No: 12/91 **Ref: EW/C1190** **Category: 2b**

Aircraft Type and Registration:	Aerospatiale AS355-F2 Twin Squirrel, G-WMPA
No & Type of Engines:	2 Allison 250-C20F turboshaft engines
Year of Manufacture:	1989
Date & Time (UTC):	30 December 1990 at 1651 hrs
Location:	3 nm North of Birmingham Airport
Type of Flight:	Private (Police Operations)
Persons on Board:	Crew - 1 Passengers - 2
Injuries:	Crew - None Passengers - None
Nature of Damage:	Severe damage to drive train from No. 2 engine to main gearbox
Commander's Licence:	Air Transport Pilot's Licence (Helicopters)
Commander's Age:	55 years
Commander's Flying Experience:	Approximately 9,600 hours (of which 280 were on type)
Information Source:	AAIB Field Investigation

Flight History

The aircraft took off from its base at Birmingham Airport for a routine police patrol with the pilot and two observers on board. When 3 nm north of the airport while in transit at 110 kt and 900 feet agl the occupants heard a dull thump and felt a rumbling vibration. Simultaneously, caution lights illuminated for the No. 2 engine magnetic chip detector and for the No. 1 and No. 2 generators, and the dual torquemeter indicated zero torque on the No. 2 engine. The No. 2 engine was shut down and the No. 1 generator was re-set satisfactorily. The pilot declared an emergency and returned the aircraft to Birmingham Airport where he carried out a single engined landing on the grass without further incident. The three occupants were able to evacuate without difficulty. There was no fire.

Aircraft Description

The AS355 is powered by two engines mounted side by side on the cabin roof behind the main gearbox (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

(Fig 1). 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 0.2-0.3 mm (8-12 x10^{-3} inch) thick stainless steel leaves able to flex with each revolution in order to cater for minor misalignment (1½° maximum) between the coupling shaft and the combiner gearbox input drive flange. 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, with each nut torqued to 168-203 in-lb and retained by a split pin through its bolt. At 100% rotor speed the engine to MGB drive train rotates at 6,016 rpm.

The MGB is pendular mounted and restrained by a flexible suspension arrangement with four laminated rubber pads. Each engine has a single point, ball joint type, flexible mounting to aircraft structure, and is structurally connected to the MGB via a universal joint (UJ) arrangement. A coupling housing tube bolted to the engine accessory gearbox casing 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, fitted with a steel bush in each UJ pivot hole. Each of the four pairs of UJ bushes is joined by a steel UJ pivot pin, retained by two 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 pins 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. The engine coupling shaft runs within the coupling housing tube, and the Thomas coupling is situated within the universal joint arrangement.

Aircraft Examination

Examination of G-WMPA showed that on the No 2 side the Thomas coupling had fragmented, into several hundred pieces, thus severing the drive train from the engine to the combiner gearbox; and 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 aircraft structure mounting until restrained by contact with the engine bay cowl. In addition there was damage to 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 components had failed. Each of the six Thomas coupling clamping bolts had fractured at the position of its split pin holes and the associated nuts were found separated, with signs of considerable external battering but generally with little thread damage. Mangled portions of split pins of a type consistent with having originated from these bolts were recovered in the MGB bay.

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. Unscrewing of the Thomas coupling bolt nuts and the damage to the coupling housing tube were consistent with such contact. Both Terry pins from the inboard UJ pin were found on the floor of the MGB bay, tie-wrapped together and undamaged, but unlatched, and the inboard UJ pivot pin was found partially translated out from its normal location although still engaged in the UJ ring bush. This bush was found to have rotated around 30° from its normal position. In addition, the forward Terry pin retaining the outboard UJ pivot pin was found unlatched, although still in situ and tie-wrapped to its partner. Considerable fretting of both rotating and static components in the area of the Thomas coupling and the UJ suggested that the failure had progressed over a relatively extended period, but this was not quantifiable. Strip examination of the No. 2 engine and the combiner gearbox revealed no evidence of pre-existing failure or defect. Some deterioration of the MGB suspension system laminated pads was found.

Specialist examination of the relevant components by the Materials Department of the Defence Research Agency, Farnborough, found that extensive post-failure damage had destroyed virtually all original fracture surfaces and positive identification of the failure mode was not possible. The damage had clearly resulted from contact between the rotating drive train and the static engine-MGB mounting components as a result of misalignment between the two, and the evidence indicated that this had initially been caused either by failure of the Thomas coupling or by partial disconnection of the UJ.

Aircraft History

At the time of the accident the aircraft had accumulated 1,131 operating hours since new. A 100 Hour Check had been carried out in the evenings of 27 and 28 December and completed on the morning of 29 December 1991, five operating hours before the accident. It had included an in situ visual inspection of each engine drive train Thomas coupling, as required by the Maintenance Schedule, 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 the two end leaves, and the maintenance organisation responsible believed that a simple fracture in a single leaf would probably not be detectable, but that more serious deterioration, often a fracture of several adjacent leaves at a similar position progressing to the leaf outer edges, would be. No Thomas coupling defect was found at the 100 Hour Check.

The Maintenance Schedule required the Thomas coupling to be removed and disassembled every 400 hours for thorough inspection of each leaf and this necessitates disassembly of the UJ assembly. The Schedule also required an assessment of the out-of-alignment of the UJ assembly every 800 hours by

means of measurement of UJ pivot pins and the bushes of the UJ ring, the coupling housing tube and the UJ flange. Both of these checks had been accomplished on G-WMPA 307 hours before the accident with no fault found. There was no maintenance requirement to check either the engine-MGB alignment, and engine and MGB mountings were not adjustable for alignment purposes, nor to check the dynamic balance of the drive train. In company with most helicopters the aircraft was not provided with any form of continuous vibration monitoring.

Terry Pin Unlatching

The Maintenance Schedule did not require any disturbance of the UJ assembly at the 100 Hour Check, and the maintenance organisation reported that neither it nor the engine or MGB mountings had been disturbed in any way for the 307 hours preceding the accident. The personnel who carried out the 100 Hour Check reported that the UJ assembly had been visually inspected in situ at the time and that all eight Terry pins had been in place, latched and tie-wrapped in pairs. Detailed examination of the procedures and actions carried out during the last 100 Hour Check and the subsequent operations revealed no indications that the UJ assembly had been disturbed at this time, and no plausible reasons for the unlatching or removal of Terry pins could be identified, such as confusion over the type of Thomas Coupling inspection to be carried out, or to gain access to other components. Examination of a comprehensive account of the events following the accident gave no indication that the UJ assembly had been disturbed between the time of the accident and the time that photographic evidence was obtained showing the one outboard Terry pin unlatched and the pair of inboard Terry pins lying on the floor of the bay.

Neither the maintenance organisation, the aircraft manufacturer, the manufacturer's UK agent or the CAA had any record of this type of Terry pin unlatching either in normal service or in failure situations. 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 could not be positively dismissed but appeared most unlikely, and the pins exhibited no signs compatible with such a scenario. Additionally, it did not appear plausible 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.

It was noted that the UJ assembly is accessible without the necessity to raise the MGB cowls via a cut-out in the lower edge of the MGB cowl intended as a foothold for access to the main rotor head area. A step fixed to the aft support tube for the landing gear skid provides ready access to the cut-out, and reaching through it while standing on the step provides ready hand access to the outboard Terry Pins and, with a small amount of manoeuvring, to the inboard Terry Pins. Evidence concerning the ground

environment for the aircraft in its normal operational role suggested that unauthorised access could have been possible at times.

Thomas Coupling Failure

The maintenance organisation and the UK agent for the aircraft type considered it highly unlikely that in five operating hours the Thomas coupling could have deteriorated from a condition of no detectable defect to gross fatigue failure unless there had been a significant change in its operating circumstances. The aircraft manufacturer considered that service experience with similar types of coupling on other variants of the Squirrel and other types of helicopter suggested that the most likely cause of the accident was either excessive deterioration of MGB suspension laminated pads, leading to engine-MGB misalignment; or loss of preload in the Thomas coupling bolts as a result of bedding in of the leaf sandwich in service. The manufacturer suggested that nut torque should be reset some five to ten operating hours after reassembly of a coupling. It has therefore been recommended that the CAA consider requiring the re-torquing of AS355 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.

Similar Cases

Evidence was found of two previous cases of complete Thomas coupling failure, in each case with resultant damage reportedly similar to that on G-WMPA. In each case the aircraft landed without further incident. Additionally, as a result of the accident the 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 in a radial sense at a position approximately mid-way between two of the bolt holes. Two of these leaves had double fractures with portions of the leaf missing. Rubbing was found to have 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 aircraft total 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.

It has therefore been recommended that the CAA conduct a review of the design and failure history of the high speed shaft assembly on AS355 helicopters and give particular consideration to more frequent inspection of the engine-MGB Thomas couplings.

Airworthiness Considerations

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 has therefore been recommended that the CAA consider requiring checks aimed at ensuring that AS355 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. It has also been recommended that the CAA consider requiring, for UK registered public transport and police helicopters, 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.

The UK agent for the type had previously increased the Thomas coupling inspection frequency for AS355 aircraft that it maintained, but this was unknown to the maintainer of G-WMPA and G-BPRJ. It was noted that the CAA Mandatory Occurrence Reporting (MOR) system does not apply to aircraft under 2,730 kg maximum gross weight, although operators and maintainers of such aircraft in the Public Transport and Aerial Work categories apparently voluntarily report most relevant occurrences under the system. It has therefore been recommended that the CAA consider extension of the Mandatory Occurrence Reporting system to include aircraft under 2,730 kg maximum gross weight in the Public Transport and Aerial Work categories, and take measures aimed at ensuring that the service experience of operators and maintainers is fed back to the manufacturer and expeditiously shared with other relevant UK operators and maintainers.

While the helicopter occupants had no indication of impending failure prior to the dull thump, 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 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 vibration monitoring system in both cases. It has therefore been recommended that the CAA consider requiring, for UK registered public transport and police helicopters, the early

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

The evidence indicated that in the event the failure on G-WMPA caused no significant hazard to the aircraft other than the loss of power from one engine, but potential airworthiness hazards were posed by the gross disruption of high speed components in the vicinity of the MGB, and the loss of engine support, with the engine left leaning against the cowl, particularly on a helicopter likely to be engaged in prolonged over-city operations.

As a result of the investigation it has been recommended that the CAA:-

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.

3. Consider extension of the Mandatory Occurrence Reporting system to include aircraft under 2,730 kg maximum gross weight in the Public Transport and Aerial Work categories, and take measures aimed at ensuring that the service experience of operators and maintainers is fed back to the manufacturer and expeditiously shared with other relevant UK operators and maintainers.

ENGINE TO MAIN GEARBOX DRIVE TRAIN - EXPLODED VIEW

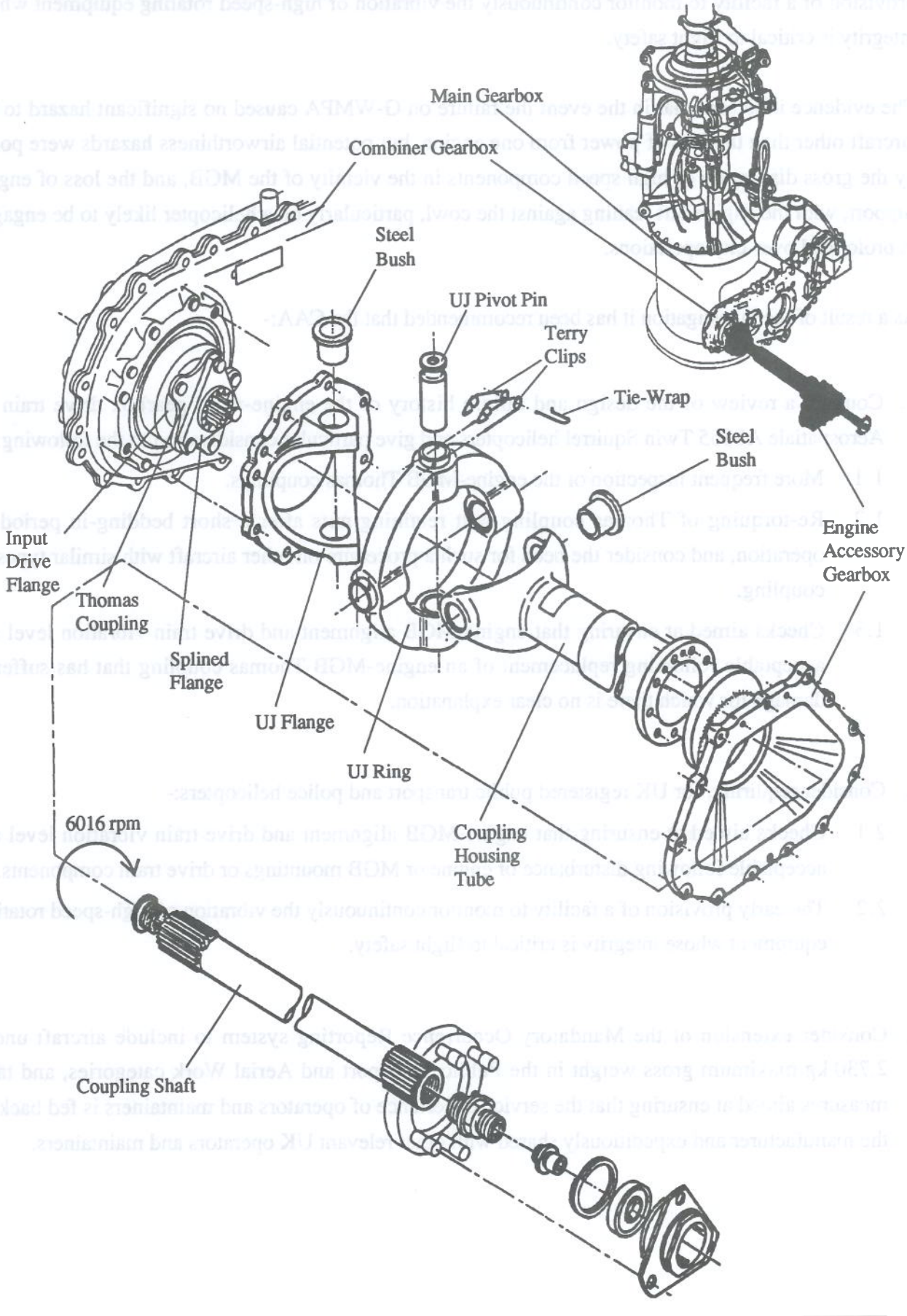

Fig 1