SA341G Gazelle 1, G-HAVA

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Aircraft Type and Registration:	SA341G Gazelle 1, G-HAVA
No & Type of Engines:	1 Turbomeca Astazou 3A turboshaft engine
Year of Manufacture:	1974
Date & Time (UTC):	28 July 1997 at 1410 hrs
Location:	Gamston Airfield, Retford, Nottinghamshire
Type of Flight:	Private
Persons on Board:	Crew - 1 - Passengers - 1
Injuries:	Crew - Serious - Passengers - Serious
Nature of Damage:	Helicopter destroyed
Commander's Licence:	Private Pilot's Licence (Helicopters)
Commander's Age:	49 years
Commander's Flying Experience:	Approximately 170 hours (of which 25 hours were on type)
	Last 90 days - 9 hours
	Last 28 days - 4 hours
Information Source:	AAIB Field Investigation

The aircraft was owned and operated for private purposes by thehusband and wife who were involved in the accident. Both thepilot and her husband had an equal amount of flying experienceon the helicopter as they had undertaken their type conversiontogether in April 1997 and shared all the flying. Earlier thatday they had flown from a private helipad at their home near Darlingtonto Gamston Airfield in Nottinghamshire to collect some headsetsfrom a Hughes helicopter that they had owned previously; the wifewas the handling pilot. After an hour and ten minutes on theground they were setting off to fly to a hotel close to ChatsworthHall in Derbyshire; the wife was again the handling pilot seatedin the right hand seat. She was wearing her normal footwear oflow-heeled slip-on shoes.

The helicopter had been parked next to the grass and approximatelyparallel to Runway 03 on the opposite side of a concrete parkingarea to a line of hangars. Start and pre-take-off checks tooklonger than normal as the pilot was waiting for her husband tocomplete the Global Positioning System (GPS) programming and therewas some discussion about waypoints. However, whilst she couldnot recall details, the pilot had no reason to believe that shehad not followed the checklist in her normal meticulous way andthat the helicopter was other than fully serviceable. The surfacewind at the time was NW at 10 kt or less and the intended departuredirection was across the airfield to the west as there was noconflicting traffic. The pilot was therefore conscious of theneed to turn left after take off. She reported that the lift-offand initial left turn felt normal but that she very quickly becameaware of a rapidly increasing yaw rate. Her husband, who wasin the left-hand seat, shouted to her to apply 'more right foot'and she replied to the effect that 'she had right foot'. Shehad no further recollection of her actions but remembers that,after a short period of time, the helicopter was left skid lowand that she could see sky in front of her. Her subsequent recollectionis of post-crash actions. Her husband has no memory of any eventson the day of the accident. Eyewitness reports are contradictoryas to whether the lift-off was gentle or rapid but it was clearthat the helicopter began to turn to the left almost immediatelythe skids left the ground.

The helicopter was seen by eyewitnesses to accelerate in yaw,rise to a height of between approximately 60 and 80 feet and tomake more than one complete revolution. As it reached its maximumheight it was seen to oscillate in both pitch and roll beforedescending across the hard-standing area and colliding withthe corner of the adjacent hangar. It came to rest right sideup against the corner and immediately caught fire. The pilotunfastened her husband's seat belt and called to him to get out,only to find that she was unable to get out herself. She wasrescued by eyewitnesses at the scene. A ground engineer attemptedto pull her husband through the shattered windscreen but he wasimpeded in his rescue by the fact that the husband's feet hadbecome entangled in the pedals. Later his ankle was found tohave been pierced by some structure. To clear this difficultyhe therefore pushed him fully back in his seat before disentanglinghis feet and then pulling him forward and through the windscreen. The airport fire service were attempting to suppress the fireduring this period but the husband suffered approximately 20%burns and three cracked ribs. The ground engineer had minor burnsto his head. The pilot received a fracture of the T12 vertebra. At the date of this report both occupants are recovering fromtheir injuries.

Previous incident

On 4 June 1997 the husband had flown the helicopter to a hotelat Ullswater with his wife as passenger. On departure that eveningin light wind conditions he carried out a normal vertical takeoff from the site but at approximately 20 feet above the groundthe helicopter commenced a rapid yaw to the left. He appliedfull right pedal and after about one and a half turns the rotationstopped and he flew the helicopter away in the opposite directionto that originally intended. He had not considered landing thehelicopter immediately the yaw occurred as the initial rotationtook it over adjacent bushes. The incident was not reported.

Following the incident, both he and his wife carried out practiceinto-wind and out-of-wind take offs and landings at their farmand each took an additional flying lesson with their instructor.

Yaw control system

Yaw control on the Gazelle is provided by a fenestron: a thirteenbladed fan located within a duct in the base of the fin whichis driven by a shaft from the main rotor gearbox. Horizontalstabilisers with a vertical fin at each tip are mounted on eitherside of the tail boom just forward of the fin. In normal flightthe flow through the fenestron is from left to right (as the mainrotor torque reaction attempts to yaw the fuselage to the left),although in the cruise most of the side thrust to counter themain rotor torque is generated by slipstream effects over thecambered fin. The pilot's yaw pedals vary the pitch angle ofthe fenestron blades and thereby control the airflow through thefenestron duct. This duct has lips on the inflow side and isslightly divergent on the outflow side. A proportion of anti-torquethrust is generated by pressure difference across the fin inducedby the flow of air through this duct. The pedals are mechanicallyconnected to the fenestron blades by a rod, bellcrank and cablesystem, which incorporates a damper to limit the rate of pedalmovement, and an hydraulic servo jack to reduce pedal forces.

Fuel flow to the engine is controlled by a governor which maintainsthe engine speed constant at a nominal 43,700 RPM. A fuel flowcontrol valve lever mounted in the cabin roof close to the centrelineprovides control over engine start, idle, and normal cruise settingsthrough the fuel governor. Adjacent to this is a fuel cock shut-offlever. Unlike most other single engined helicopters, there isno 'twist grip' style engine control on the collective lever andin the Gazelle the pilot must remove his left hand from this leverin order to, for example, reduce engine power without loweringthe collective.

Stability augmentation system

The aircraft was fitted with a SFENA Ministab Stability AugmentationSystem (SAS) which could be selected 'ON' or 'OFF' as requiredby the pilot. Following the accident the switch was found inthe 'OFF' position. When engaged, the SAS acts to oppose motionin the pitch, roll and yaw axes through limited authority hydraulicactuators in the cyclic and pedal control systems. It respondsto rate of movement in the appropriate axis and therefore providesa damping effect on aircraft response to rapid control inputsby the pilot and to external disturbance by turbulence. Followingthe accident the switch was found in the OFF position. Furthermore,the SAS had been disabled on G-HAVA, as operating informationwas not available for the SFENA system.

Site examination and impact parameters

Examination of the apron where G-HAVA had been parked revealedwitness marks that appeared to have been made by this helicopter.[See Figure 1]. Analysis of these suggested that ithad yawed to the left whilst some weight remained on the skidsbefore it became fully airborne. Witness marks attributable tothis helicopter were located some 100 feet to the east, closeto the corner of the hangar, and consisted of marks made by thetail boom bumper (beneath the fin), main rotor blade tips andmain skids. These were located some 35 feet west of the hangarcorner and indicated that the helicopter had touched down witha high rate of descent whilst yawing relatively slowly to theright, tail and right skid low, and on a heading of 220°M,before it bounced to the left and into the corner of the hangar. Debris from this break-up, including sections of the main rotorblades and the fenestron drive shaft, had been scattered overa wide area surrounding the wreckage, including the apron andan area of long grass to the side of the hangar. Witness marksof the main rotor blade tip strikes on the ground, main rotorblade slashes on two sides of the hangar forming the corner, theseverely damaged condition of the three blades themselves andthe wide distribution of debris, left little doubt that the mainrotor had been turning at a high speed the time of the accident. The helicopter had come to rest on a heading of 225°M adjacentto the northern corner of the hangar complex on the airfield. A post-impact fire broke out which consumed most of the tailboomand lower rear fuselage and seriously damaged the remainder ofthe helicopter aft of the two front seats, forward of which relativelylight heat damage occurred.

For several hours after the accident the battery continued tosupply electrical power to the instrument panel and, when firstexamined, all the warning lights, instrument and radio lightsand gyro operated instruments were seen to be functioning. Thedistribution of the wreckage at the accident site indicated thatthe tailboom suffered structural disruption prior to the accidentsuch that the fin/fenestron had become detached from the tailboom. Two of the thirteen fenestron blades were missing, onlyone of these being recovered from the site despite several searches. It was apparent that the tip of one main rotor blade had passedthrough the leading edge of the fin sufficiently deep to leavea witness mark on the fairing over the fenestron hub.

Wreckage examination

The wreckage was recovered to the AAIB at Farnborough for a detailedexamination; the yaw control system in particular. Here, it wasestablished that all failures seen in the fenestron drive systemaft of the inclined gearbox were due to overload, consistent withbeing caused during the accident. Evidence of fenestron driveshaft rotation was only found as far aft as the inclined gearbox,located close to where the tailboom joins to the fuselage, beyondwhich the characteristics of all shaft failures indicated theshaft had not been rotating, or rotating only very slowly, whenstruck. Despite the severe postimpact fire it was apparentthat the tail boom had been distorted upwards, as a result ofcontact with the ground, effectively pivoting about its upperedge close to where it attached to the fuselage. There was evidenceto indicate that this had caused the drive shaft to tear out ofthe flexible coupling immediately aft of the inclined gearbox,whilst rotating, and allow the tail boom to progressively intersectthe main rotor disc resulting in the blade strikes which disruptedthe tailboom.

Examination of the recovered fenestron blade showed this to havefailed in a single event overload by lateral bending, but in theopposite direction to the tip direction of the main rotor blades,and probably resulted from being struck by debris during the accident. The stub of the missing blade indicated that this item had alsofailed in overload, the direction of failure strongly suggestingthat it had been struck by the tip of a main rotor blade. Examinationof the yaw control system failed to reveal any pre-accident disconnectsor failures in the system, and it was apparent that the inputsystem, including both sets of pedals, had been frozen by theimpact/fire in the full right position. A strip examination ofthe main rotor servo jacks also revealed no evidence of pre-accidentdefects, and it was established that all mechanical input linkagesfrom the main rotor head to both cyclic and collective leversin the cockpit had been intact. The collective lever itself hadfailed just below to pilot's handgrip. As found, the hydraulicservo power selector switch, located on the collective lever switchbox, was in the 'OFF' position but deformation between the toggleand the switch body suggested that this had been moved to thisposition with some force. The pilot recalls that the switch was'ON' and that no hydraulic caption was illuminated on the warningpanel. The hydraulic system itself had been severely damagedin the fire, but examination of all remaining components showedno evidence of pre-accident defects.

Service history

This helicopter was manufactured in France in 1974 and, priorto being placed on the UK register 1997, saw service in the MiddleEast and Portugal. At the conclusion of each period of serviceit had been returned to the manufacturer for re-furbishment. The helicopter's maintenance history was well documented and ithad yet to reach its first 50 hour check since the issue of theUK Certificate of Airworthiness. At the time of the accidentit had achieved a total of approximately 2,530 flying hours over3,850 flights.

Gazelle yaw characteristics

A total of 29 Gazelles have been entered on the UK Register ofwhich 18 remain. Approximately 76,000 flying hours had been accruedby the fleet at the end of 1996 and there are 5 recorded accidentsinvolving loss of yaw control where there was no related mechanicalor system failure. The

UK Armed Forces have operated Gazellessince 1973 in training and operational roles and have suffered15 similar loss of yaw control accidents or incidents duringa approximately 600,000 flying hours. There is anecdotal evidenceof further unrecorded incidents to military Gazelles.

In the majority of civil and military cases, loss of yaw controloccurred in the hover or at low forward speed in light winds fromthe right. A few occurred in stronger winds or with wind fromthe left. Both inexperienced and highly experienced pilots wereinvolved in the military accidents and loss of control of pitchand roll during the subsequent high rates of rotation was a commonfeature. An 'optimised fenestron' was fitted to military Gazellesin the early 1980s as part of a weight upgrade programme. Theoptimised fenestron had revised duct and hub fairings but didnot appear to improve the incidence of sudden loss of yaw control.

The sudden loss of yaw control was attributed to 'fenestron stall'and, in response to concern, the Ministry of Defence (MOD) sponsoreda trial by the manufacturer, Eurocopter France, to investigatethe phenomenum. The trial took place in 1992/93 and demonstratedthat, in conditions of low natural wind, a relatively small leftpedal input of 5% (of total pedal travel) from the hover positioncan result in a yaw rate of 150°/sec being achieved in 10seconds. It also showed that high yaw rates to the left (165°/sec)can be rapidly arrested by application of full right pedal withoutany tendency for aerodynamic stall of the fenestron. The MODadvice included a statement that the extremely rapid build upof yaw rate in these circumstances was exacerbated if the SASwas not engaged.

The MOD trial did not establish why a small pedal input can resultin the rapid build up of very high yaw rates. However, an earlierstudy, in 1991, by Westland Helicopters Limited had suggestedthat the trigger mechanism might involve a coupling of fenestronrotor induced swirl with the circulation contained in the mainrotor tip vortices which may become aligned with the fenestronin certain flight conditions. The study also suggested that considerationshould be given to changing the direction of rotation of the fenestronto become top-blade-aft which would probably solve the interactionalaerodynamic problem. Subsequent fenestron-equipped helicopterssuch as the SA365 Dauphin, EC135 and EC120 have top-blade-aftfenestron rotation; they are not known to suffer from sudden lossof yaw control.

Effect of hydraulic system de-selection or failure

The effect of hydraulic system failure or de-selection by thepilot using the collective-mounted SERVO switch is to increasecontrol forces and to cause the collective lever to move to the8° pitch setting and the cyclic stick to the aft and right. The Flight Manual cautions that greater force is necessary toactuate the flying controls and that considerable force will benecessary to move the pedals. Following failure or de-selectionin flight, it is recommended that landing is made at the end ofa very flat final approach. Normal practice is to avoid hoveringby making a running landing to minimise power changes and reducepedal requirements.

Analysis

Had the take off been made with the SERVO switch selected 'OFF',it would have been extremely difficult to control the helicopterin all axes and a high rate of yaw might have developed, and beenvery difficult to counter, if the pedals had not initially beenin the position required for the prevailing conditions. In thatcase, however, the controls would have felt distinctly abnormal. Despite the distraction caused by her husband's programming ofthe GPS, the pilot was certain that all pre take-off checks hadbeen completed and that the helicopter felt normal on initiallift-off. It is therefore unlikely that the take off was madewith the SERVO switch selected 'OFF'.

It is also unlikely that the pilot's feet had slipped off thepedals whilst attempting to counter the yaw as she was quite usedto wearing her low-heeled shoes when flying, had not walked acrossgrass or muddy areas, and was sure that she had been applyingfull pedal when challenged by her husband.

The wind was from the left and the intended departure directionwas to the west. The pilot was therefore conscious of the needto turn to the left after take off and may inadvertently haveapplied left pedal during the take off process. The helicopter'sbehaviour would then have been consistent with the skid marksindicative of it yawing whilst still in ground contact and withwitness descriptions of it turning immediately on leaving theground. Conditions would then have been conducive to the rapidincrease in yaw rate experienced in other Gazelle accidents andincidents, particularly if the wind had been modified by adjacenthangars to provide a less favourable local wind component fromthe right. It is therefore likely that the pilot experienceda sudden loss of yaw control induced by her early left pedal input.

It is therefore recommended that the Civil Aviation Authority(CAA) reconsider the type-rating training requirements for theGazelle to determine whether additional emphasis needs to be placedon yaw control during take off, landing and low speed manoeuvres (Recommendation 97-62).

Flight Manual advice

Prior to the MOD trial, the advice in the military Aircrew Manualin respect of sudden loss of yaw control was that the dramaticincrease in rate of yaw to the left was due to so-called 'fenestronstall' and that application of right pedal would not arrest therate and might even exacerbate it. Following the trial, the advicewas amended to emphasise the tendency for small left pedal inputsto generate high yaw rates under some circumstances, delete referenceto 'fenestron stall', and to state that immediate and positiveapplication of right pedal, up to the maximum, should be appliedand maintained to arrest the rate of yaw.

The CAA Approved Flight Manual for the Gazelle, at Change Sheet1, Issue 1 dated 16 March 1992, retains reference to 'fenestron'stall in the section referring to 'uncontrolled yaw breakaway'. It recommends the same recovery technique as for tail rotor failurein the hover or at low speed and low altitude. That is, "establishautorotative flight and, during the final approach, switch theengine off and land with an accentuated flare. In the event offailure near the ground, immediately reduce the pitch, even ifa very rough landing will result".

Although control of G-HAVA was lost during the rotational sequence,marks indicated that it was rotating slowly to the right at impact. It is therefore likely that the pilot's right pedal input hadeventually countered the left rotation.

The AAIB recommended in 1991 that the CAA liaise with MOD andAerospatiale (now Eurocopter) regarding the 1992 trial and, ifapplicable, invite the manufacturer to suggest a cure for suddenloss of yaw control. The recommendation was accepted by the CAAwhich advised that any relevant results of the liaison would beacted upon as appropriate. It is not clear whether any actionwas taken, but it is recommended that the CAA review the ApprovedFlight Manual to determine whether the advice regarding uncontrolledyaw breakaway should be amended in the light of the MOD trialresults (Recommendation 97-63).

Safety Recommendations

Recommendation 97-62

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