Aircraft Type and Registration:	Aerospatiale AS350B2 Ecureuil, G-PLMG
No & Type of Engines:	1 Turbomeca Arriel 1D1 Gas Turbine Engine
Year of Manufacture:	1991
Date & Time (UTC):	7 December 1994 at 1500 hrs
Location:	Ballachulish, Scotland
Type of Flight:	Aerial Work
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - Fatal Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Airline Transport Pilot's Licence (Helicopter)
Commander's Age:	47 years
Commander's Flying Experience:	7,000 hours (of which 3,500 hours were on type) Last 90 days - 100 hours Last 28 days - 18 hours
Information Source:	AAIB Field Investigation

Flight Profile

The aircraft had flown a task from Inverness earlier on the morning of 7 December 1994 and was fully serviceable after flying for a total of 1 hour 1 minute. It landed at 0948 hrs and, before being taken over by a new pilot, was refuelled by the crewman detailed to accompany the pilot on the subsequent task.

Planned flying for the rest of the day involved three separate underslung lifting tasks at Tarbert, Bonawe, and Ballachulish respectively. The weather forecast for the day was subsequently confirmed by an aftercast from The Meteorological Office at Bracknell, and showed a very strong to gale force and unstable southwesterly airstream established over Scotland. There were frequent showers of rain, hail and rain, snow, and a small probability of thunderstorms; visibility was 30 km deteriorating to 2,000 metres in the heaviest showers; cloud was scattered, occasionally broken, base around 2,000 feet, with isolated cumulonimbus base 1,000 feet. Cloud was covering some hill tops. The surface wind was 240/20 to 25 kt with gusts 35 to 40 kt and the wind at 2,000 feet was 240°/40 kt.

The mean sea level pressure was 987 mb and the surface temperature was 5°C. With the strong surface wind, severe turbulence was a significant feature in the hilly terrain. The flight profile of G-PLMG from takeoff at Inverness to the accident site near Ballachulish was reconstructed using information from radio recordings, eyewitnesses, and technical log entries.

The pilot of G-PLMG took off from Inverness at 1015 hrs and landed at Tarbert at 1127 hrs; prior to departure the aircraft was recorded as having a total of 420 kg of usable fuel on board. In the Tarbert and Stonefield Castle area the crew carried out a total of 31 lifts, and also refuelled with 152 kg of fuel; this task took 1 hour 57 minutes to complete and was the last recorded entry in the aircraft technical log. At 1341 hrs the pilot of G-PLMG contacted Scottish Control to ask for the latest altimeter pressure settings, and informed them that he was en route from Tarbert to Bonawe. He also asked Scottish Control to contact his company, and inform them that he was running about an hour late, that he would be unlikely to get back to Inverness that night and that he would probably be spending the night at Fort William; this message was passed to the parent company of G-PLMG by Scottish Control. Subsequent timings were compiled from witness statements and from route calculations. The flight time from Tarbert to the next task at Bonawe was approximately 18 minutes and G-PLMG arrived at Bonawe around 1400 hrs; this job involved moving agricultural feed from a farm to outlying areas and took 12 lifts and about 40 minutes to complete. At Bonawe, two farmers met the crew and briefed them on where the feed was to be positioned. One of the farmers flew with the pilot in G-PLMG to show him some of the locations; he subsequently stated that the pilot, whom he knew, was in normal spirits. Both farmers confirmed that the weather conditions in the area were in accordance with the aftercast described in the first paragraph above. They also stated that they last saw G-PLMG departing with the final feed load at the completion of his task; they later confirmed that this final load had been delivered to the nominated location.

The approximate track which the pilot of G-PLMG would have been expected to take as he approached the pick up point at Ballachulish is shown on the map at Figure 1. Two witnesses saw the last few seconds of the flight of G-PLMG. The first witness was on the northern edge of Ballachulish (at position "A") looking south, and stated that he saw the helicopter for a maximum of 5 seconds. When he first saw it, the aircraft was flying towards Ballachulish but moving slightly from his right to left. He estimated that the helicopter was flying at 300 to 400 feet agl and he could see something black in colour suspended below it. He then saw the black object drop off, and almost immediately the aircraft noise stopped; the aircraft went into a vertical attitude with the nose down. There was a whisp of smoke from the tail end and the helicopter spiralled round until it went out of sight. The other witness was located near the pick up point ("B") south of Ballachulish and was waiting to assist the crew of G-PLMG who were tasked to do 12 agricultural feed lifts for a farming colleague of his. He had been waiting for the helicopter since 1400 hrs, which was the original planned meeting time, but did not hear the noise of the approaching helicopter until between 1445 hrs and 1500 hrs. When he heard it, he began to walk up to where the feed loads were positioned but, as he looked up at the helicopter he saw that it was vertical in the sky with its nose pointing to the ground; he saw a puff of smoke coming from it and the helicopter seemed to cartwheel 2 or 3 times out of his sight.

Underslung load equipment

The underslung load hook on this aircraft was of the cable-operated pilot-releasable type and was attached to a tubular lift-frame, the latter being suspended from beneath the belly of the aircraft by a system of four short cables.

The lifting strop and load hook arrangements comprised, working from the top down, a 1 metre length of thick woven rope used to *soften* the take up of load in the main strop, this being connected to the strop proper which comprised a wire cable 4.5 metres long and 14 mm in diameter, the lower end of which passed through, and was clamped to, a 3 kg ballast weight in the form of a steel ball 9 cm in diameter. Immediately below the ball, the strop cable terminated at a self-locking hook, the safety catch of which comprised a sprung-loaded tab which was recessed into the *shoulder* part of the hook. Attached to this hook, was a separate self-releasing hook assembly weighing some 11 kg.

The diagram at Figure 3 shows the general arrangement of the self-releasing hook and its attachment to the main lifting strop. The hook assembly comprised a pair of separate hooks attached to the ends of an "L" shaped *chassis* frame formed from a pair of steel plates bolted back-to-back, with the hooks interposed between. The attachment point, to which the hook on the main strop was connected, comprised a spacing pillar bolted between the two plates at the *corner* of the "L". One of the two hooks was fitted with a steel counterweight on the end of an arm attached to the top of the hook, arranged in such a way that without a moderate load attached to the hook the counterbalance weight would fall to the lowest point, thereby swinging the hook into the inverted (release) position. The other hook was a standard self-locking type. In use, a ground handler would manually attach the load by lifting the counterweight so as to bring the hook into the lower position, placing the load straps over the hook and holding them in place until the aircraft started to pick up the load. Once the load started to lift, its weight maintained the hook in the *bottom* position where it remained throughout the flight until the drop off point was reached and the pilot lowered the load onto the ground. As weight came off the hook, the counterweight was sufficient to overcome the weight of any webbing or other straps attached to the load itself, thereby swinging the hook up into the vertical position and disconnecting the load straps without any need for a ground handler to be present. (The *fixed* hook was used to facilitate certain types of lifting operation in which the load was suspended from a strap looped from the fixed to the self-releasing hooks; only the self-releasing hook was being used on the day of the accident.)

A range of strops and hooks had been developed by the operator over many years of underslung operations, and the strop and hook combination in use on the day of the accident was intentionally ballasted, both by the use of the steel ball and by the heavy weight of the self-releasing hook, so as to reduce risk of the hook trailing back and entering the tail rotor disc during transit hops between the drop-off and pick-up points. Notwithstanding this, it was company practice to disconnect the strop from the belly hook and to stow it in the cabin during transit flights between tasks.

The impact site

The aircraft had impacted the side of the hill in a slightly nose down pitch attitude with negligible forward speed, but with a very high rate of descent and a substantial sideslip velocity to the left. Although rescuers reported a very strong presence of fuel when they first attended the scene, and indeed had located the wreckage initially by the strong smell of fuel, there was no post-impact fire.

The combination of the aircraft's sideslip velocity to the left and the steeply sloping hillside (the high ground being to the aircraft's left side) resulted in total disruption of the left side of the cabin and fuselage. Debris from the cockpit and cabin area was thrown up the hillside over an area extending some 75 metres from the main wreckage.

The rearmost part of the tail boom, with both vertical stabilisers still attached, was found separate from the main wreckage some 400 metres to the south. Figure 2 identifies the point of separation.

The area was searched thoroughly, both on foot and from the air. Although the nature of the terrain made it impossible to exclude the possibility entirely, no evidence was found to suggest that the aircraft had been carrying an underslung load, eg a fuel drum, on the accident flight.

Examination of wreckage on site

None of the hatches, doors, or fairings had separated prior to impact. All flying control linkages were found to have been connected and intact at the time of impact; none of the main rotor pitch control hydraulic actuators was at an extreme position, and the main gearbox mountings (which can influence the main control actuator reference positions) were sound. The tail rotor actuator was at the full pedal position, consistent with the response one would have expected from the pilot to the loss of tail rotor drive. The collective pitch lever, as found, was at a low pitch position but would have been subject to impact disturbance; the governor input quadrant was at a position consistent with approximately 45% torque. Fuel was present in the engine fuel filter and the engine fuel control was in the *flight* position at impact. Extensive main blade damage and ground penetration, together with a torsional overload failure of the main gearbox input coupling, indicated that there was substantial rotational energy in both the main rotor and the engine at impact.

The underslung load strop, together with its hook, had trailed back from its attachment point beneath the belly of the aircraft, the hook and cable passing up on the right side of the tail boom between the trailing edge of the right horizontal stabiliser and the tail rotor, and looping up and over the top of the tail boom, onto the left side. In doing so, the strop had sliced forward into the trailing edge of the right stabiliser as far as the front (main) spar. As found, the lift strop had released from the belly hook, but the *top* end of the strop was lying immediately adjacent to the hook and it was apparent that ground impact forces had wrenched the mechanical release cable, causing the belly hook to release the strop when the aircraft struck the ground. (It was evident, therefore, that contrary to the usual practice, the strop had not been removed and placed in the cabin prior to the aircraft starting the transit flight to Ballachulish.) The counterbalance weight of the self-releasing hook had punctured, and remained impaled within, the lower sector of tail boom on the left side, opposite and just forward of the tail rotor. The self-releasing hook assembly was disconnected from the self-locking hook on the end of the main stop; however, these two hooks were lying immediately adjacent to one another in the wreckage and it was apparent that the impact of the self-locking hook into the soil had forced back the recessed locking-tab, allowing it to release its connection to the self-releasing hook assembly.

The tail rotor blades displayed no evidence of rotational energy at impact, and there was a clear static imprint caused by transfer of paint from the face and trailing edge of one blade onto the surface of a rock at the impact point. The leading edge capping at the extreme tip of this blade exhibited evidence of a glancing blade strike, and the fibreglass skinning of the blade adjoining the strike was damaged and smeared with red paint; further inboard, the face of the blade was randomly scored and scratched where it had impacted the rock. The other tail rotor blade was virtually undamaged over most of its length but the blade had been cleanly severed at a point approximately 75% from the root due to a strike on its leading edge. Smears of red paint were present on the surfaces of the stainless steel leading edge capping strip adjoining the strike. The severed part of this blade was never recovered.

Examination of the (red painted) self-releasing hook revealed fragments of tail rotor blade leading edge material jammed tightly into the gap between the secondary (fixed) hook and the side-plate members, indicating beyond all doubt that the hook had struck the tail rotor, resulting in the separation of the outer part of the blade. The direction of rotation of the tail rotor is such that the lowermost blade arcs forwards and upwards, and it was evident that the strop and hook had trailed rearwards and upwards into the tail rotor disc, the resulting strike throwing the hook, and the attached strop and ballast weight, up and over the trailing edge of the right-hand horizontal stabiliser. The energy associated with this process caused the strop to cut forward through the trailing edge of the right stabiliser, and the hook-end of the strop to wrap violently up and over the tail boom, the counterbalance weight of the self-releasing hook impaling the tail boom as it reached the end of its *swing*.

The extreme rear section of the tail boom, together with the still attached vertical stabilisers, had separated from the tail boom due to disruption of the tail boom structure at the tail rotor gearbox mount frame. The remote location of the detached parts was consistent with airborne break-up of the tail boom structure in this region, and separation of the rear section of tail boom and stabilisers at altitude. The structural damage associated with this break-up was consistent with heavy out-of-balance tail rotor forces following the blade strike, these forces being transmitted from the tail rotor gearbox casing into the thin tail boom shell structure via the heavy gearbox mount frame. The resulting disruption of the tail boom shell structure, combined with aerodynamic loading on the vertical stabilisers (which are mounted aft of the gearbox mount frame), evidently resulted in separation of the stabilisers and the rearmost part of the tail boom. Evidence of rotational rubs and scores were found on the tail boom structure adjacent to the tail rotor gearbox input coupling, which could not have occurred in the absence of gross movement of the gearbox in relation to the tail boom structure. A characteristic cut in the tail boom structure in the area of separation showed that, following structural separation, the tail section and vertical stabilisers had remained briefly attached to the aircraft by electrical cables before finally separating and falling free. (This is a possible explanation of the dark object seen by one of the witnesses suspended from the aircraft, then dropping away.)

The tail rotor drive shaft had failed at the input to the tail rotor gearbox, due to a bending mode of failure associated with the gross rocking movements of the gearbox following the tail rotor strike. Prior to the shaft failing, these movements had produced the rubs and scores on the tail boom structure remarked upon previously, and it was therefore evident that the shaft failure had occurred after the blade strike, at about the time when the tail section had separated. With this exception, and random damage directly attributable to the ground impact, no evidence of tail rotor drive-line failure was found. It was therefore evident that the tail rotor strike itself had not resulted in an overload failure of the tail rotor drive system, and consequently the tail rotor would have continued to be driven at undiminished speed following the blade strike until the out-of-balance gearbox loads and associated damage resulted in failure of the tail boom structure, fracture of the drive shaft, and separation of the tail section and vertical stabilisers.

Additional Information

Medical factors

The post-mortem examination revealed no evidence of any medical condition which may have contributed to the accident.

Fuel management

Company regulations state that the minimum fuel quantity in flight is 10% of full capacity, ie 42 kg; the aircraft fuel warning light comes on at 12% capacity, ie 47 kg and this fuel amount would give a flight time of approximately 18 minutes at maximum continuous power. Normally the aircraft are refuelled at base but the company have established fuel dumps at various diverse locations to optimise aircraft operations. On the accident flight, the crew had refuelled to full prior to departure and had then added a further 152 kg of fuel from a fuel dump at Stoneyfield Castle. The fuel dump at Stoneyfield Castle had been replenished on 20 July 1994 with 2 barrels of fuel, and the use of one by G-PLMG was the first time the dump had been used since then; subsequent examination of both the empty and remaining full barrels showed no apparent problems with the fuel. Calculations were also made to ascertain the amount of fuel used by G-PLMG during the accident flight. Comparing the assessed flight time of 4 hours 30 minutes against the documented fuel on board of 572 kg, there would have been approximately 47 kg of fuel left at the time of the accident. There is another fuel dump just to the east of Ballachulish, and the normal practice would have been for the pilot of G-PLMG to have overflown his next customer before going to refuel.

Operating with an unloaded strop

A previous incident had occurred on 28 March 1988 to a similar helicopter of the same company and flown by the same pilot, reported in AAIB Bulletin 6/88. During a flight to transfer a load of fish between 2 sites the helicopter experienced severe turbulence and the strop contacted the tail rotor. On that occasion the pilot landed the aircraft safely. Following that incident, the operator had modified his procedures and equipment and instituted a recommended maximum airspeed of 80 kt when flying with an unloaded strop, this being intended to reduce to a minimum the probability of the strop or a hook *flying* up into the tail rotor. However, the company's experience of operations with the particular strop and hook combination involved in the accident suggested that even if the pilot on this occasion had temporarily forgotten that he was transiting between tasks with the strop attached (an unusual situation) and had allowed his speed to rise, this still should not have resulted in the hook getting anywhere near the tail rotor.

In the immediate aftermath of the accident, the operator elected to explore the behaviour of a similar strop and hook combination by flying an AS350 aircraft with a strop and hook similar to that involved in the accident at progressively increasing airspeeds up to a maximum of 110 kt, and also during autorotation from 90 kt in gusting conditions of up 25 to 35 kt, during which the pilot called out his airspeed over the radio and the behaviour of the strop was videoed. The strop never reached angles in excess of approximately 60 degrees from the vertical.

Subsequent investigation

It was apparent from the on-site evidence that the hook had entered the tail rotor disc in flight, and that this had resulted, probably very quickly, in the loss not only of tail rotor thrust but also the stabilising effect of both the tail rotor disc and the vertical stabilisers. The resulting loss of directional stability would almost certainly have rendered the aircraft uncontrollable in yaw, and the forward centre of gravity shift due to the separation of the tail section and vertical stabilisers would have resulted in a significant nose down pitching moment. The probable motion of the aircraft in response to these events would have been a combination of a violent pitch down and rapid rotation in yaw, which is broadly consistent with the witness evidence. Once the aircraft was precipitated into such a manoeuvre, recovery would not have been possible.

Considerable effort was directed toward establishing why the hook should have entered the tail rotor disc. A large number of possible reasons were considered, including excessive airspeed and the gusting conditions as the aircraft came over a ridge. The possibility that a technical defect may have resulted in unusual aircraft movement or attitude changes, causing the strop to fly rearwards and upwards into the tail rotor, was also considered but rejected in the light of the wreckage examination.

More detailed examination of what initially appeared to be accident damage to the self-releasing hook revealed that this damage was in fact not consistent with the impact, and consequently must have occurred between the point of last departure, when the hook had been used successfully (and must therefore have been serviceable) and the accident. The lower corner of the counterbalance weight was heavily bruised and its mounting arm was bent (in the same direction as the bruise); both of the two keeper rods adjacent to the self-releasing hook were bent and bruised at their ends (the bruising and bending being in the same direction as that of the counterbalance), and there was a bruise and gouge at the *tip* end of the hook. A deep bruise was also visible on the counterbalance arm, where the bent keeper rod been driven forcibly back against it. Figure 4 shows the deformation of the hook and identifies the sites of the damage. The surface textures of the bruises to the counterbalance weight and the ends of the keeper rods, in particular, were rough and irregular, and not typical of bruises caused by metal-to-metal impacts. Taken overall, the damage formed a pattern consistent with the hook having struck a rock whilst suspended from the aircraft in flight, presumably as the aircraft crested the ridge upon entering the valley in which it crashed. There is little doubt that a strike against a rock in these circumstances would have been capable of knocking the hook back with sufficient energy to cause it to swing rearwards and upwards into the tail rotor disc.

A foot search of the ridges to the south of the accident location was carried out by the operator in an effort to pinpoint the site of the rock strike, but owing to the high density of surface rocks in the area and uncertainty over the aircraft's precise track, nothing was found.

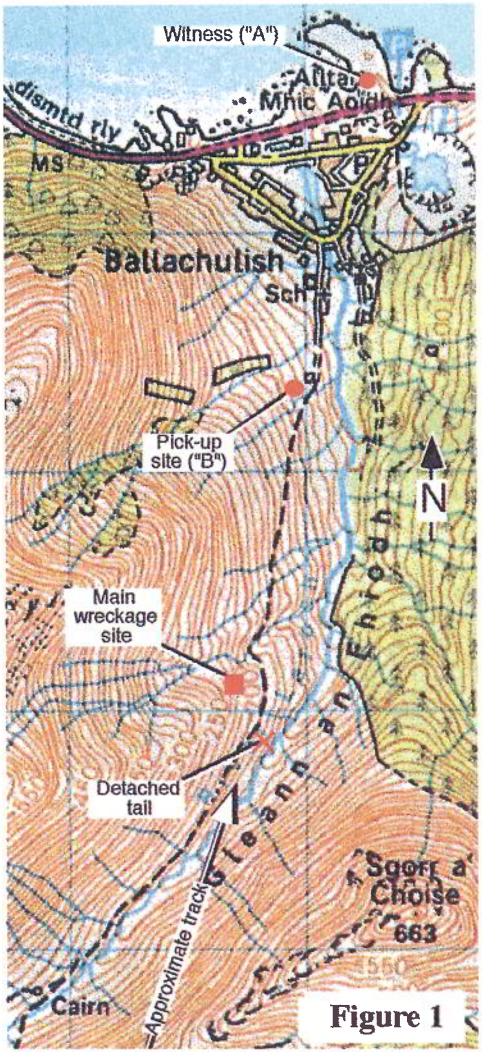

Figure 1

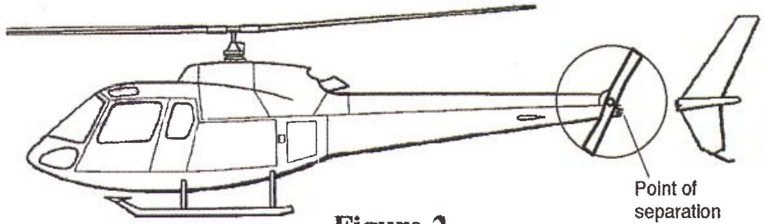

Figure 2

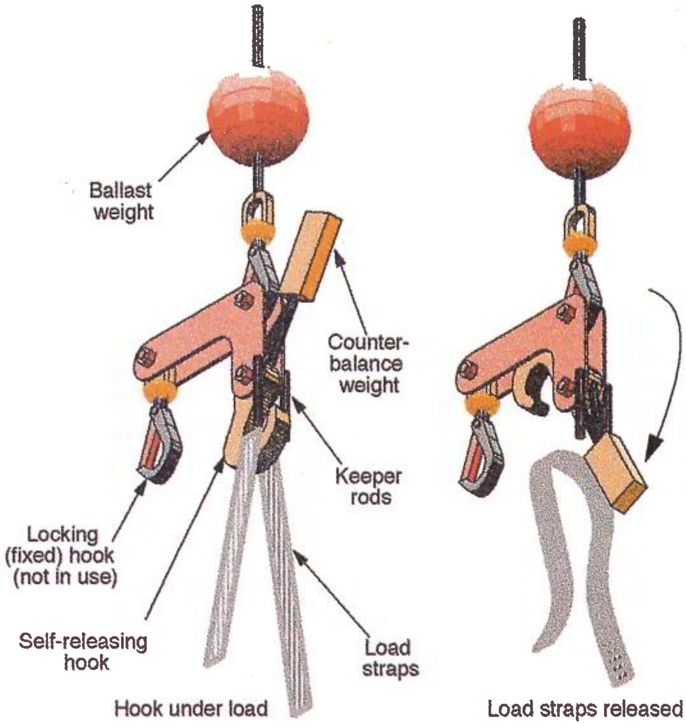

Figure 3

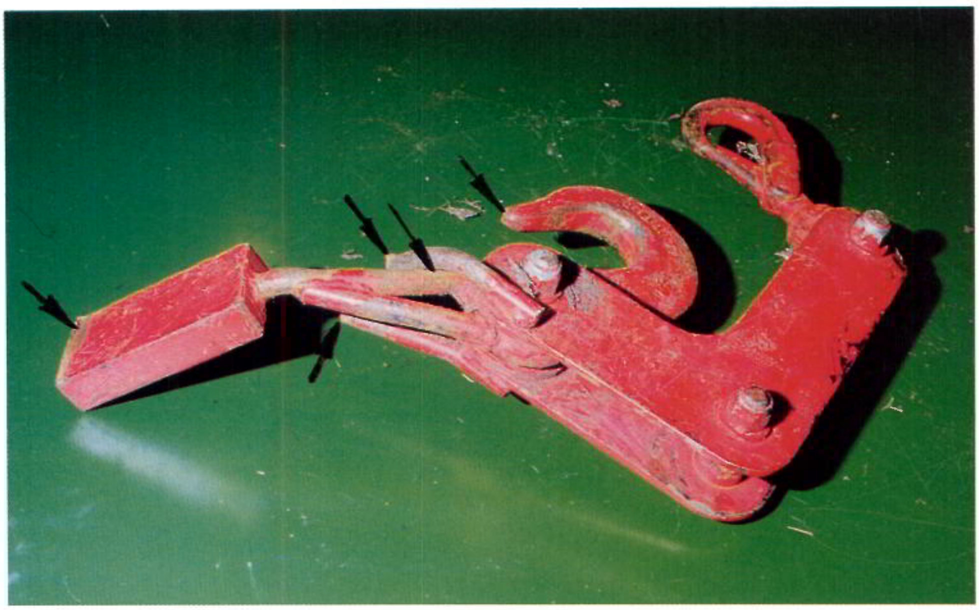

Figure 4