AIRCRAFT ACCIDENT REPORT 1/94

Air Accidents Investigation Branch

Department of Transport

Report on the accident to Aerospatiale AS355F1 Twin Squirrel, G-OHMS, Near Llanbedr Airfield, Gwynedd, on 8 December 1992

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

London: HMSO

First published 1994

ISBN 0 11 551211 X

LIST OF RECENT AIRCRAFT ACCIDENT REPORTS ISSUED BY AIR ACCIDENTS INVESTIGATION BRANCH

2/92	Royal Air Force Jaguar T2A, XX843 and Cessna 152, at Carno, Powys, Wales, on 29 August 1991	June 1992
3/92	De Havilland DHC-7, G-BOAW, between Brussels and London City Airport, on 30 January 1991	July 1992
4/92	British Aerospace ATP, G-BMYK, 10 miles north of COWLY, near Oxford, on 11 August 1991	October 1992
5/92	British Aerospace ATP, G-LOGA, at Edinburgh Airport, Scotland, on 5 February 1992	October 1992
6/92	British Aerospace ATP, G-BTPE, at Sumburgh Airport, Shetland Islands, on 23 December 1991	December 1992
1/93	Piper PA-28-161 Cadet, G-BPJT, at Oxford Airport, Kidlington, on 12 July 1992	April 1993
2/93	AS 332L Super Puma, G-TIGH, near the Cormorant 'A' platform, East Shetland Basin, on 14 March 1992	May 1993
3/93	Lockheed 1011 Tristar, 9Y-TGJ, near 'KIRN' VOR, Germany, on 9 March 1992	June 1993
4/93	British Aerospace 146-300, G-UKHP, at Aberdeen Airport, Dyce, Scotland, on 31 March 1992	August 1993
5/93	British Aircraft Corporation/SNIAS Concorde 102, G-BOAB, over the North Atlantic, on 21 March 1992	November 1993

These Reports are available from HMSO Bookshops and Accredited Agents

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

20 December 1993

The Right Honourable John MacGregor
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr M M Charles, an Inspector of Air Accidents, on the circumstances associated with the accident to Aerospatiale AS355F1 Twin Squirrel, G-OHMS, which occurred near Llanbedr Airfield, Gwynedd on 8 December 1992.

I have the honour to be
Sir
Your obedient servant

K P R Smart
Chief Inspector of Air Accidents

Contents

Contents (continued)

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	-	Air Accidents Investigation Branch
CAA	-	Civil Aviation Authority
hrs	-	hours
Hz	-	Hertz
kg	-	kilogram(s)
km	-	kilometre(s)
kN	-	Kilonewton
kt	-	knot(s)
LAMS	-	Light Aircraft Maintenance Schedule
lb	-	pounds
lbf in	-	pounds force per inch
LTO	-	Letter to Operator
MGB	-	main gearbox
MHz	-	Megahertz
mm	-	millimetre(s)
MOR	-	Mandatory Occurrence Reporting
N	-	Newton
N_1	-	Gas generator speed
RPM	-	Revolutions per minute
UJ	-	universal joint
UK	-	United Kingdom
UTC	-	Coordinated Universal Time

Air Accidents Investigation Branch

Aircraft Accident Report No: 1/94 (EW/C92/12/3)

Registered Owner	South Western Electricity PLC
Operator	Compass Aviation Ltd
Aircraft Type and Model:	Aerospatiale AS355F1 Twin Squirrel
Nationality:	British
Registration:	G-OHMS
Place of accident:	Near Llanbedr Airfield, Gwynedd
	Latitude: 52° 48' N
	Longitude: 004° 08' W
Date and Time:	8 December 1992 at 1310 hrs

All times in this report are UTC

Synopsis

The accident was notified to the Air Accidents Investigation Branch (AAIB) at 1545 hrs on 9 December 1992 and an investigation began on the following day. The investigation was conducted by Mr M M Charles (Investigator in Charge), Mr P D Gilmartin (Operations) and Mr A N Cable (Engineering).

The helicopter was in cruising flight when, without warning, the drive train from the No. 2 engine to the main gearbox severed and the engine mount onto the gearbox fractured. A successful single engine landing was made. The damage resulted from the disintegration of a Thomas coupling in the drive train located concentrically with a universal joint in the support structure between the engine and the main gearbox. The similar coupling in the No. 1 drive train had started to break up. The evidence indicated that severe deterioration of a number of laminated rubber pads that restrain the bottom of the main gearbox had allowed excessive main gearbox movement under the influence of main rotor reaction loads, resulting in fatigue failure of the Thomas coupling due to excessive angular misalignment. The severance of the mounting structure allowed the No. 2 engine to rotate about its remaining flexible ball mounting and it had pivoted until restrained by the engine bay door. Two pairs of Terry pins retaining the pivot pins for the universal joint had detached and one pivot pin had slid out of engagement; this was most probably the result of drive train vibration. Three safety recommendations have been made.

1 Factual Information

1.1 History of the flight

The helicopter had been parked overnight at a Hotel helipad at Old Colwyn Bay. On the day of the accident, the helicopter was flown to Caernarfon Airfield for refuelling. It departed Caernarfon at 1300 hrs, with the commander and one passenger on board for a flight to Carmarthen. The weather was fine and clear, and the commander contacted Llanbedr Tower on 122.5 MHz for clearance to cross the Llanbedr Aerodrome Traffic Zone at an altitude of 1,500 feet. Both engines were synchronised at 71% torque at this time. Whilst transmitting this request, the commander heard a loud bang, which was initially thought to be a bird strike. However, an engine instrument check showed that the No. 2 engine had run down to zero torque, with a corresponding N_1 engine speed of 63.5%, and a T4 temperature of 480°C. No yaw was experienced, and the No. 1 engine had taken the load and remained within operating limits. The No. 2 engine fuel control lever was pulled to the flight idle position, and a precautionary single engine landing was made at Llanbedr, approximately three minutes after the initial occurrence. When on the ground, with the No. 1 engine fuel control lever fully forward and the No. 2 engine at flight idle, there was another, less loud, noise. The No. 2 engine was shut down immediately, and the No. 1 allowed to idle for two minutes before shutdown.

On inspection of the transmission deck, the No. 2 drive train Thomas coupling was found to have disintegrated and the coupling housing tube severed, with debris scattered on the decking. The commander contacted the aircraft's owners and the maintenance organisation to inform them of the problem. It was decided that the helicopter could carry out a single engine ferry flight, without passengers, back to its operating base at Bristol Airport.

The debris was cleared from the transmission deck, and preserved for engineering examination. The commander carried out a thorough inspection of the engine and transmission bay area and, once he was satisfied that there was no further damage, carried out a ground run of the No. 1 engine and a check for any leaks. The commander satisfied himself that the helicopter would have a satisfactory climb performance on one engine at the proposed take-off weight. A cushion-creep take-off was made at 1444 hrs, and the helicopter carried out an uneventful flight on a direct track to Bristol, arriving just before sunset at 1552 hrs. Neither the aircraft Flight Manual nor the company Operations Manual made any reference to the conduct of single engine ferry flights.

1.2 Injuries to persons

There were no injuries.

1.3 Damage to aircraft

Drive train and support structure between No. 2 engine and main gearbox (MGB) severely damaged.

1.4 Other damage

None.

1.5 Personnel information

1.5.1

Commander:	Male aged 48 years	
Licence:	Airline Transport Pilot's Licence (Helicopters)	
Aircraft ratings:	AS350B, AS355F, B206, B212, B222, Hiller UH12, Hughes 269A/B/C	
Medical examination:	31 October 1992	
Instrument rating:	Not applicable	
Last base check:	27 July 1992	
Flying experience:	Total all Types:	6,835 hours
	Total on AS355F:	192 hours
Duty time:	1 hour 10 minutes	

1.6 Aircraft information

1.6.1 Leading particulars

Type:	Aerospatiale AS355F1 Twin Squirrel
Constructor's number:	5194
Date of manufacture:	1982
Certificate of registration:	No. G-OHMS/R1, South Western Electricity PLC
Certificate of airworthiness:	United Kingdom CAA Certificate in Transport Category (Passenger), valid until 20 June 1993
Total airframe hours:	4,878.8 hours
Maximum total weight authorised	2,400 kg
Estimated weight at time of accident:	1,884 kg

1.6.2 Aircraft description

The AS355 is powered by two engines mounted side by side on the cabin roof behind the MGB. A coupling shaft from each engine, driven by an output gear of the engine accessory gearbox, drives a combiner gearbox, forming the input section of the MGB, via a Thomas coupling (Figs 1 & 2). The Thomas coupling connects a triangular splined flange on the coupling shaft with an input drive flange of the combiner gearbox. It comprises a 14 element sandwich of stainless steel leaves, 0.2 to 0.3 mm (8-12 x 10^{-3} inch) thick, able to flex with each revolution in order to cater for minor misalignment (1°30' maximum) between the coupling shaft and the input drive flange of the combiner gearbox. The sandwich is clamped to the splined flange by one set of three bolts and nuts, with washers, and to the input drive flange by a second set. Nominal nut torque is 168 to 203 lbf in; each nut is retained by a split pin passing through a drilling in its bolt. At 100% rotor speed the engine to MGB drive train rotates at 6,016 RPM.

The MGB is mounted near its top on 4 ball-jointed suspension struts and restrained at its base by a bilateral flexible suspension arrangement with four pairs of laminated rubber pads (Fig 2). Lateral and longitudinal pads have dimensional differences but are otherwise similar. The pads are intended to be flexible in shear and rigid in compression. They restrain the MGB pitch and roll relative to the fuselage due to rotor flight loads, and one pad in each pair, acting in series, reacts MGB yaw loads resulting from torque reaction. The pads are formed of a stack of alternating rubber and light alloy discs bonded together and covered with a protective nitrile coating. In typical flight conditions torque reaction subjects the pads to a compressive load in the order of 4,000 to 6,000 lb (18 to 27 kN), in addition to flight loads. The original type of pad for the AS355 had reportedly been modified twice in attempts to overcome problems of deterioration due to contact with aircraft fluids. G-OHMS was fitted with the latest standard (Part No. (PN) 704A33-633-152 and -153).

Each engine has a single point, ball joint type, flexible mounting to the aircraft structure and is structurally connected to the MGB via a universal joint (UJ) arrangement. This comprises a coupling housing tube bolted to the engine accessory gearbox casing which is connected via a UJ ring to a yoked UJ flange bolted to the combiner gearbox casing. The coupling housing tube, the UJ ring and the UJ flange are of aluminium alloy, with a steel bush fitted in each UJ pivot hole. Each of the four pairs of UJ bushes is joined by a steel UJ pivot pin, retained by two large sprung Terry clips. Each Terry clip passes through a pair of holes in the outer end of each UJ ring bush and through a circumferential groove in the UJ pivot pin. The two Terry clips forming a pair are tie-wrapped together such that when installed they are triangulated and thus prevented from lying

against and fretting the UJ ring surface. They are 3 inches (78 mm) long with a spring preload when latched of around 1 lb (4 N); full unlatching requires a force of approximately 1.7 lb (8 N) applied to the free end of the pin. The UJ pivot axes are orthogonal but are not coincident with principal aircraft axes, such that the axis of the ring/MGB pivot pins is angled downwards around 10° from the horizontal towards the aircraft centre. The engine coupling shaft runs coaxially within the coupling housing tube, and the Thomas coupling is situated within the universal joint arrangement.

1.7 Meteorological information

An aftercast from the Meteorological Office showed that, at the time of the accident, there was a ridge of high pressure persisting over Ireland and Scotland, with a light northerly airflow over Wales. The visibility was probably over 12 km, with scattered patches of stratocumulus cloud, base around 1,500 feet. The surface wind was 360°/10 kt, increasing to 15 kt at 1,000 feet.

1.8 Aids to navigation

Not relevant.

1.9 Communications

Two way communication with Llanbedr Approach/Tower on 122.5 MHz was already established at the time of the accident, and was maintained until after the helicopter landed at the airfield.

1.10 Aerodrome information

The relevant aerodrome facilities were all serviceable.

1.11 Flight recorders

No flight recorders were fitted and none was required.

1.12 Wreckage and impact information

Markings showed that the helicopter had made a running landing on the apron at Llanbedr Airfield. No damage resulted from the landing. Immediately after the forced landing, photographs were taken by the pilot before he left the vicinity of the aircraft. These show the outboard Terry pins to be missing from the UJ. A ground handler who was present immediately after the forced landing and assisted the pilot confirmed that the Terry pins were found lying on the floor of the bay. The helicopter was examined in detail after the single engine flight to the owner's maintenance base at Bristol Airport.

1.12.1 No. 2 powerplant

Examination of G-OHMS showed that on the No. 2 engine side the Thomas coupling had fragmented, into several hundred pieces, thus severing the drive train from the engine to the combiner gearbox. In addition, the forward end of the coupling housing tube forming the horns for the UJ had disintegrated, thus leaving the engine free to pivot on its single mounting to aircraft structure until restrained by contact with the engine bay door. The first stage compressor of the engine suffered minor damage consistent with debris ingestion, but strip examination of the No. 2 engine and the combiner gearbox during repair revealed no evidence of pre-existing failure or defect. Other components damaged were the engine coupling shaft, the splined flange, the UJ ring, the UJ flange and the input pinion bearing housing of the combiner gearbox, although none of these had failed. There was evidence of fretting of both rotating and static components in the area of the Thomas coupling and the UJ. Five of the six Thomas coupling clamping bolts had fractured at the position of their split pin holes and five of the associated nuts were found separated, with signs of considerable external battering but in some cases with little thread damage. The remains of a mangled split pin were present in the split pin hole of the unfractured bolt and other fragments of split pin were recovered in the MGB bay.

Detailed examination found that extensive post-failure damage had destroyed virtually all original fracture surfaces. It was evident from the damage characteristics that the splined flange and the Thomas coupling and its connecting bolts and nuts had contacted the interior of the coupling housing tube while rotating at high speed.

Two pairs of Terry pins, from the inboard and outboard UJ pivot pins, were found on the floor of the MGB bay, unclipped, tie-wrapped together and undamaged, together with the inboard UJ pivot pin. The outboard UJ pivot pin remained in position, engaged in the bush carried in the UJ ring and in the bush fitted in a fractured portion of the coupling tube.

1.12.2 No. 1 powerplant

No signs of damage to the No. 1 engine or its drive train were apparent while the engine was in situ. This included the Thomas coupling, whose whole outer edge and forward face were comprehensively and closely examined using an illuminated magnifier. However, on removal and disassembly it was found that leaves No. 13 and 14 (numbering the 14 leaves from the front) were fractured radially and No. 12 was radially cracked right across its aft face. The damage to each of the three leaves was at almost the same circumferential position, roughly midway between two bolt holes. Before disassembly, Thomas coupling attaching bolt/nut torque was found to be within limits.

Additionally, considerable notching of the Terry pins was evident, consistent with fretting against the UJ ring steel bush in which they were located. In the worst case the wear had reduced the section of both pins of one pair by more than half, and the action of unlatching the pins caused permanent bending at these points.

1.12.3 Main gearbox

Inspection showed that five of the eight laminated pads of the MGB bilateral suspension system exhibited deterioration, with areas where the rubber had become soft and had bulged or split or partially disbonded from the end plates. Four of these were the pads that react normal torque reaction loads, and three of these were particularly badly affected. Some of the pad damage could be seen with the MGB still installed, but some of the pads are fairly inaccessible in this condition. The aircraft manufacturer reported that with the deterioration seen, it could be expected that the pads would have become appreciably more compressible and the limited testing possible (paragraph 1.16.1) indicated that this was the case.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

There was no fire.

1.15 Survival information

Not applicable.

1.16 Tests and research

1.16.1 Engine to MGB alignment and MGB bilateral suspension system

A check of the alignment of Engine No. 1 and the MGB did not prove possible. The manufacturer stated that the alignment relied on build to drawing dimensions and was not measured at any stage and that no jigs to enable measurement existed. Pressures to repair the aircraft precluded attempts to develop a method of accurately measuring alignment while simulating MGB loading. Only at the very last moment before completion of the final report did the manufacturer provide the AAIB with some data quantifying Thomas coupling misalignment angle as a function of laminated rubber pad deformation. They stated that, in a maximum power condition:

'The crush for a set of new laminated bearings under flight load is thus 1.6 mm when stiffnesses are combined and this corresponds to a 0°31' MGB rotation. (Note: the MGB's theoretical presetting is 0°30')

The laminated bearings removed from Compass Aviation Ltd helicopter S/N 5194 (G-OHMS) have been tested under the pressing load specified on drawing with the following results:

Longitudinal bearing	*1.65 mm under 2000 daN (against 0.45 theoretical).*
Lateral bearing	*Too damaged for tests; the crush can reasonably be estimated to 2 mm under 2000 daN minimum by comparison with the longitudinal bearing.'*

The combined calculated stiffnesses of the bearings therefore ..... *'provides a displacement under load equal to 5.53 mm and, consequently, an MGB rotation equal to 1°48'. When this value is compensated with the 30' theoretical presetting, MGB misalignment is 1°18' and thus excessive.'*

The above estimated misalignment was within the reported maximum Thomas coupling misalignment of 1°30' (paragraph 1.6.2) and it was not apparent why the aircraft manufacturer considered it to be excessive.

1.16.2 Terry pin vibration assessment

Testing was undertaken to assess the behaviour of the Terry pins when subjected to vibration over a range of excitation frequencies and amplitudes. It was clear that there could be a wide range of variables associated with the possible situations in which vibration would be experienced, such as due to imbalance in normal operation or, with a partially failed Thomas coupling, due to imbalance and/or impact of drive train and static components. In view of this, the testing was not intended to be exhaustive but rather to provide general qualitative indications of behaviour.

Sample Terry pins were mounted on a linear vibrator capable of producing sinusoidal, square wave and mixed wave forms and the behaviour observed using a strobe light synchronised to the vibrator. Frequencies explored ranged around the nominal drive train once per revolution frequency of approximately 100 Hz. Both severely worn and unworn pins were used, located in a variety of orientations to the vibrator axis and to the vertical. Pin fixture methods included rigid clamping of either the straight or curved latch portion of the pin, and loose location in a UJ bush, both with and without a pivot pin present, of both a single pin and a pair of pins, tie-wrapped together.

In a number of the test conditions heavy chattering of the Terry pins was evident and considerable relative movement between the straight and formed ends of the pin was apparent at times, although in no case was a pin induced to unlatch. It was also found that at times the pins mounted in the UJ bush would tend to ride upwards under the influence of the vibration and an open pin could depart the bush in these conditions. The particularly lively behaviour occurred at a number of frequencies, but commonly over only a narrow frequency band and the effects were generally not readily reproducible.

1.17 Additional information

1.17.1. Aircraft history

At the time of the accident the aircraft had accumulated 4,879 operating hours since new, 1,165 hours of which had been accumulated by the current owner since buying the helicopter in mid 1990 after its transfer from the US Registry. The owner had used the CAA Light Aircraft Maintenance Schedule Rotary Wing (CAA/LAMS/H/1978) for maintenance of the helicopter, plus reference to the schedule and practices recommended in the helicopter manufacturer's Master Servicing Recommendations document. This document, following the system of document coding used by Eurocopter, is widely referred to as the 'PRE'. The LAMS requires that *'Recommendations issued by the manufacturer of the aircraft . . . . . shall be evaluated and appropriate action shall be taken as considered necessary'.*

The No. 2 engine had been removed, repaired and refitted in April 1992 some 294 operating hours before the accident after sustaining foreign object damage. This was the last occasion identified from the records on which there had been a requirement to make any disassembly of the No. 2 UJ assembly.

A 50 Hour LAMS Check carried out on the day before the accident, 4 operating hours prior to the accident, had included an in situ visual inspection of both engine drive train Thomas couplings. This check had originally been called for by the PRE Schedule at 100 hour intervals but, following an accident to an AS355-F2, G-WMPA, in 1990 (paragraph 1.17.2), the CAA had suggested in Letter to Operators (LTO) No. 1191 of 7 February 1992 that the check be carried out at an interval not to exceed 50 hours. The check on G-OHMS had been carried out as usual by rotating the drive train by hand and closely inspecting the visible parts of the Thomas coupling through the apertures between the UJ components for signs of leaf fracture, buckling or blistering (leaf distortion resulting in excessive gaps between leaves). The inspection permits viewing only of the thin outer edge of the leaves, except for part of the outer face of the two end leaves. No excessive Thomas coupling deterioration was observed.

The three Engineers of the maintenance organisation that had maintained G-OHMS for approximately 2½ years considered it normal practice to visually check the presence and latched condition of the Terry pins for the UJ pivot pins while conducting the in situ Thomas coupling visual check and this had been done at the last 50 Hour Check on 8 December 1992, with no Thomas coupling or Terry pin defect found. The PRE Schedule did not require any disturbance of the UJ assembly between the 400 and 800 Hour Checks, and all three maintenance Engineers reported that neither the UJ nor the engine or MGB mountings had been disturbed in any way for the 294 hours preceding the accident. In particular, they had not unlatched any of the Terry pins since the No. 2 engine fit in April 1992 and no plausible reason for this to have been done during the subsequent maintenance activities was found. The personnel believed that all Terry pins had been in place and latched at the 50 Hour Check the day before the accident.

The PRE Schedule required a detailed inspection of the Thomas coupling every 800 hours that implied the need to disassemble the coupling. Due to an oversight in carrying over this item to the checks scheduled under the LAMS, this disassembled check had not been accomplished on G-OHMS during the 1,165 hours operation with its current owner.

The PRE Schedule also required an assessment of the out-of-alignment of the UJ assembly every 800 hours by means of measurement of the dimensions of the UJ pivot pins and the bushes of the UJ ring, the coupling housing tube and the UJ flange. The owner stated that the check had been accomplished on the No. 2 UJ at the time of the engine removal 294 hours before the accident and on the No. 1 UJ 244 hours before the accident, with satisfactory results in both cases, although the owner's maintenance system had not required specific certification of these checks. There was no maintenance requirement or recommendation to check at any stage either the dynamic balance of the engine-MGB drive train, nor to check engine-MGB alignment, and engine and MGB mountings were not adjustable for alignment purposes.

The MGB suspension laminated pads on G-OHMS were last replaced when the aircraft was transferred to the UK Register in mid 1990, 1,165 operating hours before the accident. The pads were 'on-condition' items but the recommended means of maintaining them in satisfactory condition could not be positively established from the PRE because of ambiguity and confusion in the relevant sections. A PRE Worksheet (63.00.00.602) gave instructions for visual checking of the pads both in situ and after removal of the MGB. A schedule in Section 5.15 listed the interval for checking the suspension system as 'OC' (On-Condition); Section 5.23.01 recommended a visual in situ check at a 400 Hour Check and Section 5.23.03 recommended a check at a 1200 Hour Check, but without making it clear whether this should be with the MGB removed or not.

The pads were variously referred to as 'laminate stops' and 'laminated bearings'. The aircraft manufacturer reported that the intention was for an in situ visual inspection at 400 hour intervals and a disassembly inspection at 1,200 hour intervals. The maintenance engineers reported that in practice they had inspected the pads in situ at 50 Hour Checks.

G-OHMS had suffered from a lateral vibration some months before the accident while carrying out a filming task. As one of the spherical bearings in the main rotor head showed some wear the bearings were changed as a set of three and this had cured the vibration. As with most other types of helicopter, the aircraft was not provided with any form of continuous vibration monitoring.

1.17.2 Similar cases

Evidence was found of four previous cases of complete Thomas coupling failure, in each case with resultant damage reportedly similar to that on G-OHMS. In each case the aircraft landed without further incident. Three of the cases, reported by the helicopter manufacturer, had been attributed to deteriorated MGB suspension pads, in all cases affecting the No. 2 drive train. The other was the accident to a UK registered AS355, G-WMPA on 30 December 1990 near Birmingham (AAIB Bulletin 12/91), where the damage was almost identical to that resulting to G-OHMS. UJ Terry pin unlatching occurred almost identically as well, except that one of the outboard pins remained latched and the outboard pair did not detach. No deterioration of the MGB suspension pads was apparent and the cause could not be conclusively established. However, possible contributory factors were identified and a number of recommendations were made to the CAA.

As a result, G-WMPA's operator decreased the Thomas coupling inspection interval to 50 hours and at a 50 Hour Check on 7 March 1991 found severe damage to the No. 2 coupling of another AS355 helicopter, G-BPRJ. One leaf had fractured from one of the bolt holes and three other adjacent leaves near the centre of the sandwich had completely fractured radially approximately midway between two of the bolt holes. Two of these leaves had double fractures with portions of the leaf missing. Rubbing had destroyed fracture surface details but specialist inspection concluded that the failures had resulted from fatigue cracking. None of the nuts securing the six Thomas coupling bolts was found to be loose, but some loss of torque on two or three of them was reportedly apparent during disassembly. Records gave no indication as to a possible reason in the aircraft's history for the damage. It was found at 3,847 total aircraft operating hours, 222 hours after the No. 2 engine had last been disturbed. 140 hours later, when the MGB was removed following a main rotor strike by a ground vehicle, slight deterioration of the MGB suspension system was found.

Service experience has reportedly shown that when this type of coupling deteriorates it is usual for the end leaves to be affected first but that, on occasion, inner leaves can be the first to fracture. It also appears that fractures may cause significant damage without necessarily progressing to the outer edge of the leaf.

1.17.3 Previous recommendations

Three safety recommendations were made to the CAA on 5 November 1991 following the accident to G-WMPA, two of which are repeated below:

1 Conduct a review of the design and failure history of the engine-main gearbox drive train on Aerospatiale AS355 Twin Squirrel helicopters and give particular consideration to the following:

1.1 More frequent inspection of the engine-MGB Thomas couplings.

1.2 Re-torquing of Thomas coupling bolt retaining nuts after a short bedding-in period of operation, and consider the need for such a procedure on other aircraft with similar types of coupling.

1.3 Checks aimed at ensuring that engine-MGB alignment and drive train vibration level are acceptable following replacement of an engine-MGB Thomas coupling that has suffered damage for which there is no clear explanation.

2 Consider requiring, for UK registered public transport and police helicopters:

2.1 Checks aimed at ensuring that engine-MGB alignment and drive train vibration level are acceptable following disturbance of engine or MGB mountings or drive train components.

2.2 The early provision of a facility to monitor continuously the vibration of high speed rotating equipment whose integrity is critical to flight safety.

1.17.4 CAA response to the recommendations

The CAA fully accepted both of the above recommendations at the time of publication of the AAIB report and, on 25 October 1993, they summarised by letter the action taken to date as:

'a) Action taken.

i) CAA LTO 1191 was issued on 7 February 1992 and revised on 28 April 1993, calling for more frequent in-situ inspections of engine to MGB Thomas coupling condition and, at the same time, integrity checks including correct latchment of Terry clips.

ii) CAA LTO 1274 was issued on 16 March 1993, calling for MGB suspension laminated pads to be inspected within 10 flight hours and at 100 flight hours thereafter (reduced from 400 flight hours).

iii) Eurocopter Service Letter 1169-63-93 has been issued calling operators attention to the Maintenance Manual requirement for checking correct Terry clip latchment after the last flight of the day.

b) Action in hand

i) Maintenance Manual amendments are being prepared to require checks of laminated pads whenever Thomas coupling damage is found, and vice-versa.

ii) Maintenance Manual amendment is being prepared to reduce the inspection frequency of laminated pads from 400 flight hours to 100 flight hours. (Eurocopter are also considering a Service Bulletin calling for a once around the fleet inspection of laminated pads within 10 flying hours - as LTO 1274).

iii) Maintenance Manual work and amendments are in hand to clarify laminated pad inspection criteria and remove various ambiguities.

c) Significant new evidence

i) Rejections have resulted from inspections carried out in accordance with the LTO's mentioned above. MGB suspension laminated pads from two helicopters were removed for deterioration in the form of blistering, swelling and extrusion of elastomeric material. On one of these aircraft, three months later, Thomas coupling damage was found with one leaf cracked and another fractured between retaining bolt holes (indicative of excessive deflection). No adverse experience has been reported for other aspects of the LTO inspections.

ii) Eurocopter has now positively established that the MGB suspension laminated pad deterioration from G-OHMS gave a misalignment that resulted in excessive fatigue damage of the Thomas coupling leaves. It is their belief that this misalignment was the likely cause of failure for G-OHMS.

Dialogue is continuing with Eurocopter, other airworthiness authorities and constructors on all aspects of the investigation and AAIB's Recommendations.'

The current status of the above recommendations is 'Open' and the CAA has reported the following in CAP 625, Progress Report 1993:

'Recommendation 1 - CAA action

The constructor and the DGAC were requested to review the design and failure history of the engine-MGB drive train on AS355 Twin Squirrel helicopters.

Their response notes that three similar incidents of AS355 engine-MGB flexible coupling ruptures are known to have occurred since 1987. Two ruptures were due to misalignments caused by damaged MGB suspension laminates and one due to poor engine mount fitment which caused an excessive misalignment. For all these, as for G-WMPA, the flights were continued on one engine and normal landings made and it is considered the consequences on flight safety are equivalent to an engine stop in flight.

Addressing the Recommendations sub-parts in turn:

(i) As an interim measure, pending advice from the constructor and DGAC, CAA published a "Letter to Operators" No. 1191 dated 7 February 1992 giving the status of CAAs investigations and advising more frequent in-situ inspection of AS355 engine-MGB Thomas couplings.

In his response the constructor stated that experience demonstrates that flexible coupling ruptures are generally caused by significant engine-MGB coupling shaft misalignments with gross degradation and failure too fast to allow detection with periodic inspection. As a consequence Eurocopter and DGAC do not recommend changing the in-situ inspection frequency of the couplings nor the frequency of removal for more extensive inspections.

CAA believe recent experience supports this position. A further incident of engine-MGB Thomas coupling failure occurred on 9 December 1992 on AS355 helicopter G-OHMS with similar characteristics as for G-WMPA. The Thomas couplings were inspected to LTO 1191 only two days and 2.2 flight hours previously with no damage noted. LTO 1191 has been amended to include inspection of the gearbox mount laminates.

(ii) The constructor is re-examining the necessity for the introduction of tightening torque checks of AS355 engine-MGB Thomas coupling bolt retaining nuts after a short bedding-in period. This procedure proved necessary and effective when introduced on Puma and AS365 aircraft and recent AS350 service experience of tightening torque loss gave rise to instructions calling for tightening after a few operating hours. In the meantime LTO 1191 has been amended to include an appropriate action.

Further, in consideration of other helicopter types, the CAA have written to all certificating authorities of types validated by the CAA requesting they instigate a review with constructors to establish if similar procedures exist and are effective or are necessary. Their advice is awaited.

(iii) *The constructor and DGAC do not believe vibration checks of the flexible coupling would help detect installation errors or coupling degradation at an early stage. Misalignment checks are not required if the engine and coupling are installed in accordance with the manufacturer's instructions. CAA believe the constructors response to be incomplete and dialogue continues.*

Recommendation 2 - CAA action

(i) *UK and foreign manufacturers of rotorcraft have been contacted for their views and information on the means of ensuring correct engine-MGB coupling alignment and checks of drive train vibration levels. Responses are awaited but overdue, CAA consider them to be of high priority and will pursue the matter accordingly.*

(ii) *This Recommendation is similar to Recommendation 4.7 of AAIB Report 1/90 and Recommendation 4.14 of AAIB Report 3/90.*

The current UK Certification standard for new large helicopter types is BCAR 29 which defines the safety objectives. A safety assessment is required to confirm that they will be met. The CAA is satisfied that the objectives will not be met with current transmission technology without vibration health monitoring.

BCAR 29 will be superseded by JAR 29 which is the subject of a harmonisation exercise with FAR 29. Both will require a safety assessment which will lead to similar provisions for health monitoring.

The CAA Discussion Paper "The Airworthiness of Group A Helicopters" has led to proposals for retrospective application of the JAR 29 design assessment requirements, targeting those helicopters operating over hostile terrain and city centres.

The proposals will be submitted for JAA consideration with a view to joint implementation.

The application of HUMS to small public transport helicopters will be reviewed following the publication of JAR 27 in 1993.'

1.18 New Investigation techniques

None.

2 ANALYSIS

2.1 General

It was evident from the damage characteristics that the splined flange and the Thomas coupling with its connecting bolts and nuts had contacted the interior of the coupling housing tube while rotating at high speed. Unscrewing of the Thomas coupling bolt nuts and the damage to the coupling housing tube were consistent with such contact. Detailed examination found that extensive post-failure damage had destroyed virtually all original fracture surfaces and positive identification of the failure mode was not possible. However, the damage had clearly resulted from gross misalignment between the rotating drive train and the static engine-MGB mounting components, and the evidence indicated that this had initially been caused either by failure of the Thomas coupling or by partial disconnection of the UJ.

2.2 Single engine ferry

The single engine ferry flight was conducted after telephone discussions between the commander and the aircraft owner's engineering staff. No reference to single engine ferry flights was contained in the aircraft Flight Manual or the company Operations Manual. It is a requirement for the holders of Air Operators Certificates (CAA publication reference CAP360) requiring to operate ferry flights with one engine inoperative that they include a section in the Operations Manual detailing the procedures for carrying out such (non revenue) flights. In addition, the manufacturer has not carried out the relevant flight testing to support such operation. In view of the much degraded structural support for the failed engine in the case of this accident, the aircraft manufacturer would not permit single engine ferry flights to be carried out with the aircraft in this condition. The decision to conduct a single engined ferry to Bristol was imprudent.

2.3 Terry pin unlatching

The unlatching of the two pairs of Terry pins, allowing the inboard UJ pivot pin to be released, was particularly difficult to explain, as either a cause or an effect of the accident. It had occurred in an almost identical fashion in the case of the accident to G-WMPA in 1990 (paragraph 1.17.2). In view of the apparent improbability of the pins having become detached in use, the possibility that they had been left unlatched was examined in detail. However, there had been no recorded maintenance that could have required any of the pins to have been unlatched since the last removal of the No. 2 engine (294 hours before the accident), no plausible reason for them to have been unlatched during subsequent maintenance activities and the presence and latched condition of the pins had

reportedly been confirmed during the last 50 Hour Check. It was also clear that unlatched outboard pins, occupying a prominent position in the MGB bay, should have been readily apparent during pre-flight checks. Thus it was concluded that it was highly unlikely that the Terry pins had become unlatched as a result of maintenance activities.

Immediately after the forced landing, photographs were taken by the pilot before he left the vicinity of the aircraft. These show the outboard Terry pins to be missing from the UJ. A ground handler who was present immediately after the forced landing and assisted the pilot confirmed that the Terry pins were found lying on the floor of the bay. The possibility that the Terry pins had been interfered with after the landing could be dismissed.

The possibility that the aircraft had been tampered with was considered. During the night before the accident it had been parked where it was accessible. No cases of unauthorised interference with parked helicopters has been recorded at that location. While the possibility of interference with the Terry pins could not be totally dismissed, tampering of this sort was considered very unlikely.

Neither the maintenance organisation, the aircraft manufacturer, the manufacturer's UK agent nor the CAA had any record of this type of Terry pin unlatching, either in normal service or in failure situations, except in the case of G-WMPA's accident. It did not appear possible that the pins could become unlatched as a result of fouling against other components, even if the UJ ring bush in which they were located were to rotate in the UJ ring to any orientation. The possibility that very severe vibration, such as could result from operation with a grossly deteriorated Thomas coupling, could cause the Terry pins to resonate and thereby unlatch and migrate from the UJ ring bush also appeared quite unlikely. Although the testing to assess the behaviour of the Terry pins under conditions of vibration did not cause pins to unlatch in any case, it was of necessity limited in relation to the wide range of possible conditions. It was shown that on occasion an unlatched pin could migrate upwards out of the bush. The testing also demonstrated that significant motion of the pin ends in the unlatching sense could occur. In view of this, and the evidence tending to dismiss the other possible causes, and in light of the close parallels with the G-WMPA accident, it was concluded that severe vibration was the most likely cause of the Terry pin unlatching. Even so, the evidence did not allow complete dismissal of the possibility that drive train vibration that was abnormal, but not due to gross deterioration, could have caused the Terry pins to unlatch and thereby precipitate the Thomas coupling disintegration. In view of this doubt, it was recommended on 19 April 1993 that the CAA require, for UK registered AS355 helicopters and other types with similar design features, a positive means of retaining the UJ pivot pins that does not rely on springs.

2.4 Thomas coupling failure

In view of the discussion at paragraph 2.3, the balance of evidence therefore suggested that failure of the Thomas coupling had caused the disconnection of the UJ, rather than vice versa. As neither Thomas coupling had been subjected to the manufacturer's recommended 800 hourly disassembly inspection for at least 1,165 hours, it was possible that either or both had been operating in a damaged state for a considerable period. Had the fracture of the No. 1 coupling aft leaf, found after the accident, been present at the time of the inspection, it should have provided a clear indication. However, the inability of the close post-accident inspection of the edge of the No. 1 coupling to detect the considerable damage found on disassembly showed that an in situ visual check could be ineffective in detecting significant damage, except where the end leaves were affected, and experience suggested that coupling damage did not always include the end leaves. Damage could also remain hidden because it did not extend to the outer edge of other leaves. In either case, any damage should be readily apparent on disassembly but no evidence was found to indicate whether or not the 800 hour interval recommended for disassembly inspections was sufficiently frequent to prevent severe coupling deterioration. It could not be established whether or not 800 hourly disassembly inspections carried out on G-OHMS's coupling would have provided warning of impending failure.

The aircraft manufacturer's experience with similar types of coupling on other variants of the Squirrel and other types of helicopter suggested that loss of preload in the Thomas coupling bolts as a result of bedding in of the leaf sandwich in service could have been a factor in the failure of the Thomas coupling. The manufacturer suggested at the time of the G-WMPA investigation that nut torque should be reset some 5 to 10 operating hours after reassembly of a coupling. Although checks showed that loss of clamping had not been a factor in the damage to G-OHMS's No. 1 Thomas coupling, there was no direct evidence to show whether or not it could have contributed to the disintegration of the No. 2 coupling.

While the possibility that loss of Thomas coupling bolt preload had contributed to the failure could not be dismissed, the poor condition of the MGB bilateral suspension system pads was significant as the helicopter manufacturer reported that there tended to be an appreciable softening of the pad load/deflection characteristics when this happened. The result would be increased MGB movement relative to the fuselage under flight and torque reaction loads, resulting in misalignment of the MGB with both engines and hence angular deflection at the UJs that could impose excessive flexing on the Thomas couplings as the drive rotated, possibly leading to fatigue fracturing of the leaves. The aircraft manufacturer concluded from pad testing results that the stiffness of the pads had

reduced to the point where excessive misalignment had resulted, although the analysis obtained from the manufacturer was not sufficiently coherent to confirm this. In the absence of full quantitative information the evidence was not conclusive but indicated that this was probably the cause of the accident to G-OHMS. This was supported by the fact that both Thomas couplings suffered appreciable damage.

Although three of the previous four known cases of complete Thomas coupling failure had also been attributed to the effects of MGB suspension pad deterioration, no evidence to support this was available, and such a feature had not been present in the case of the failure to G-WMPA.

Recommendations concerning Thomas couplings were made to the CAA on 5 November 1991, following the accident to G-WMPA (paragraph 1.17.3).

2.5 Main gearbox suspension

The helicopter manufacturer reported that a number of previous cases of deterioration of the laminated pads of the bilateral suspension system had occurred, in some cases resulting in drive train failure similar to that occurring to G-OHMS (paragraph 1.17.2). While the pads on G-OHMS were due for disassembly inspection within 35 hours after the accident, they had been inspected in situ at 50 hour rather than the PRE recommended 400 hour intervals, although the extent to which the PRE rejection criteria had been applied when carrying out these inspections could not be established. It was generally considered that pad deterioration would be made apparent by excessive helicopter vibration experienced in flight, but such a subjective measure would be unlikely to be reliable. The evidence suggested that the possible effects on drive train integrity of pad deterioration were not generally appreciated. It was clear that the pads were hidden to a greater or lesser extent while installed, even if an inspection mirror were used, being located underneath the MGB in a recessed portion of the transmission deck. Small clearances from suspension system components made parts of the pads fairly inaccessible for checking by feel. It appeared that in situ inspection could possibly be made more effective, for example by slackening the nuts on the pad clamping bolts to allow pad rotation during inspection, possibly requiring special tools and techniques. It was therefore recommended on 19 April 1993 that the CAA require, for UK registered AS355 helicopters and other types with similar design features, more frequent inspection of the MGB bilateral suspension system laminated pads of a type that permits adequate assessment of their condition, and require recommended inspection intervals and methods to be clearly specified.

2.6 Additional airworthiness considerations

The evidence showed that the sudden loss of power from one engine that resulted from the failure on G-OHMS caused no unmanageable hazard to the aircraft. However, potential airworthiness hazards were also posed by the gross disruption of high speed components in the vicinity of the MGB. In particular the loss of engine support resulted in the engine being restrained by the lightweight composite engine bay door, and it was free to strike it with considerable energy under the influence of aircraft manoeuvres. In a recent case of loss of part of an engine bay door from an AS355 helicopter (G-BOOV on 6 January 1993 near Liverpool) parts of the door struck the main and tail rotors and caused in-flight severance of the tail rotor drive shaft (AAIB Bulletin 5/93). Such an occurrence as occurred to G-OHMS could, therefore, have resulted in the detachment of the engine cowling with disastrous consequences, particularly to a helicopter engaged in prolonged over-city operations.

It is noted that the specified maintenance action on finding a damaged Thomas coupling was to replace it, with no requirement or guidance for checks aimed at establishing the cause of the failure, such as engine-MGB alignment checks or drive train vibration checks. It was the evidence that severe Thomas coupling damage or disintegration can result from causes other than MGB suspension pad deterioration, and the fact that alignment was critical to drive train integrity, that led to the recommendations of 5 November 1991 to the CAA (paragraph 1.17.3).

The investigation raised questions about the suitability of the LAMS for maintenance of a Public Transport aircraft of this type. Although the Twin Squirrel qualifies within the 2,730 kg maximum total authorised weight category, it is relatively complex in some areas and it appears likely that operators would not always be in a position to make a realistic judgement about what constitutes appropriate action with regard to manufacturer's recommendations, as required by LAMS. A system whereby maintenance is scheduled and carried out in accordance with a very generalised schedule such as the LAMS but with read across to detailed manufacturer's recommendations, based on wide service experience, appears inherently prone to confusion and omission, as occurred with G-OHMS. It was therefore recommended on 19 April 1993 that the CAA include considerations of the complexity of the aircraft and the type of operation in the criteria for approving use of the LAMS.

Similarly, a weight limit as the criterion for application of the CAA Mandatory Occurrence Reporting (MOR) system (maximum total weight authorised exceeding 2,300 kg) appears questionable for modern aircraft. Although operators of such aircraft often voluntarily make reports, the mandatory reporting of all occurrences on a particular type would, by assisting in preventing the

recurrence of problems with airworthiness implications, bring benefits to all operators. It was therefore recommended on 19 April 1993 that the CAA include considerations of the complexity of the aircraft and the type of operation in the criteria for application of the MOR system.

While the helicopter occupants had no indication of impending failure prior to the bang, the indications from the considerable component fretting suggested that the drive train had operated in an abnormal situation for some time and that there had therefore been a significant period in which the vibration levels generated by the 6,016 RPM drive train would have been abnormally high. The same applied in the case of G-WMPA's accident, and the imbalance created by the missing portions of Thomas coupling on G-BPRJ would also have generated vibration levels significantly above normal. It is possible that engine and MGB flexible mountings could isolate the occupants from abnormal vibration, but it is likely that this would have been detectable by a simple gearbox mounted vibration monitoring system in both cases. These considerations resulted in the recommendations of 5 November 1991 (paragraph 1.17.3).

3 Conclusions

(a) Findings

(i) The helicopter suffered failure of the No. 2 engine-MGB drive train and engine mount while in the cruise. No damage resulted from the single engine landing.

(ii) The decision to conduct a single engined ferry to Bristol was imprudent.

(iii) A number of the laminated pads of the MGB bilateral suspension system had suffered severe deterioration and softened as a result. This would have allowed increased MGB movement and hence possibly caused increased drive train misalignment, particularly under torque reaction loads.

(iv) Serious potential airworthiness hazards were posed by the sudden loss of the engine mount which allowed the engine to rest against the engine bay door.

(v) No means were available of readily checking engine-MGB alignment and there was no requirement or recommendation for such a check.

(vi) The laminated pads were only partially accessible to in situ inspection, unless clamping bolts were slackened to allow pad rotation.

(vii) Four previous cases of complete Thomas coupling failure were known to have occurred. Three had been attributed to the effects of deterioration of MGB suspension system laminated pads.

(viii) The failures of the drive train and the mount of the engine to the MGB in G-OHMS resulted from gross misalignment that was most probably due to deterioration of the MGB suspension system laminated pads.

(ix) Three of the leaves of the No. 1 Thomas coupling had fractured.

(x) The Thomas couplings had operated without a disassembly inspection for considerably more than the period recommended by the helicopter manufacturer. The likely contribution of this to the accident could not be established.

(xi) The possibility that loss of Thomas coupling bolt preload in service had contributed to the failure of the No. 2 coupling could not be dismissed.

(xii) It was not possible, by visual inspection of the Thomas coupling in situ, to detect serious damage to the coupling in all cases.

(xiii) Specified maintenance actions on finding a damaged Thomas coupling did not include measures aimed at ascertaining the cause or confirming acceptable engine-MGB alignment or drive train vibration level.

(xiv) There was no warning of the impending drive train failure. It is likely that a simple gearbox mounted vibration monitoring system would have provided such warning.

(xv) Terry pins retaining two of the No. 2 engine-MGB mount UJ pivot pins had detached, allowing the UJ inboard pivot pin to disengage. Similar effects occurred in the case of a previous accident to another aircraft. The Terry pin unlatching and detachment most probably resulted from the effects of severe vibration caused by incipient drive train failure.

(xvi) The possibility could not be totally dismissed that unlatching of the Terry pins had resulted from vibration that was abnormally high and that this had in turn contributed to the Thomas coupling failure by allowing the UJ inboard pivot pin to disengage.

(xvii) The LAMS was considered to be unsuitable for the maintenance of a more complex public transport category helicopter of this type for which a detailed manufacturer's recommended maintenance schedule was available.

(xviii) The criterion of a weight limit for application of the MOR system was questionable for an aircraft of this complexity.

(b) Causes

The following causal factors were identified:

(i) Failure of the No. 2 Thomas coupling, probably as a result of deterioration of the main gearbox suspension system laminated pads.

(ii) Lack of Thomas coupling disassembly inspection may have contributed to the accident.

(iii) Lack of a vibration monitoring system to warn of impending failure.

4. Safety Recommendations

The following safety recommendations were made to the CAA on 19 April 1993:

93-33 Require, for UK registered AS355 helicopters and other types with similar design features, a positive means of retaining the UJ pivot pins that does not rely on springs.

93-34 Require, for UK registered AS355 helicopters and other types with similar design features, more frequent inspection of the MGB bi-lateral suspension system laminated pads of a type that permits adequate assessment of their condition, and require recommended inspection intervals and procedures to be clearly specified.

93-35 Include considerations of the complexity of the aircraft and the type of operation in the criteria for:

a) Approving use of the CAA Light Aircraft Maintenance Schedules (LAMS).

b) Application of the CAA Mandatory Occurrence Reporting (MOR) system.

M M Charles
Inspector of Accidents

Department of Transport

November 1993