaded cargo sling attached. The sling was not identical to the type carried by G-PLMA, having a different type of hook, but was generally similar in overall terms. The accident occurred when it flew low over a ridge and the weighted hook at the lower end of the sling struck the ground. The hook assembly then travelled rearwards and upwards in an arc until it contacted the tail rotor blades. The tail then separated and the aircraft crashed in a nose-down attitude. In the immediate aftermath of this accident, the company carried out flight trials with an unloaded cargo sling. These trials which included cruising at 110 kt and autorotating at 90 kt in gusty conditions indicated that the sling never reached angles in excess of approximately 60° from the vertical.

The operator reported that the use of a shorter sling had been assessed. They had judged that usage of a sling that was sufficiently short to make it incapable of entering the tail rotor disc would create additional difficulties for ground handlers dealing with sling loads and was not practicable.

The effects of contacting a sling on a water surface while in forward flight were indicated by an overseas accident to another helicopter type when the release of a load being towed on the surface at around 40 kt groundspeed allowed a float part way along the sling to contact the surface. The float and sling immediately rebounded violently off the surface and contacted both main and tail rotor blades.

1.19 Useful or effective investigation techniques

Not applicable.

2 Analysis

2.1 The most significant event

The accident was brought about by a sequence of events but there can be little doubt that the event which made it inevitable was separation of the tail rotor gearbox. The proximity of the gearbox and tail rotor blades to the remainder of the wreckage indicate that separation happened seconds before ground impact. Once the gearbox broke away, there was no tail rotor force with which to counteract the torque of the main rotor transmission system and the helicopter would have begun to spin around its main rotor. The only way to contain this situation is to reduce engine power and execute a forced landing. That this was attempted is fully consistent with all the evidence available.

The in-flight fracture of the tailboom was consistent with the effects of the heavy blade strike on the lower fin. It was also apparent, from the tail rotor strikes on the fins and the machining damage to the tail rotor control rod by the gearbox input coupling, that the system had operated briefly with the tail rotor gearbox displaced from its normal position while the tail rotor had been rotating at high speed. Relative movement between the gearbox and the structure would have produced uncommanded changes in blade pitch angles because of the pitch control rod geometry. This in turn would have caused the uncontrolled yawing and rolling reported by many witnesses. During this phase the control difficulties were probably so severe that the commander was unable to attempt any form of 'controlled' crash landing until the tail rotor had broken free from the tail boom.

Unfortunately when the tail rotor separated, the helicopter's height was probably too great to use main rotor inertia to cushion a vertical landing and too little for effecting a run-on landing after tail rotor drive failure, which depends for its success on forward airspeed and a reasonably flat surface. Consequently, a very hard landing in an unusual attitude was unavoidable.

The bulk of this analysis concerns the processes which led to detachment of the gearbox, the factors which combined to cause the accident and the reasons why the commander did not survive the crash landing.

2.2 Helicopter serviceability

The helicopter was apparently serviceable when the relief pilot handed over to the commander at 1645 hrs and it appeared to be functioning normally when it arrived for the final landing on the lawn at Meall Mhor. Thorough examination of photographs taken by a bystander revealed nothing amiss and examination of the wreckage did not reveal any pre-existing defect which might have contributed to the accident.

The only evidence of anything untoward was the aural impression of a bystander who thought the helicopter was emitting a strange noise. The witness had worked in the offshore oil industry for many years and was familiar with helicopters; he likened the noise to the sharpening of a knife on a grindstone and the noise was still present when the helicopter took off.

No positive explanation could be found for this unusual noise, however, the noises generated by helicopters can vary considerably between different types because of the different characteristics of particular types of engine, rotor and transmission systems; in particular, a smaller helicopter will tend to have significantly higher rotor speeds than larger ones in use in North Sea operations. Considerable differences in the predominant characteristics of the noise generated by the numerous sources in the helicopter also can occur in different phases of operation or when the aircraft is observed from a different aspect. The driver of the fish lorry had also seen and heard the helicopter at close range several times during the afternoon at Tayinloan. Neither he nor any of the other persons who witnessed these operations commented on an abnormal noise, and the pilot also had the opportunity to hear any abnormalities when he left the helicopter with rotors running shortly before the accident flight. The noise heard by the bystander cannot be lightly dismissed, especially as he expressed his concern before he knew of the accident, however it is considered that the report may have related to unfamiliarity of the witness with this type of helicopter and did not indicate an abnormal condition of G-PLMA.

Furthermore, the commander made no mention of any problem with the helicopter in which, for almost four hours, he had been performing tasks which required great precision. That he was content to take-off again from Meall Mhor indicates that he was satisfied with its airworthiness.

2.3 Departure from Meall Mhor

After taking-off for its final flight, the helicopter was seen to clear all the obstacles presented by trees and power lines and to head out to sea. Certainly, at this stage it was carrying an unladen sling which was suspended normally from the attachment point under the helicopters belly and no damage was inflicted to the tail rotor by contact with any object on land.

Over Loch Fyne the helicopter was seen to turn to the right followed by a reversal to the left, as if, according to the witness, the commander had decided to return to Meall Mhor and then changed his mind. The reasons for this cannot be determined but the manoeuvre would be consistent with the witness's interpretation or it may have simply been to gain separation from the shore before continuing northwards. Had the commander initially decided to return to Meall Mhor, it may have been because he realised that he had forgotten to leave the sling behind or that there was something wrong with the helicopter. He did not need the sling for the return flight to Loch Glashen and carrying it imposed a speed restriction of 80 kt whereas, without it, he could fly faster and save time. He may have started to turn back and then changed his mind, reasoning that the extra time taken to fly to Loch Glashen at 80 kt, where he could release the sling and place it in the cabin, was less than the time lost in returning to Meall Mhor and dropping it on the lawn. On the other hand, he was in the habit of transit flying with an unloaded sling. Apparently this was discouraged by his employer but witnesses stated that he had done so several times before, including the previous return leg from Meall Mhor to Loch Glashen.

Alternatively, if the serviceability of the helicopter had suddenly come into question, logically the commander would have turned towards land to find a suitable site for a precautionary landing. If the perceived problem was related to the tail rotor, Meall Mhor was unsuitable for a run-on landing and he would have had to look elsewhere. The western shores of the Loch were generally rocky and so he could be expected to have headed east rather than north to find a more suitable site. Also, if the helicopter's engine, gearbox or tail rotor systems were exhibiting signs of impending failure, he would probably have climbed to give himself ample height for an engine-off landing. That he continued northwards without climbing indicates that the commander was not aware of anything significantly wrong with the helicopter.

2.4 The sling

The sling was still underneath the helicopter as it passed abeam Stronachullin but it was not found with the wreckage and nobody saw it suspended underneath the helicopter just before it coasted-in or at any time afterwards. The land between the promontory and the crash site was searched several times and so was the shore and the waters along the shore line but no there was no sign of the sling. Therefore, it seems most probable that it was deliberately jettisoned over the Loch. There was no reason to jettison the sling other than an in-flight emergency and so it seems almost certain that the commander first became aware of a problem after passing abeam Stronachullin but before reaching the promontory at Castleton and whilst the helicopter was still over the water.

2.5 Tail rotor failure

The high-strain, relatively low-cycle fatigue fracture of the tail rotor gearbox forward mount bracket, with associated flexural overheating of the adjacent paint, was indicative of large cyclical loads having been applied to the gearbox, as were the characteristics of the rear mount damage. The possibility that the effects could have resulted from a deficiency in the mounts, such as an undertorqued rear mount bolt, was considered, given that the severe hammering damage in the area of the rear mounts and the overload failure of the associated attachments could have masked any long term fretting damage that could have been present. However, no signs of long term looseness in any of the mounts was apparent, and it was considered most unlikely that all such evidence would have been totally obliterated. There was no record of a history of AS350 tail rotor gearbox mount problems. Additionally, while a rear mount deficiency could have altered the loadings on all the mounts, it would not have caused the severe cyclical loading evident on the forward mount, and the characteristics of both forward and rear mount damage made it clear that the forward mount had been the first to fail.

It was therefore positively concluded that the excessive loading had resulted from gross imbalance forces applied by the tail rotor for a period of operation. The damage to the rear mounts was also fully consistent with such a condition, following the failure of the forward mount. While the period of operation in this state could not be accurately quantified, specialist opinion based on the characteristics of the forward mount failure suggested that the gross imbalance had been present for around a minute or two.

This was consistent with the evidence that even a relatively minor abnormality to a tail rotor blade tip area is readily apparent to the pilot by virtue of the high imbalance forces generated, which suggested that blade damage could not have occurred long before the accident without it having prompted the pilot to investigate. In particular, it was highly unlikely that the pilot would have departed on its last flight had a tail rotor blade been damaged at this time.

2.6 Tail rotor imbalance

The only reason for a rotor gross imbalance, given the normal functioning of the tail rotor gearbox indicated by its condition after the accident, would be blade damage that caused loss of part of a blade. The absence of a history of break-up of this type of blade, except as a result of contact with an obstruction, indicated that loss of a portion of blade because of bonding or fatigue failure was most unlikely as the initiator of the damage to the rear end of the helicopter. It was therefore concluded that the tail rotor gross imbalance had resulted from a blade strike on an obstruction in the course of the last flight. The eyewitness evidence suggested that the problem had occurred during the latter part of the transit over the loch, well before the partial in-flight break-up just before the main part of the helicopter impacted the ground, and the tail rotor gearbox mount failure evidence was consistent with this.

2.7 Tail rotor obstructions

Over the unobstructed surface of the loch the only possible objects that the tail rotor could have contacted were a bird, a detached part of the helicopter, a released item of aircraft equipment, or the sling. These are considered in turn.

2.7.1 Bird strike

If a bird such as a seagull had entered the tail rotor disc, blood, tissue and feather deposits on the blades and possibly the tail area would have been likely, particularly as there was no rain or fire to destroy the evidence. No deposits or traces of any organic material other than soil and grass were found on the tail rotor and so this damage mechanism was discounted.

2.7.2 Detached part of helicopter

The only parts of the aircraft not found at or near the crash site were the detached portion of the damaged tail rotor blade and the aft part of the tailcone from the end of the tailboom. As the fracture of the tailcone had clearly resulted from a substantial overload on its aft end, quite possibly from a tail rotor blade strike, any possibility that the initial tail rotor imbalance had been caused by the rear part of the tailcone having detached and contacted a tail rotor blade could be dismissed. The location of the other parts of the helicopter that had detached in flight and were recovered showed that the detachment had occurred only shortly before the main part of the aircraft had crashed and well after the point at which the control difficulties had initiated. Their loss had thus been a result of the tail rotor imbalance and not its cause and it was concluded that the initial tail rotor strike had not been on a detached part of the helicopter.

2.7.3 Released aircraft equipment

It was not possible conclusively to account for all items of equipment that may have been carried in the helicopter as no definitive list of the items on board was available. However, most items believed to have been carried were accounted for. A number of cases of AS350 baggage doors opening in flight had occurred, including G-PLMA, but modifications aimed at preventing such occurrences had been incorporated on all three doors of this aircraft. The evidence that the safety latches fitted to the side doors had been engaged precluded the possibility that either of these had opened in flight. The cases of aft baggage bay door opening had been attributed to incomplete latching on closure of the door and it appeared that it may be possible to achieve such a situation in certain circumstances with the type of latch fitted. However, the door warning light system that had been incorporated appeared to provide an effective indication to the pilot and should have prevented a take-off without the door latch fully engaged. No reports of the aft baggage door being open in flight had been made following the addition of the warning system.

Two witnesses close to the accident site reported seeing a cabin door open whilst the helicopter was flying low over the land at Castleton, apparently looking for somewhere to land. One of these witnesses also reported seeing objects fall from the helicopter. However, given that the helicopter had by this stage jettisoned the sling, almost certainly over the Loch, and that its commander was looking for a place to land, it seems highly likely that the tail rotor was already damaged.

No defect was found with the cabin door latches but it appeared that they could possibly be susceptible to releasing because of severe cabin distortion under extreme loading. It was considered that the loading applied to the helicopter by the imbalanced rotor, possibly accentuated by failure of one or more of the tail rotor gearbox mounts by this stage, combined with loads resulting from the erratic aircraft manoeuvring seen was the most likely cause of a door opening at this point.

It was not possible to determine conclusively the source of the PRC sealant on one of the tail rotor blades, however, it was most unlikely to have originated from equipment likely to have been carried within the aircraft. It was considered most probable that the PRC sealant had been transferred to the blade from part of the aircraft as the tail rotor detached.

Thus, while the evidence was not totally conclusive, it was unlikely that release of an object from the helicopter in flight had been the initiator of the tail rotor blade damage.

2.7.4 Sling

The length of the sling is such that the arc swept by it in the fore and aft axis brings the heavy weighted hook into contact with the tail rotor blades if the sling rises much above the horizontal. Although an unloaded sling does tend to oscillate in flight, trials after the accident to G-PLMG showed that speed alone was insufficient to make the sling trail high enough to contact the tail rotor. Turbulence could be a compounding factor but the air was very calm on the evening of the accident. However, evidence from another case showed that if the sling were to touch the water at the speed that the helicopter was estimated to have been travelling over the loch, the end of the sling would be very likely to have rebounded violently upwards. In such circumstances it is quite possible that it would have hit the tail rotor.

Evidence of such an impact on the hook was not available as the hook was not recovered. Neither was positive evidence available on the damaged tail rotor blade of contact with the hook. A substantial portion of one blade had detached and it was not possible to ascertain when this had occurred because of damage sustained by the blade due to contact with the fins after the gearbox mount failure. This contact could have caused further loss of material from a blade that had already sustained damage and, having occurred over the littoral, the relatively low density GRP and/or foam parts that may have detached at this point could have been removed from the accident site area early on by tidal flows. However, the characteristics of the tail rotor blade damage were consistent with the effects of an initial substantial leading edge tip strike on a part of the sling (such as the hook or ball weight) which had caused the tip weights, the outboard part of the leading edge strip and possibly part of the skin to separate from the blade. The scraping and puncture marks on the tailboom right side in the area of the tail rotor also were a possible sign of hook contact in this area.

Although not conclusive, the evidence therefore strongly indicated that G-PLMA's tail rotor blade strike had been on part of the sling after the end of the sling had contacted the surface of the loch during the transit and rebounded into the tail rotor disc as a consequence.

2.8 Speed over the Loch

Without the sling, the commander could have cruised at about 110 kt rather than being limited to 80 kt. The extra speed would have been useful because he was behind schedule and there was still about an hour's flying of the task remaining. Moreover, if before he took off from Meall Mhor, the commander had decided to enjoy a spell of low flying on the transit flight, it is odd that he did not drop the sling whilst he had the chance, unless he forgot to do so. If he had totally overlooked the presence of the sling, there would have been no apparent reason for him to restrict his speed to 80 kt. Therefore, the speed at which he transited over the Loch is important because it is indicative of whether the commander was aware of the presence of the sling and the speed restriction it imposed.

It is not possible to determine the exact speed of the helicopter over the Loch but some indication may be derived from the experience of two witnesses. One in Ardrishaig saw the helicopter crossing from his right to his left at unusually low height but flying straight and not fast. In his words *"It was making headway but* *taking its time. I know that when they are zooming along they have the nose down a bit to get extra speed but he wasn't like that".* The second piece of evidence arises from the time taken by a witness to drive from Stronachullin, where she saw the helicopter abeam her, to the southern outskirts of Ardrishaig where she saw it spinning out of control. In that time the helicopter had flown about 4 nm. The drive from Stronachullin to Ardrishaig took an investigator 4 minutes 38 seconds at a reasonable driving speed. This equates to a average speed for the helicopter of 52 kt. Allowing for errors of half a mile in the distance flown by the helicopter and 30 seconds for the time to drive between the two points, the average speed of the helicopter must have been between 39 kt and 65 kt. If it flew from abeam Stronachullin to the promontory at Castleton in a fast cruise at 110 kt, this would have taken it only 1 minute and 38 seconds and the eyewitnesses who watched it from the time it coasted in to the time it crashed would have been watching it for about 3 minutes. This length of time over land was inconsistent with the recollection of most of the witnesses in the Ardrishaig and Castleton areas. Therefore, the balance of the available evidence indicates the helicopter was flying at a speed well below its normal fast cruise speed of 110 kt. This in turn demonstrates that the commander was probably aware that the sling was still attached.

2.9 Low flying

After its departure from Meall Mhor, witnesses in cars on the A83 road reported seeing the helicopter on its northward journey across Loch Fyne. Coincidentally, both were passing the Stronachullin area when they saw the helicopter with its sling attached flying at unusually low height. Just how low cannot be determined accurately but both witnesses made their own estimates. One witness thought the sling was about 20 to 30 metres long and the end of the sling was 10 metres above the water. The sling was in fact only 6 metres long. Since the witness estimated the clearance between the sling and the sea as a proportion of the length of the sling, the estimate may well have been very generous. The other witness compared the helicopter's height to that of a similar type seen scooping up water from the Loch for fire fighting. Both descriptions are consistent with the sling trailing close to the water and so the helicopter is unlikely to have been more than 100 feet above the sea.

Other eye-witnesses in the Ardrishaig and Castleton areas also saw the helicopter flying at unusually low height over the sea just before it pulled up sharply as it coasted-in near the crash site. One lost sight of it temporarily behind a gravel bank and another estimated its height at 30 feet above the sea. Consequently, it seems likely that the helicopter was low-flying for most if not all of the 3 mile leg from abeam Stronachulin to the promontory at Castleton. There was no operational requirement for the helicopter to fly so low and it is inconceivable that a pilot would intentionally do so if the serviceability of the helicopter had suddenly come into question. Therefore, these observations indicate that the helicopter was responding normally to control inputs for much of the leg from Meall Mhor to Castleton.

2.10 Commander's intentions

The commander was very experienced at low flying; he would have learned the art in military service and honed it during his later years of crop spraying and electricity line inspection for civil employers. A member of the operator's ground staff who had flown with him since he joined the company had experienced his low flying and knew from conversation with him that he enjoyed it and found it exhilarating. Consequently, the commander may have decided to enliven an otherwise dull transit flight by low-flying up the Loch. There was nothing illegal or improper in doing so, provided that he avoided overflying any vessels, but it was quite unnecessary. The direct route from Meall Mhor to Loch Glashen involved flying over the land for the last few miles and, to be lawful and considerate to the public, that part of the leg would have to be flown at least 500 feet above or to one side of any person or structure. However, by keeping the Castleton promontory on his left, and remaining over Loch Fyne, the commander could have flown most of the leg over water and continued low-flying until he approached the village of Lochgair which is about a mile away from the landing site at Loch Glashen. Both witnesses who saw the helicopter abeam Stronachullin gained the impression that, at that time, it was proceeding either towards the head of Loch Fyne or towards its east coast. These impressions are consistent with a route which maximised the time spent low-flying over water. They could also be construed as evidence that the commander had diverged from the direct route because of a navigational error. However, given the excellent in-flight visibility that evening, that the helicopter remained at low-level, and the number of times the commander had flown the route that afternoon, consistently overflying the inhabited Castleton area, this interpretation seems unlikely. Moreover, he had not, according to several witnesses, used this route to avoid overflying populated areas when carrying the fish buckets to and from Meall Mhor and so the sum of the evidence points to a deliberate intention by the commander to fly low over Loch Fyne.

2.11 The low flying risk

The commander would have appreciated the hazards of low flying especially when carrying a sling. Because the helicopter had no radio altimeter, he would have had to estimate his height visually but, given his experience, he was probably a good judge of height. Nevertheless, with a sling trailing underneath, the commander needed to allow a sensible margin for error to ensure that the sling remained clear of the surface. The commander had first flown with the operator three months after the company's fatal accident in December 1994 when a sling touched the ground during a transit flight and swung upwards into the tail rotor. He was properly trained and tested by more than one management pilot and he was employed principally to overcome the pilot shortage resulting from that accident. He had also been given a personal copy of the operator's guiding notes to pilots on smolt transfer which alluded to the risk of the hook striking the tail rotor. Under these circumstances, it is inconceivable that the commander was unaware of the risk of allowing the sling to touch the surface during transit.

It is difficult to define any particular estimated height above which the aircraft would be safe and below which it would be at risk; the hazard is both gradual and subjective.

In avoiding the hazards beside the road at Meall Mhor, the commander would have had to set off at a reasonable height but once over the Loch, it seems that he descended to a height significantly below 100 feet soon afterwards. His moderate speed and perhaps the jink after take-off indicate that he was aware of the presence of the sling; had he a moment's doubt about it he could easily have checked at any time using the external mirror. There has, therefore, to be some logical explanation as to why the commander descended to a dangerously low height over the water.

2.11.1 Distractions

One reason for flying too low might be that the commander was distracted but it is difficult to imagine what the distraction could have been. He had flown the route several times that evening and would not have needed to study a map, and there were no passengers or cargo of fish to tend. Had the distraction been a malfunction, a pilot of his experience could be expected to climb to a safe altitude before attending to the problem. If he had needed to avoid a bird seen at the last moment, it is unlikely that his instincts would have provoked a sudden descent. His reaction would most probably have been to climb or turn sharply to the side. There were no eyewitness reports of any such manoeuvres and so it is unlikely that the commander was distracted or took evasive action.

2.11.2 Height judgement

When flying close to the surface without a radio altimeter, pilots have to judge their height in one of three ways. They can estimate height by assessing the position of the horizon relative to some known or intuitive datum. This is a fairly coarse method and dependent on the pitch attitude of the helicopter which, in turn, varies with speed. A more reliable method is to relate the apparent size of objects to their known or expected size (eg trees, vehicles and structures), but this technique is dependent on the presence of such objects and they are sparse over water. The third method is to estimate height by the texture of the surface and the speed at which it appears to be passing underneath the aircraft. This method is heavily dependent on the surface having a texture and, for example, small ripples can be visually interpreted as larger waves giving the false impression that the aircraft is much higher than is actually the case. When the wind is light and the water sheltered, the surface of the sea can be smooth and glasslike which reduces the sensation of speed and makes judgement of height difficult, even for the very experienced. Sometimes, in these conditions an aircraft can slowly descend or 'drift down' towards the surface without the pilot noticing the loss of height. All the local witnesses reported that the weather was fine and the wind very light or non-existent. Therefore the conditions were probably conducive to the 'drift down' reduction of height described above.

2.11.3 Fatigue

The commander had started work early on the previous day and had completed a long duty period encompassing nearly 8 hours of flying, much of which was demanding underslung work and he had finished duty at 1815 hrs. On the day of the accident he chose to rise early, most likely at about 0430 hrs, to start another long day. He worked all morning (over 7 hours) and then borrowed the relief pilot's car to go to Loch Glashen. The drive there, including a stop to buy food, would have taken about an hour and cannot realistically be considered as taking rest. He started flying again at 1645 hrs having had a break of about $4^1/_2$ hours but less than 4 hours rest. The environment in which he rested, a shed, was hardly ideal and he might have preferred to resume flying rather than wait another 2 hours for the relief pilot to complete the penultimate task as the operator had planned. In the event, he resumed flying and continued without a break until the accident some $3^1/_2$ hours later.

With regard to fatigue, the most significant factor is that the commander had been unable to take proper rest for nearly 16 hours since he arose that morning. Coming so soon after another early start and very long day, the commander may have been suffering from some of the effects of fatigue and these possibly contributed to the accident. It is also possible that he was so engrossed in low flying that he forgot about the relevance of the sling even though he knew it was still fitted. Alternatively, he may have decided to fly at a safer height and slowly drifted down without noticing the trend.

2.12 Flight time limitations

The CAA had approved the operator's flight time limitation scheme for aerial work which limited pilots to not more than 12 hours duty time per day and not more than 7 hours flight time. The commander exceeded both limits on the day before the accident. At the time of the accident he had been on duty for 11 hours and 10 minutes and he had exceeded the 7 hour flying limit.

Although not relevant to this accident, it was noted that there were a number of other air transport undertakings engaged primarily in underslung operations who had not been required to produce a flight time limitations scheme for approval by the CAA. This long standing situation is contrary to the ANO. It is therefore recommended that the CAA should either ensure compliance with the ANO requiring air transport undertakings engaged solely in aerial work activities to have a flight time limitations scheme or review this requirement.

2.13 The pressures to work long hours

The reasons why the commander apparently needed to work long hours deserve examination. Firstly, the salmon transport season is short and the work competitive; this naturally leads to commercial pressures on the operator to obtain maximum work from its aircraft and pilots for a short burst of a few weeks. The work rate can be enhanced by the use of part-time or short-term contract pilots and so the rosters tend to become more complicated than normal. Secondly, the salmon smolts are delicate and one lift of fish can be worth £10,000 to the customer. The prospect of dead or damaged fish would harm the relationship between customer and operator and so, if there is a lorry load of fish to transfer, a pilot will naturally feel some pressure to complete a task even if this means turning a blind eye to the letter of the law or company regulations. These are factors which cannot easily be ignored or overcome. There were, however, three factors which conspired to increase the pressure on the commander to work long hours which may have been avoidable.

2.13.1 Estimation of lifts

Customers estimated the number and size of fish to be transported and the operator estimated the time and number of 'lifts' required to complete a task. The operator appreciated that the customer had difficulty in estimating the size and number of fish. A certain degree of flexibility was incorporated into the daily schedule to allow for small errors, however, estimates were sometimes wildly inaccurate. For instance, on the day of the accident the commander started work at Jura at the appointed time but finished the task one hour later than expected. The reasons for the delay are unknown but whatever caused it, the slip in the schedule had three effects: firstly the commander worked for an hour longer than anticipated; secondly, it delayed the remaining tasks by an hour; and thirdly it meant that the commander would finish duty more than 12 hours after he had started if all the tasks were to be completed.

A second example is the penultimate task of moving fish from Loch Glashen. Four lifts were anticipated but in fact seven were required. The estimate was so inaccurate that there was insufficient space for all the fish in the sea cages at Tarbert and the commander had to take some to Portavadie. These deviations added about 90 minutes to the time the company's operations manager had allocated to the task.

The operations manager was an experienced scheduler and made allowances for small estimation errors but if the customer made a big mistake, the operator's schedule suffered. When that happened, all the other customers waiting that day also had their schedules disrupted and the operator's staff had to work longer hours or abandon some tasks. It was therefore recommended that the operator should explore methods of refining the accuracy of customer's estimates.

2.13.2 Estimation of turn-round times

Another reason why the day's schedule was unnecessarily extended was the use of a difficult site for the transfer of fish at Killean. Because the hatchery was surrounded by trees, loaded buckets had to be moved before being attached to the helicopter's sling. This difficulty delayed the plan by 40 minutes. The operator kept a log of landing sites and should have known that turn-rounds at Killean would take longer than normal for an unobstructed site. It was recommended that the operator should explore methods of refining techniques for estimating the time required to complete a given number of lifts.

2.13.3 Split shifts

Given the size of the task, it was a reasonable precaution for the company to roster a relief pilot to complete a proportion of the work and prevent the commander from exceeding his flying hour limitations. There was also no reason, according to the company flight time limitations scheme in Section 5 of the Operations Manual and the variation for aerial work in Section 3, why the pilot should not have worked a split shift system to extend his working day. The company FTL scheme stipulated that there should be "a quiet and comfortable place, not open to the public, if available" for a rest period of less than 6 hours. However, separating the FTL scheme into different sections of the Operations Manual gave scope for confusion between the main scheme and any variations. It is therefore recommended that the CAA should ensure that Operations Manuals which contain a FTL scheme should incorporate any authorised variations to the scheme in the same section of the Operations Manual as the main scheme.

What went wrong on the day of the accident was that the 'relief' pilot did not complete the tasks the operations manager assigned to him. He was supposed to do the Loch Glashen task and the commander was supposed to take over for the final hourlong task from Meall Mhor. However, the two pilots agreed between themselves that the deceased pilot would do both the remaining tasks. Why the two pilots agreed on this work share cannot now be determined accurately but by the time the relief pilot had completed two of the three tasks assigned to him, the schedule was about 3 hours 10 minutes adrift. This meant that the commander could not possibly have finished the remaining work within 12 hours of starting duty.

From about 1400 hrs the commander had been waiting for the helicopter to arrive at Loch Glashen and when it did arrive at 1630 hrs, having already waited two and a half hours, the commander might have preferred to resume flying rather than wait another two hours with only a shed or a vehicle in which to rest.

Because the first task of the day took one hour longer than planned, it should have been obvious to the commander at 1200 hrs that if all the tasks were to be completed that day he would exceed his duty and flying hour limits. During his 4 hour rest period he could have sought advice from the company and possibly re-scheduled some tasks for the next day but he did not do so. Moreover, the commander had exceeded his duty and flying hour limits the previous day without informing the company and so it seems more likely that he overlooked or ignored the time limits.

2.14 The monitoring of pilots' working practices

The operator had established methods for monitoring pilot fatigue but because the system was based on paperwork supplemented by telephone calls, it could not monitor the situation on a hourly basis for pilots operating away from base. In these circumstances pilots have to be trusted to obey the company's instructions and to keep a record of their own flying and duty hours. Pilots had a measure of discretion to alter their own flying programme but they were expected to keep the company informed of any problems and to observe the law.

In the days leading up to this accident there was evidence that the commander had begun to deviate from company instructions on several matters when operating away from the main base. He had transported fish farm workers in the helicopter directly across the Sound of Jura. (Despite the CAA exemptions, this was illegal because there was no liferaft on board). He had on more than one occasion left the helicopter unmanned with the rotors running. Despite having had the dubious practice drawn to his attention by ground crew, he had flown several transit sectors with an empty sling attached. He had also infringed the company's aerial work flight time limitation scheme and had not informed the operations manager that he had exercised discretion in so doing. Whilst no adverse comment about his skill is applicable, it is right to draw attention to the fact that although the commander apparently obeyed the company rules when he was under training and close supervision, he did not invariably do so when he was operating away from the main base.

2.15 Flight with an unloaded sling

The *'Transport External Loads'* supplement to the aircraft's flight manual contained an absolute maximum permissible speed limit of 80 kt *'with a load on the hook'* but no mention of any constraints regarding flight with an unballasted sling. There was scope for confusion in this section. With a sling attached to the helicopter there could be two devices called a hook; one which attached the upper end of the sling to the underbelly called the release unit hook, and another at the lower end of the sling to carry the payload. It was not obvious to the casual reader which hook was which, but on careful reading it was evident that the limit applied to the underbelly hook. This interpretation was reinforced by the operator's policy which was that if anything was attached to the underbelly hook, the helicopter would be carrying an underslung load, even if the sling had nothing attached to the lower hook. However, this policy was not written in any of the operator's various instructions to its pilots at the time of the accident.

It was noted during the AAIB's investigation of the accident to G-PLMG that this aircraft, an AS350B2, had a complementary flight manual. Section 9 of this manual contained recommendations for cargo sling operations. The final recommendation which was underlined stated: 'Never fly away with an empty net or an unballasted sling' This statement dispelled any confusion created by the wording of the supplement to the main flight manual.

Although there is little external difference between the dimensions of the AS350B and the AS350B2, the G-PLMA's flight manual did not contain a complementary section or any recommendations similar to those contained in the G-PLMG's complementary flight manual. Moreover, no separate complementary flight manual for G-PLMA was recovered from the aircraft. Consequently, the only way for the commander to know for sure that transit flights with an unballasted sling were forbidden was if he was told or if he asked. He had been told on more than one occasion by ground crew. Moreover, the commander had extensive experience of underslung load operations and he should have known of the inherent dangers without being told or having to ask. It was a simple matter of common sense and discipline.

Following the accident to G-PLMG, the operator reviewed company procedures for underslung loads. The management discussed the accident with the workforce and on 4 April 1995 PLM Helicopters wrote to the CAA explaining that their pilots were surprised that the pilot of G-PLMG had transited with a sling attached. The letter also stated that it was *'more firmly our policy not to transit with a trailing sling'*.

Given all these factors, it is surprising that the operator did not take additional precautions to ensure that both statements - an important warning in a flight manual and the company's firmer policy - were made more visible to all its pilots, including the freelance pilots. The management did take other actions which were laudable but there was no mention in the company's operations manual or its 'Smolt Transfer' document that transit flights with an unballasted sling were prohibited. Given that by this time, the operator had acted to ensure that all its slings had been fitted with ballast weights, this was reasonable. On the other hand, no mention was made of the company's firm policy which discouraged transit flights with a trailing sling.

It was not until after the accident to G-PLMA that the operator issued a clearly worded Notice to Pilots stating that "*pilots SHALL ensure that, whenever possible, the aircraft does not transit with an unballasted sling attached to the cargo hook*". To avoid any future misunderstandings, it is recommended that:

a. The operator should prohibit transit flights with an unballasted sling and discourage transit flights with a trailing sling in the aerial work section of the company's operations manual.

b. The operator should define the phrase 'transit flight'.

c. Eurocopter should clarify its stipulated and recommended procedures and limitations for flight with an external load and place the amended text in the appropriate supplement to the official flight manual.

Eurocopter has confirmed that the complementary flight manual exists for the AS350BA, B1 and B2 helicopters but that it is not approved by the certification authorities. They have stated their intention to incorporate this manual in a future revision of the AS350B Flight Manual.

2.16 Survivability

Undoubtedly the separation of the blade tip was the key event in the process which led to the accident. It was not, however, the direct cause because helicopters have been force-landed before with similar damage. There can be no doubt that as soon as the tip broke off, the commander would have been aware of severe vibration. At that point he would have known that his best chance of survival lay in landing as soon as practicable. He had two choices: either to ditch on the water or to continue towards land. We know that he chose the latter option but his decision may have been influenced by the fact that he had chosen not to wear either a lifejacket or a survival suit when flying over cold water.

The nearest land was probably the promontory at Castleton but there was little flat ground in the area. The commander probably flew low over the fields looking for a flat, unobstructed piece of ground upon which to execute a run-on landing. Suitable terrain was sparse in that area and he may have decided to return to the beach. On the other hand, it may be that loss of control randomly brought him to the beach. In either case, the separation of the gearbox foreclosed on any other option but to crash land on the rocky ground beside the shore.

The crash was survivable but the commander died, principally because the seat and the restraint systems failed and he remained attached to the aircraft by his headset lead under tension which resulted in his asphyxiation. These survival aspects are analysed in the following paragraphs.

2.16.1 Cabin

While the cabin bottom structure did not suffer severe damage, most of the panels forming the above floor cabin structure broke up and detached. The panels were of relatively lightweight plastic construction and it did not appear that they would provide a high level of protection to cabin occupants in a crash situation. However, there were no signs that they had experienced large incursion loads during the rollover or that the cabin space had suffered gross incursion that was likely to have had a decisive effect on survivability in this case.

In spite of the absence of severe damage to the bottom structure, it was clear that ground impact on the forward right part of the structure had resulted in local deformation of the floor in the region beneath each forward seat. Loads applied to the bottom structure by the seats may have contributed to this and the location of the seat attachments in relation to the bottom structure stiffeners may have been a factor. Each seat straddled one of the two bottom structure longerons, the main structural members; local longitudinal stiffening was present beneath each floor rail but this was not particularly robust. The turnbuckles were located between the frames that formed the lateral stiffeners of the bottom structure and there were no lateral floor panel stiffeners directly between the forward and aft pairs of turnbuckles for each seat that could have assisted in reacting lateral buckling loads on the panel in these areas. The bearing area of the captive nut for each turnbuckle was relatively small and only very localised failure of the floor panel and longitudinal stiffener had been necessary for the aft left turnbuckle for the left seat to pull through the stiffener and the panel.

2.16.2 Pilots' seats

The seat detachment appeared incommensurate with the relatively moderate damage to the main structure of the cabin and with the pathology evidence that both the in-flight problems and the ground impact had been survivable. However, the detachment was unsurprising in view of the apparent lack of robustness of the seat and its attachments, as demonstrated by the release of the left seat, which had been unoccupied and did not exhibit signs of substantial impact. The detachment of the occupied right seat had been occasioned by failures both in the seat moulding and in the floor attachments.

Specialist opinion judged that the GRP material of the base around the seat rail would have been relatively weak in through-plane shear and the fracture of the right seat base in this area left the right side of the seat separated from the floor. Similar failures had occurred on both sides on a previous survivable AS350B accident (G-PLME, para 1.15.2), and the pilot had sustained a back injury. The localised failures of the GRP at the rear end of the seat rail that had been found in a number of cases after normal service usage also indicated a lack of robustness in this area.

The foreshortening in the lateral distance between the left and right pairs of turnbuckles for each seat occasioned by the floor buckling would have applied inward loading on both seat rails; given their channel section they would be expected to be able to cope with relatively high loads in this direction without major rail distortion. However, the reaction to such loads by the rail/seat attachment bolts would produce an outward rolling moment on each rail which would be reacted in turn by local twisting of the seat base structure and of the bottom structure. As the seat was likely to be comparatively flexible locally, a substantial part of the rolling moment would probably be transferred to the twisting reaction between the seat rail and the turnbuckle/bottom structure.

The seat rails were comparatively robust, but the slots accommodating the turnbuckles were long and the part of the rail forming the outer edge of each slot was slender and would be expected to have relatively low bending stiffness in either the vertical or horizontal plane. Apart from reducing the spacing between the turnbuckles, the floor buckling would also locally have attempted to force the seat rails upwards and this would have been reacted as downward loading applied to the rails by the turnbuckles; it also was possible that the twisting effect described above, and/or dynamic responses of the structure and the seats during the impact, had at some stage applied outward loading on the outer part of the seat rails. In the case of the right seat, the failure of the laminate on the right side of the base could have caused a transfer of loads to the left seat rail and in the initial part of the impact there was likely to have been a component of inertial loading to the right, which would have applied outward lateral loading on the left seat rail from the turnbuckles. While the overall loading could not be quantified, it was apparent that most of the seat rails had been distorted in a manner that had widened the slots and that the attachment method was quite intolerant of this, with only some 5 mm slot widening being necessary to release the rail from the turnbuckles. This had occurred for three of the four rails.

The seat rail reinforcement modification described in SB 25.24 would have provided some additional resistance to rail distortion in the slot widening sense, although it appeared unlikely that it would have produced a gross improvement, given the cantilevered mounting of the reinforcement bracket. (G-PLME was fitted with this modification and suffered seat failure.) However, G-PLMA had been constructed before the reinforcement had been incorporated on the production line. The SB apparently is classified by the manufacturer as Optional, had not been classified as Mandatory by the CAA and the modification had not been incorporated on G-PLMA. The SB did suggest that, although the manufacturer reported no knowledge of cases of serious failure of this type of seat in normal service or in survivable accidents, it had identified slot widening distortion of the seat rails as a weakness. The modification had clear implications of survivability enhancement and no information was available as to why the manufacturer had not classified it as mandatory. The inconsistency between the operator's claim to have informed the manufacturer of their concern over seat detachment and the manufacturer's report of no knowledge of previous failure cases in survivable accidents could not be resolved.

It was therefore concluded that a number of factors had probably contributed to the release of the forward seats. These were the relatively low through-plane shear strength of the seat base laminate in the seat rail attachment area, the relatively low buckling resistance of the local floor structure and the comparatively low bending strength of the outer part of the seat rails, given the intolerance of the attachment method to seat rail distortion, particularly in the absence of the rail reinforcing modification. Such failures had not occurred during the seat certification test but this required the effects of loading only along principal axes without the simulation of floor deformation, dynamic responses or pre-existing normal usage damage. The seat test loads had exceeded the FARs applicable at the time and met or exceeded the BCARs applied by the CAA to UK type certification.

Irrespective of the adequacy of the requirements, it was clear that the seat and its attachments had suffered catastrophic failure in an accident that was survivable. It was apparent that the seat and its attachments lacked robustness, and that the attachment of the shoulder strap inertial reel to the seat itself would force the seat to transfer shoulder strap tension loads into the aircraft structure. These would comprise the principal crash inertia loads in some cases and the seat floor attachment loads would be greatly reduced were the inertial reel to be mounted directly to the floor. Additionally, the consequences of seat detachment could then be less serious as the shoulder straps would at least remain attached to the aircraft in the event of the seat breaking free.

It has been recommended that the CAA, in conjunction with the DGAC, should require reassessment of the crashworthiness of the AS350 forward seat and its floor attachments, including consideration of seat rail reinforcement, relevant aspects of the helicopter bottom structure strength and floor mounting of the shoulder strap inertia reel, with the aim of preventing seat detachment from the floor in a survivable impact. A similar assessment should be made for the AS355 helicopter which has an identical seat.

It appeared likely that the detachment of the pilot's seat had an adverse effect on the pilot's chances of surviving the accident. In the impact experienced, with the pilot initially being thrown forwards, downwards and to the right, it would be expected that the seat would play a part in reacting the inertial loads, to a minor extent by acting directly on the pilot but principally by anchoring the shoulder straps. The detachment of the seat therefore may have had the effect of increasing the loads applied to the lap strap and may have contributed to its failure (para 2.16.3). It was also likely that seat deformation would have provided some load attenuation for the pilot, particularly in the downward sense, if the seat had remained attached, whereas its detachment could have allowed the pilot to make violent contact with parts of the helicopter. This was made more likely by the failure of the harness lap strap.

2.16.3 Pilot's harness

An absence of distress to components of the harness other than the failed loop stitching, and the absence of markings on the pilot's body characteristic of high harness restraint loads, suggested that the stitching failure had resulted without the lap strap having been grossly overloaded. In the circumstances it was judged likely that the maximum loads on the lap strap had occurred when the seat detached from the floor, thus removing any restraint on the pilot provided by direct contact with the seat and by the shoulder straps and leaving the lap strap to react all the inertial loads of the pilot and his seat.

Although specialist opinion considered that the pattern and extent of the stitching used to fasten the strap loop was unsuitable, testing did not indicate that this constituted a weakness in practice; only one of the four straps tested to destruction broke due to loop stitching failure and this occurred at a somewhat higher load than that required to fail the webbing of one of the other test straps. No signs were found that the repair to the lap strap that failed in the accident had significantly affected its strength. The testing, albeit limited, did suggest an appreciable loss of strength in service, with the used straps failing at between 63-79% of the load at which the unused straps broke. The age and repair date of the used straps was unknown but they appeared to be in a similar condition to the right harness, which had a 1980 repair date.

The unused strap failure loads achieved in the testing exceeded both the BCAR and FAR factored loads applicable at the time of certification of the helicopter type; the used straps, while exceeding BCAR loads, failed at somewhat less than the FAR factored load. While left and right harnesses appeared to be in similar condition, the right harness was likely to have been much more extensively used than the left and it was possible that it had suffered a greater loss of strength. The reasons for the failure of the pilot's harness at an apparently moderate load could not be positively established. It does appear likely that the failure was a crucial factor in the pilot's death following what was a potentially survivable accident. Eurocopter have stated their intention to include an operating time limit for this type of equipment in a future revision of the Master Servicing Recommendations.

The effectiveness of a visual inspection in determining the strength of a stitched fabric component is clearly limited and yet this is the only means employed to assess the fitness of a harness for continued service. It has therefore been recommended that the CAA give detailed consideration to requiring a programme of sample testing of aircraft harnesses aimed at establishing their fitness for continued use and, if necessary, imposing a life limitation.

2.16.4 Pilot's headset lead

It was clear that the failure of the headset lead plug to disconnect from the helicopter socket during the accident sequence, or of the assembly to break, had left the pilot forcibly restrained by his helmet chinstrap, causing his tragic asphyxiation. This was particularly unfortunate in view of the high degree of protection otherwise provided by the helmet.

Although the combination of failures which resulted in this fatality were unusual, there were considered to be other circumstances when the ready release of the headset lead would be vital for the rapid egress of the crew; for example in a post-crash fire when the crew were not otherwise incapacitated, or following a ditching. Measures aimed at ensuring the release of the headset lead in such situations, such as the provision of an in-line plug and socket in the lead, could be simple and inexpensive. Eurocopter have stated their intention to issue a Service Letter to customers recommending the insertion of a small flexible extension lead between the helmet lead and its receptacle in the cabin. Because this may have relevance to other aircraft it has been recommended that the CAA assess the need for measures aimed at ensuring that headset leads readily disconnect if tensioned during an accident.

2.16.5 Airworthiness

No evidence was found to indicate that the seats and associated floor attachments or the pilot's harness had failed to meet the requirements considered by the airworthiness authorities to be applicable to type certification, and the results of a static test of a sample unused seat and harness combination by the manufacturer had indicated that it met, and in some regards exceeded, these requirements. However, it was clear that the forward seats and their attachments and the pilot's harness had suffered catastrophic failure in an accident that was survivable. While accepting that the required standards cannot protect against all eventualities, it could reasonably be expected that the occupants' seats would remain in place and harnesses would remain intact in a case such as this, where there were no signs of massive shock loading and where the aircraft was substantially intact with the pilot alive and without immediately life-threatening injuries. Such an expectation was effectively reflected in the issue of BCAR G4-4 to which the AS350 was certificated, namely that the requirements "are intended to ensure that the occupants of a rotorcraft are provided with reliable and adequate facilities for resisting dangerous movement when subjected to the forces appropriate to normal and emergency conditions."

That both the pilot's seat and his harness failed could have been influenced to some extent by in-service deterioration, but the evidence also strongly indicated that the crash load requirements applied had been inadequate. Such an inadequacy was also indicated by specialist opinion that crash accelerations very much greater than those specified by FAR Amdt 10 and the 1966 BCAR issue are likely to be experienced in many potentially survivable aircraft accidents. It was also borne out by the three to four fold increase in the principal crash load requirements in the 1989 FARs resulting from studies of experience.

While it could be prohibitively expensive and difficult to require retroactive application of all upgraded airworthiness requirements to previously certificated aircraft types, it would seem reasonable for some improvement to be required in safety-critical areas where experience had demonstrated that original requirements had been inadequate. The approach that no improvement is necessary in such a case because original certification requirements were met does not seem reasonable or to reflect the likely expectation of those using the aircraft. In the absence of such improvement, relatively recent, and indeed new, aircraft remain fitted with equipment crucial to crash survival that is qualified to airworthiness requirements that were superseded many years previously; in this case to requirements last revised almost 42 years ago, that had been upgraded before UK type certification was granted and that are grossly inferior to current requirements, by a factor of 3 or 4.

Given this context, the apparent absence of any action in response to the operator's concerns over the crashworthiness of the seat that were brought to the CAA's attention in 1993 in a CAA Mandatory Occurrence Report on a previous accident is of particular concern. It has therefore been recommended that the CAA revise their procedures to ensure that evidence of unsatisfactory in-service performance of components in safety critical areas reported to the CAA results in investigation by the Authority. Where a potential hazard is identified this should result in significant improvements to those components, even where the requirements in force at the time of type certification were demonstrated to have been met.

2.16.6 Survivability summary

The accident was judged to be potentially survivable and this was supported by the absence of immediately life-threatening injuries to the pilot. The crucial factors leading to his death were the failure of his harness and the level of restraint provided by the headset lead assembly. The detachment of the seat may not have directly greatly diminished his chances of survival but may have made a substantial contribution to the catastrophic harness failure. Available evidence indicated that the strength of an unused harness of the type met airworthiness requirements applicable at the time of type certification, but suggested that the harness had failed without having been grossly overloaded, possibly in part due to undetected deterioration in service. It is judged that the current method of assessing the continued airworthiness of restraint systems is unsatisfactory. The seat and harness failure probably resulted largely from crash loads that exceeded those specified by the original certification requirements. It is likely that loads greatly in excess of the latter will be experienced in many survivable accidents.

3 Conclusions

(a) Findings

(i) The pilot was licensed and qualified to conduct the flight.

(ii) The helicopter had valid Certificates of Airworthiness and Maintenance and had been maintained in accordance with an approved schedule.

(iii) The helicopter was below the maximum permissible weight and was within the centre of gravity limits.

(iv) The helicopter was flying in transit with a ballasted sling attached to the underbelly hook and without any load attached to the bottom hook of the sling.

(v) The commander probably was aware that the sling was still attached to the helicopter when he deliberately flew at low height over Loch Fyne.

(vi) It is probable that the end of the sling contacted the surface of the loch and rebounded into the tail rotor.

(vii) The separation of the tip of one tail rotor blade was probably caused by impact with the weighted hook on the end of the sling.

(viii) The severe out of balance forces on the tail rotor resulting from the loss of one blade tip caused the separation of the tail rotor gearbox from the tail boom.

(ix) Separation of the tail rotor gearbox made an accident inevitable.

(x) Weather and sea conditions at the time of the accident would probably have impaired the commander's ability to judge his height above the sea whilst low flying.

(xi) The commander was probably suffering from a degree of fatigue having worked in excess of the permitted duty and flying hours.

(xii) The operator's flight time limitation scheme for aerial work did not specify a minimum overnight rest period.

(xiii) The commander did not invariably obey the operator's instructions when operating away from main base.

(xiv) Delays in the operator's plan for the days work increased the commander's duty hours.

(xv) The operator's plan relied upon the commander working a split shift.

(xvi) The pilot survived the ground impact without sustaining immediately life-threatening injury but remained attached to the aircraft by his headset lead and helmet strap under tension and died from asphyxiation.

(xvii) The pilot's seat, its attachments and the local floor structure appeared to lack robustness.

(xviii) The seat detachment and the harness failure severely reduced the pilot's probability of survival.

(xix) The reasons for the harness failure could not be positively determined but deterioration with age and usage was likely to have been a factor.

(xx) The current method of assessing the continued airworthiness of aircraft restraint systems is unsatisfactory.

(xxi) A modification to the pilot's seat rails issued by the manufacturer ten years before the accident would have reduced the likelihood of seat detachment, but probably only marginally. This modification was categorised as non-mandatory and had not been incorporated.

(xxii) The crash loads to which the pilot's seat and its attachments had been tested for type certification met or exceeded those required by BCARs.

(xxiii) It is likely that crash loads greatly in excess of the values specified by the original certification requirements will be experienced in many survivable accidents.

(b) Causal factors

(i) The commander unwisely decided to fly low over Loch Fyne with a sling attached to the belly of the helicopter.

(ii) The commander's judgement of height may have been adversely affected by the calm sea and weather conditions.

(iii) The commander may have been suffering from a degree of fatigue because he had worked in excess of the permitted duty and flying hours.

(iv) The inaccurate estimation of the task resulted in increased pressure on the commander to complete the work.

4 Safety Recommendations

The following recommendations were made during the investigation:

4.1 The CAA should either ensure compliance with the ANO requiring air transport undertakings engaged solely in aerial work activities to have a flight time limitations scheme or review this requirement. [Recommendation 96-51]

4.2 The operator should explore methods of refining the accuracy of customer's estimates. [Recommendation 96-52]

4.3 The operator should explore methods of refining techniques for estimating the time required to complete a given number of lifts. [Recommendation 96-53]

4.4 The CAA should ensure that Operations Manuals which contain a flight time limitations scheme should incorporate any authorised variations to the scheme in the same section of the Operations Manual as the main scheme. [Recommendation 96-54]

4.5 The operator should prohibit transit flights with an unballasted sling and discourage transit flights with a trailing sling in the aerial work section of the company's operations manual. [Recommendation 96-55]

4.6 The operator should define the phrase 'transit flight'. [Recommendation 96-56]

4.7 Eurocopter should clarify its stipulated and recommended procedures and limitations for flight with an external load and place the amended text in the appropriate supplement to the official flight manual. [Recommendation 96-57]

4.8 It has been recommended that the CAA, in conjunction with the DGAC, should require reassessment of the crashworthiness of the AS350 forward seat and its floor attachments, including consideration of seat rail reinforcement, relevant aspects of the helicopter bottom structure strength and floor mounting of the shoulder strap inertia reel, with the aim of preventing seat detachment from the floor in a survivable impact. A similar assessment should be made for the AS355 helicopter which has an identical seat. [Recommendation 96-58]

4.9 The CAA should give detailed consideration to requiring a programme of sample testing of aircraft harnesses aimed at establishing their fitness for continued use and, if necessary, imposing a life limitation. [Recommendation 96-59]

4.10 The CAA should assess the need for measures aimed at ensuring that headset leads readily disconnect if tensioned during an accident. [Recommendation 96-60]

4.11 It has therefore been recommended that the CAA revise their procedures to ensure that evidence of unsatisfactory in-service performance of components in safety critical areas reported to the CAA results in investigation by the authority. Where a potential hazard is identified this should result in significant improvements to those components, even where the requirements in force at the time of type certification were demonstrated to have been met. [Recommendation 96-61]

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