DH82A Tiger Moth, G-AOBJ

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Aircraft Type and Registration:	DH82A Tiger Moth, G-AOBJ
No & Type of Engines:	1 Gipsy Major 1C piston engine
Year of Manufacture:	1942
Date & Time (UTC):	20 August 1997 at 1831 hrs
Location:	Cardiff Airport, Wales
Type of Flight:	Private
Persons on Board:	Crew - 1 - Passengers - 1
Injuries:	Crew - 1 serious - Passengers - 1 serious (subsequently fatal)
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	740 hours (the majority of which were on type)
	Last 90 days - 11 hours
	Last 28 days - 8 hours
Information Source:	AAIB Field Investigation

History of flight

The pilots of two Tiger Moth aircraft, G-ANFI and G-AOBJ, plannedto carry out air-to-air photography with the photographer in 'FI'. The pilot of 'FI' made the radio calls for both aircraft andthey entered Runway 30 at taxiway 'H'. They were cleared to takeoff at 1829 hrs. 'FI' took off first, followed after a few secondsby 'BJ'. The pilot of 'FI' turned right onto the downwind leg;when he last saw 'BJ' flying it was climbing on the runway headingat about 150 feet agl.

The ATC controller saw 'BJ' start to turn crosswind but his attentionwas momentarily drawn to an aircraft on final approach. Whenhe looked back, 'BJ' was descending in a nose down attitude, bankedto the right. It then disappeared behind a hangar to the northwest of the Control Tower, only to reappear seconds later climbingin a steep nose up attitude, tracking crosswind. It was reportedto be "twisting and yawing" as it turned to the leftand then descended into a field just outside the airfield perimeter. Aircraft accident action was initiated at 1831 hrs and the AirportFire Service (AFS) was on scene at 1832 hrs.

Both occupants were seriously injured in the impact; the pilothad managed to escape from the wreckage, but the passenger wastrapped in the front seat and had to be cut free by the AFS. The pilot of 'FI' landed and went to the accident site. The pilotof 'BJ', who was conscious and a few feet from the wreckage, toldhim that he had been unable to move the ailerons to the left dueto a restriction. Both casualties received first aid treatmentand, at 1855 hrs, were transferred to hospital by ambulance.

The passenger was a qualified pilot. An injury to his left anklewas of the type that is associated with the application of leftrudder at impact. He also suffered head injuries and was unableto recall any detail of the flight. The pilot subsequently diedof his injuries three months after the accident.

Meteorology

An accident special observation was made at 1836 hrs. It containedthe following:

Surface wind 300°/7 kt

Visibility 3,500 metres

Weather Haze

Cloud 1 octa, base 3,000 feet

Temp/Dew point 22°C/18°C

QNH/QFE 1016 mb/1008.4 mb

Brief history of the aircraft

The aircraft was built by Morris Motors Ltd in 1942 and enteredRAF service in 1943. It was eventually sold and converted forcivilian use, and registered as G-AOBJ. The registration wascancelled when it was exported to Europe. It was transportedto the USA in 1972, where it operated until 1990, when it wasre-imported into the UK. Considerable re-work on the airframeand engine was then carried out. It was re-registered as G-AOBJand issued with a Certificate of Airworthiness, in the PrivateCategory, in May 1992. The most recent maintenance was an Annualinspection, carried out in April 1997. This aircraft was notfitted with anti-spin strakes or leading edge slats, nor was itrequired to be.

Engineering investigation

The aircraft had crashed on a heading of 120°(M) in a steepnose-down attitude, estimated to be around 40°. It was apparentthat some left yaw had been present at impact, as the left wingshad suffered severe disruption. In contrast, the lower rightwing was only slightly damaged as a result of ground contact onits leading edge, and the upper right wing was undamaged, nothaving contacted the ground. There was no groundslide, with theaircraft having come to an immediate halt, resting on its collapsedmain landing gear, nose and lower left wing. The tail structurehad remained clear of the ground, apart from a light impact onthe left tailplane tip. A curious feature therefore was the fractureof the tail skid spring close to its attachment fitting on theunderside of the rear fuselage. The fracture was fresh in appearance,and it was concluded that it may have been caused by inertialloads at impact. There was no evidence that it had impeded operationof the rudder.

The fuel tank was leaking slightly after the accident. Howeverseveral gallons of fuel were drained before the wreckage was recovered,and so it was concluded that there had been adequate fuel on boardat the time of the accident. One propeller blade had broken offand was found lying underneath the aircraft. The remaining bladewas undamaged, not having struck the ground. The broken bladesections showed no evidence of leading edge impact damage or circumferentialscuffing, thus suggesting there had been little or no power, oreven rotation, at impact.

Following an on-site inspection, the aircraft was recovered tothe AAIB's facility at Farnborough for a detailed examination

Detailed examination of the wreckage

Flying controls

In view of the pilot's reported comments immediately followingthe accident, the investigation initially focused on the flyingcontrols. The aircraft was equipped with dual controls, withmuch of the cockpit components enclosed within a wooden compartmentattached to the floor of the cockpit. The front and rear controlcolumns were attached to the aileron torque tube, which extendedalong the length of the compartment. A lever arm at the rearof the torque tube protruded downwards through a transverse slotcut in the floor of the rear cockpit. Aileron operating cableswere attached to the end of the lever and were in turn connected,via turnbuckles, to chain assemblies in the lower wings. Thechains located onto sprocket wheels which were connected to theailerons by means of adjustable rods.

No disconnections had occurred in the flying control operatingsystem in the accident, although the structure in which many ofthe components were located had been damaged. The wooden compartmenton the cockpit floor had split open in the impact. The controlsin this area were examined for evidence of a jam or restriction. There was clearly scope for a loose article to cause such a problem,especially if it had become lodged in the slot in the cockpitfloor. However there was no evidence of foreign objects, jammedor restricted controls in the post accident condition.

Both control columns had broken off near their bases, within thegaiters on the top of the wooden compartment. Examination ofthe fracture of the rear column indicated that it had broken offin a forwards direction, due to pilot induced loads in the impact. The front column had failed in a predominantly rearwards direction,due to the front left side of the cockpit structure and instrumentpanel having crushed inwards and rearwards onto it, suggestingthat the front seat occupant had not been holding it.

The cable runs in the lower mainplanes were examined, but no problemswere found. The sprocket and chain assemblies, to which the cableswere attached, were effectively built into boxes, with the uppersurface being formed by the wing fabric, and the lower by an aluminiumalloy cover plate. The cables entered the boxes, which were otherwisesealed against foreign object ingress, through small aperturesin the inboard ends, and then joined onto the chains via the turnbuckles. Two wooden ribs within each box were protected, with alloy plates,from abrasion by the chains and turnbuckles. These also limitedthe amount of vertical movement of the chains in the event ofslack cables, and thus assisted in keeping the chains locatedon the sprocket teeth. In addition, guides in the form of leafsprings were located in the tangent areas where the chain metthe sprocket teeth.

On the undamaged right wing, the chain was found properly locatedon the sprocket wheel and the associated aileron operated normally(although its operating rod had been damaged during wreckage recovery). Even after the cables had been cut, thus eliminating any tensionin the system, the chain could not be encouraged off the teeth. The chain in the left wing was found partially off the sprocketwheel, which in fact limited the movement of its associated aileron. However, the alloy cover plate had been torn off during the impact,and this had resulted in the fracture of one of the shielded woodenribs. It was found that with the excessive amount of verticalmovement of the chain that could then occur (with slack cables),it was possible to encourage the chain to become disengaged fromthe sprocket without too much difficulty. In the absence of anywitness marks on the sprocket teeth and chain links, it was concludedthat the left chain came off the sprocket during the impact.

It was noted that one of the turnbuckles in the left wing wasbadly bent on the end that connected to the chain. This had resultedin a 'kink' in the chain-to-turnbuckle connection such that thelatter contacted the side of the sprocket assembly box structurewhen cable tension was applied. This condition had clearly existedfor some time, as a light wear pattern could be seen on the sideof the enclosure. However, this interference was not sufficientto produce a jam of the aileron operating system. Although itwas not immediately obvious as to how the turnbuckle had becomebent, it was found that if the sprocket wheel was rotated to apoint at, or beyond, the full right stick position, the shacklelinking the chain to the turnbuckle contacted the sprocket teethin a manner that displaced the turnbuckle into the side of thebox structure. A small amount of additional rotation of the sprocketwheel may result in bending of the turnbuckle. However rotationcould not occur beyond a point where the shackle became wedgedbetween the sprocket teeth and its associated chain guard. Theaccompanying photographs show the sprocket wheel and turnbuckledetails. The wedged position of the shackle appeared to producethe as-found amount of distortion in the turnbuckle, and therewere contact marks on the side of the box structure that couldhave been caused by the bending process. However, there wereno heavy contact marks on either the shackle or sprocket teeth,and the shackle was easily released from the wedged position,ie the system could not be made to jam.

Assuming that the turnbuckle did in fact become bent as a resultof the shackle contacting the sprocket teeth, it is consideredthat the bending may have occurred as a result of multiple applicationsof full aileron deflection, such as during 'full and free' flyingcontrols checks. The reason the shackle was able to contact thesprocket appeared due either to mis-rigging, or more probably,due to excessive aileron system travel (see below).

It was found that there were two relevant modifications that appliedto the aileron system. In 1941, Tiger Moth Modification 101 introducedimproved aileron stops which, in the case of GAOBJ, wouldhave been incorporated at build. These took the form of hardwoodblocks screwed to the underside of the cockpit floor at the endsof the aileron lever slot. The modification sheet stated that; '*cases had occurred of jamming and failure of the aileroncontrols in the bottom wing due to the chain and anchorage shacklescoming into contact with the aileron sprocket teeth.'* Itwas found that on certain aircraft the slot in the floor had beencut too long, thus allowing excessive travel of the control cables. Subsequently, in 1943, Modification 101 was superseded by AirMinistry Modification No 125. This introduced an improved aileronsprocket chain guard and reduced the aileron lever slot lengthto 5 inches in order to reduce the possibility of the chain ridingup on the sprocket due to sagging cables, or when the controlcolumn was at full deflection. Modification No

125 was declaredmandatory by the CAA and its status is discussed in TechnicalNews Sheet (TNS) Nos 1 and 5, issued by British Aerospace, whichis the Type Design Organisation for Tiger Moth aircraft. ThusModification No 125 was designed to eliminate the very conditionthat was found on GAOBJ, notwithstanding the fact that acontrol jam could not be reproduced.

G-AOBJ was found to have the sprocket guards, but there was noevidence of any aileron lever stops ever having been fitted tothe underside of the cockpit floor, and the lever slot was foundto approximately 6.5 inches in length. Nevertheless, the modificationstatement in the aircraft log book listed Modification No 125as "Found complied with", dated 6 May 1992. There wereno log book entries which indicated that any additional work hadbeen carried out in this area.

Engine and fuel system

The fuel tank on a Tiger Moth forms the upper wing centre section,and is mounted on struts on the forward fuselage, ahead of thefront cockpit. The ON-OFF cock is mounted on the tank underside,and is connected by rods and bellcranks to a knob on the leftside of each cockpit.

Inertial loads during the impact had caused the tank to applycompressive loads to the struts, thus crippling them. This relativemovement between the tank and the fuselage had applied an inputto the fuel cock operating linkage in a manner which had tendedto drive the cockpit end of the linkage towards the ON direction. The loads had been sufficiently severe to drive the rear cockpitselector knob into a paxolin guide block such that it had beendistorted. A bellcrank at the forward end of the cockpit linkagehad also been moved in the impact, and it was apparent that oneof its arms had come into contact with an adjacent throttle controlrod, such that black paint on the latter had been scraped off. The extent of the scraped area suggested that the fuel cock bellcrankhad been moved during the impact from a position which had beenclose to OFF. Taken in conjunction with the lack of power indicationon the propeller, this evidence raised the possibility of theengine having failed due to fuel starvation. However the natureof the evidence was somewhat tenuous, and it fact it was possiblethat additional linkage movement occurred during a recoil processfollowing the impact. It was noted that the fuel cock linkagehad no detent or over-centre mechanism, but relied simply on frictionto maintain the selected position. During the investigation someanecdotal evidence emerged, concerning other Tiger Moth aircraft,which suggested that the mechanism was susceptible to movementdue to vibration, with an attendant risk of power failure. Itwas noted that aircraft on the Australian register have a mandatorymodification (Reference DCA/DH82/2) which introduced a lockingclip on the fuel cock ON-OFF selector.

The engine was taken to an overhaul agent for a strip-examination. This revealed that the components were in generally good condition. The magneto timing was checked, and the right hand (impulse)unit was found to be correctly timed to 30° before top deadcentre (BTDC), with respect to the No 1 cylinder. However, theleft hand magneto was timed to top dead centre (ie 0° BTDC). It was considered that this error was the result of timing themagneto with the throttle closed as opposed to open; this wouldhave introduced a 30° angular error in the associated ignitionadvance ring (which was connected to the throttle) on the magneto. It was then observed that the internal mechanism was 180°out of position. However, the situation had been recovered bytransposing plug leads Nos 1 with 4, and Nos 2 with 3. It wasconcluded that despite the timing error, the engine would haverun reasonably normally, although there may have been a largerdrop in rpm with the engine running on the left magneto comparedto the right.

The carburettor and associated hot air system was checked andfound to be satisfactory apart from a slight leak when the unitwas connected to a pressurised fuel supply.

Seat harnesses and survivability issues

The harnesses were the original 'Sutton' type which consistedof lap and shoulder straps made from canvas webbing, reinforcedlocally with leather. The shoulder straps terminated in smallpulley assemblies located on a cable that was fixed across thefuselage at the rear of each cockpit. This type of harness hasnot been manufactured for many years and the age of this particularharness was not recorded.

The right hand attachment of the front cockpit shoulder restraintcable had failed in the impact. This had allowed the occupant'storso to flail forwards, which may have contributed to his headinjuries. The cable attachment brackets had been the subjectof Technical News Sheet (TNS) No 12 (although this had not beenmandated by the CAA), which called for 50 hour inspections forsigns of corrosion. In addition, the TNS specified a check toensure that the brackets were attached to the fuselage longeronsby means of high tensile steel (HTS) bolts. The remains of oneof the failed bolts on the right hand side, together with boththe intact bolts from the left side, were subjected to hardnesstests (the second bolt from the right hand side was not recovered). These revealed that two bolts were made from low tensile steel,with one of the intact bolts being of medium tensile strengthsteel. The aircraft log book contained entries, coinciding withthe annual inspections (including the most recent one in April1997), which recorded compliance with TNS No 12.

In the rear cockpit, the shoulder restraint cable had broken atits mid-point. In addition, the right hand lap strap had torncompletely through, close to a stitched joint that attached oneof the leather reinforcing strips. This had caused the rear seatpilot to be effectively unrestrained, with the result that hesustained facial injuries, together with a severe chest injurydue to contact with the P-type compass that protruded from theinstrument panel. Both occupants had additionally suffered severeback injuries as result of the high vertical component of theimpact forces.

The shoulder harness cables were of the correct diameter and appearedto be in reasonable condition; the rear seat cable had failedpurely as a result of overload.

Sutton harness failures have featured in previous accidents, mostrecently involving Tiger Moth G-ANPK, which was reportedin AAIB Bulletin 2/97. Tests on that aircraft indicated thatalthough the webbing did not appear to be in a significantly deterioratedcondition, it had actually lost between 50 and 75% of its strength. It was considered that as this harness type has not been availablefor many years, it was reasonable to assume that equipment whichremains in service may be similarly deteriorated. The harnesswebbing in G-AOBJ was noted to be stiff, dirty and frayed in severalplaces, with deteriorated stitching on the leather reinforcing. Although the Light Aircraft Maintenance Schedule (LAMS) callsfor regular visual inspections of harnesses, they are not generallysubjected to periodic load tests due to the risk of damaging them. By way of comparison, RAF aircraft harness webbing, both canvasand nylon, has a maximum in-service life of ten years.

Safety Recommendation 96-59 (first published in August 1996 inanother AAIB accident report, Air Accident Report 4/96, and re-statedin AAIB Bulletin 2/97 referred to above) stated:

"The CAA should give detailed consideration to requiringa programme of sample testing of aircraft harnesses aimed at establishingtheir fitness for continued use and, if necessary, imposing alife limitation"

The CAA conducted an investigation into all types of harness,but concluded that; "...there is insufficient evidence inthe findings of this report (*ie Air Accident Report 4/97*)to indicate the need for [such a programme]...".

Discussion

The pilot's comments in the immediate aftermath of the accidentand subsequently in hospital indicated that the accident couldhave been caused by a loss of control following an aileron jamor restriction.

It was found that a mandatory modification which was designedto limit the amount of aileron travel was not completely embodiedon this aircraft. It is probable that the resulting excessivecable travel which this omission allowed had repeatedly causeda turnbuckle shackle to contact the left aileron sprocket wheel(when full right aileron was applied), which eventually causedthe turnbuckle to become bent. However, despite this conditionthe tests conducted on the aileron system did not succeed in reproducingan aileron jam or restriction, although in-flight dynamic loadingeffects could not be reproduced. Nevertheless, the justificationfor the aileron system modification indicated that such a jamcould occur. The Type Design Organisation has asked the de HavillandMoth Club to inform their members of the importance of Modification125, as discussed in TNS No. 5. In addition the CAA, in responseto a request from the Type Design Authority, has published anarticle on the subject in a recent edition of the General AviationSafety Information Leaflet (GASIL), issue number 1 of 1998 (February).

The investigation was complicated by the lack of power indicationson the propeller, together with evidence that suggested the possibilityof the fuel cock having been near the OFF position before theimpact. If a power loss had occurred immediately after take off,because the fuel cock had moved from ON to OFF due to the effectsof vibration on the associated linkage, and the aircraft had stalledas a consequence, there is the possibility that the airflow overthe ailerons, with the wings in a stalled condition, may haveresulted in 'snatch loads' (which reportedly can occur in theaileron circuit under such conditions) that may have been interpretedby the pilot as an aileron restriction, or jam. The subsequentfinal climb observed could have been achieved without power bytrading speed gained in the preceding descent for height.

However since the pilot did not think that he had suffered a powerloss, and if his recollection was correct, the apparent lack ofpower on the propeller may have been due to his final closureof the throttle and fuel cock in recognition of his inabilityto control the aircraft sufficiently, as a result of an aileronrestriction or jam, to avoid the impending ground impact. TheController's observations of the aircraft 'twisting and yawing'as it turned left before the ground impact could be consistentwith left rudder inputs to oppose a right roll tendency.

Safety recommendations

The condition of the wreckage indicated that the impact had beensufficiently severe to be at the margin of the 'survivable' category. However both occupants did survive, although the pilot died lateras a result of complications from injuries probably sustainedas result of the failure, in two places, of his Sutton harness.

Over the years many Tiger Moth aircraft have been fitted withreplacement harnesses made from modern synthetic materials. Thisis especially the case in Australia, where Sutton harness havebeen prohibited for almost 30 years on such aircraft. This accidenthas highlighted the shortcomings of this type of harness, withthe result that the following Safety Recommendation has been madeto the CAA:

Recommendation 98-40

In order to avoid unnecessary injury to the occupants of vintageaircraft during accidents, and since most Sutton harnesses currentlyfitted to such aircraft in service are likely to be in a deterioratedcondition, it is recommended that all affected aircraft, includingthe de Havilland Moth series, be the subject of mandatory actionby the CAA to equip them with improved modern harnesses.

This investigation revealed the potential for the fuel cock linkageto move, under the influence of vibration, towards the OFF position. As with the Sutton harness issue, this has been recognised bythe Australian regulatory authority, which has addressed thisproblem by means of a simple modification. The following SafetyRecommendation has therefore been made:

Recommendation 98-41

It is recommended that the CAA, in conjunction with the Type DesignOrganisation for the DH 82A Tiger Moth, make available amandatory modification which ensures that the associated fuelcock linkage resists any tendency to displace due to engine vibrationand remains in the ON position, unless otherwise selected OFF.