ACCIDENT

Aircraft Type and Registration:	Mooney Aircraft Corporation M20J, G-EKMW
No & Type of Engines:	1 Lycoming IO-360-A3B6D piston engine
Year of Manufacture:	1991
Date & Time (UTC):	16 October 2004 at 0648 hrs
Location:	Jersey Airport
Type of Flight:	Private
Persons on Board:	Crew - 1 Passengers - None
Injuries:	Crew - 1 (Fatal) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	783 hours (of which 311 were on type) Last 90 days - 40 hours Last 28 days - 3 hours
Information Source:	AAIB Field Investigation

Synopsis

Shortly after takeoff, the aircraft suffered an engine malfunction and the pilot attempted to return to the airfield. During the turn, the aircraft appeared to stall and impacted the ground in a nose low attitude, fatally injuring the pilot. A defect was discovered within the engine's dual magneto, which had recently been refitted following a 500 hr inspection, affecting both ignition systems. This led to a loss of power, accompanied by misfiring, that was consistent with aural evidence from witnesses. Issues concerning quality control of maintenance activities and maintenance data were identified during the investigation. Four safety recommendations are made.

History of the flight

The pilot used this aircraft most weekends to commute between mainland UK and Jersey. Six days prior to the accident he flew the aircraft to Jersey from Fowlmere, Cambridgeshire and parked it on the grass outside the airfield's flying club. It remained there until the evening before the accident when he taxied it onto the adjacent hardstanding in preparation for refuelling. He submitted his airways flightplan and stowed his baggage on the aircraft that same evening.

The following morning, Saturday 16 October, the aircraft was refuelled with 63 litres of AVGAS 100LL giving a total fuel load of approximately 230 litres. At 0733 hrs, the pilot requested, and was granted, start clearance from ATC and seven minutes later he taxied the short distance to holding point A1. He was cleared to depart via an ORTAC 1A Standard Instrument Departure and at 0746 hrs he took off from asphalt Runway 27; this has a takeoff run available of 1,645 m. Shortly after takeoff, the pilot transmitted 'GOLF MIKE WHISKEY EMERGENCY PAN MAYDAY MAYDAY MAYDAY RUNNING ROUGH RUNNING ROUGH'. The tower controller replied 'YOU ARE CLEAR LAND, THE WIND IS 280/12 KT'. Shortly afterwards, the aircraft impacted the ground in a shallow valley below the runway elevation, just short of the airfield boundary, and caught fire. The pilot received fatal injuries in the accident.

Airfield accident response

Jersey ATC alerted the airfield's Rescue and Fire Fighting Service (RFFS) to the accident immediately after the aircraft disappeared from the view of the visual control room. Due to the fact that the air traffic controllers could not see the accident site, and thus had to estimate the range from the airfield, only proximate location information was given. The RFFS watch commander received information that a single engine aircraft had crashed with one person on board and decided to send one fire appliance. Acting on ATC reports that the accident site was possibly close to a local seaside café, this appliance left the airfield by Emergency Access Gate 4 and travelled by public road to the café area. When they reported that no accident site or smoke could be seen, a second appliance was subsequently dispatched to assist with the search from within the airfield boundary. This appliance proceeded along the Bravo Taxiway to holding point Bravo 2 and became visual with the accident site. It proceeded through a maintenance gate, travelled a short distance along a public road and, on reaching the site some minutes after the accident, rapidly extinguished the fire. Hand-held portable radios were used to communicate with ATC and the watch commander. Communication occasionally had to be relayed from ATC via another station to the watch commander.

The airport is regulated by the Harbours and Airport Committee of the States of Jersey but aspires to meet the regulations laid down in the CAA Civil Aviation Publications (CAPs). CAP 168, titled *'Licensing of Aerodromes'*, states that '*the AFS should be able to respond to an airfield accident within two minutes under favourable conditions'*; obviously, guidance towards off-airfield accident response times cannot be given.

Witness information

Several witnesses provided consistent information on the aircraft's flightpath. Shortly after takeoff, when the aircraft was at a height of approximately 200 ft, witnesses heard two distinctive 'pops' from the engine, as if it was backfiring. These were followed by sounds of the engine spluttering which, possibly, stopped before impact. The aircraft was seen to climb to approximately 300 ft and then commence a left turn; this was confirmed by data from the airfield radar. This turn was initially level but, after the aircraft had turned through about 90°, the nose appeared to rise slightly, before the left wing and then the nose dropped. The aircraft entered a dive from which there was no sign of attempted recovery. During the dive the aircraft was seen to rotate slowly.

Weather

A meteorological observation was taken immediately after the accident at 0750 hrs. This recorded a surface wind of 290°/12 kt and a visibility of greater than 10 km. There was also a broken layer of cumulonimbus cloud with a base of 1,600 ft above the airfield and a temperature of +10°C. The meteorological weather forecaster at the airport also reported that rainfall in the previous week had been significantly heavier than average for Jersey. On the previous Monday and Tuesday a total of 60 mm of rain had fallen compared with the monthly average for the whole of October, of 92 mm.

Local terrain

Jersey Airport is located on level ground at 274 ft amsl. At the westerly end of Runway 27, the ground drops away steeply approximately one mile before the coastline. From the position where the pilot reported his rough running engine, the terrain ahead contained few areas suitable for a forced landing and, as the tide was in at the time of the accident, this negated the possibility of a beach landing.

Aircraft stalling sharacteristics

The Mooney M20J pilot's operating handbook (POH) recommends an initial climb speed of 71 KIAS prior to landing gear retraction and then 91-100 KIAS for the normal clean climb. At maximum takeoff weight, the POH indicates that, with idle power and 30° angle of bank, the aircraft would stall at 65.5 KIAS. A stall warning system provides an aural warning at 4 to 8 kt above the actual stall speed and the POH states that at maximum weight a stall could lead to an altitude loss of 290 ft. Data from the airfield radar suggests that the aircraft did not climb higher than approximately 300 ft above the airfield. A familiarisation flight was undertaken in a similar aircraft to examine the potential handling characteristics of a turnback. It was noted that, with the probable conditions encountered immediately prior to the turnback, a small application of bank would activate the stall warning system, commonly followed by wing drop if pitch attitude was increased.

Pathology

The pathological examination of the pilot revealed that he died from multiple injuries. No evidence was found of any disease, drugs or alcohol which could have caused or contributed to the cause of this accident. Toxicological analysis revealed the probability of an elevated level of carbon monoxide in the pilot's muscle tissue. The pathologist's report concluded however, that the level of carbon monoxide saturation:

> *'would not be expected to produce any symptoms or decrement of performance in an individual, particularly at the low altitude of this short flight'.*

Wreckage examination

Examination in situ

The aircraft had struck the upward sloping side of a gulley bordering the southern boundary of the airfield, at a point approximately 200 m to the left of the far end of Runway 27. At the time of impact, it was heading approximately 170ºM and pitched approximately 10º below the horizon, but approximately 40º nose down relative to the local terrain. The impact drove the engine rearwards and upwards against the firewall, and the whole of the forward section of the aircraft was effectively crushed back to the line of the wing spars. This was consistent with an impact speed significantly above the aircraft's stall speed and probably in excess of 80 kt. Both the structural deformation and the distribution of debris implied rotational momentum to the left at impact, consistent with the aircraft having been in a spiral descent to the left, possibly associated with an attempted recovery from either an incipient or early-stage spin to the left.

The integral fuel tanks in the both wings had split and a severe post impact fire developed, fed by the fuel from the disrupted tanks. The fire destroyed most of the cabin interior and instrument panel. Both fuel filler caps were in place, and secure. The rubber seal from the left filler cap was undamaged and in good condition; the seal from the right filler cap also appeared to be in good condition, except for some localised embrittlement and cracking caused by heat from the post impact fire.

The propeller had come to rest with one blade projecting vertically, and the other crushed up against the underside of the engine: the former was completely undamaged, the latter exhibited only very slight rotational scoring, consistent with the engine having been either stopped or rotating at very low power at the time of impact.

All of the aircraft's extremities were present in the wreckage, and it was evident that nothing had separated prior to ground impact.

Detailed examination of the wreckage

The wreckage was recovered initially to a hangar on the airfield, where it was subject to more detailed examination.

The fuel system in the fuselage, including the fuel selector valve and electric boost pump, was disrupted during the impact and the delivery pipework in the wing damaged by a combination of impact forces and post impact fire. Consequently, the pre-impact status of the fuel system could not be determined. No residual fuel was present in either fuel tank, but approximately 5 cc was recovered from the boost pump. This was found to be clean, free of visible water contamination, and its colour and odour were consistent with AVGAS 100LL.

The remains of the pilot's throttle lever, propeller, and hot air controls suffered deformation and potential disturbance in the impact, but their post impact positions were broadly consistent with those which would be set for takeoff. The burnt remains of the flap screw jack actuator were recovered, and it was later established from the position of the internal screw-jack mechanism that, prior to impact, the flaps were in the fully retracted position.

The engine and propeller were subsequently taken to an approved overhaul facility, where they were subjected to bulk disassembly and inspection, under AAIB supervision. Key components were disassembled further and inspected internally at this stage. At a later stage in the investigation, further detailed examinations of key components were undertaken at the AAIB facility at Farnborough.

Engine strip examination

Preliminary visual inspection showed extensive impact damage to the engine's ancillary components, including the mechanical fuel pump, propeller governor, magneto, and fuel injector housing. The air inlet trunking was severely deformed and consequently the pre-impact integrity of the induction seals between individual trunks and the sump casing could not be established; however, no evidence was found to suggest that these seals had been leaking prior to impact. All spark plugs exhibited normal appearance except for external signs of the post impact fire; the colour and condition of all electrodes, in particular, was normal. The propeller shaft was bent, causing some rotational stiffness of the crankshaft, but otherwise it turned without obstruction allowing the integrity of the drive train to the camshaft, and the correct operation of associated pushrods, rockers and valves, to be confirmed. Bulk disassembly showed that all valve heads were intact and that the pistons and cylinders were in good condition with normal carbon build-up in the cylinder heads.

The engine-driven fuel pump casing was fractured in the impact, but its internal components were all in a serviceable condition; in particular, the diaphragm was intact and in good condition. The fuel injector was damaged externally by the impact but both diaphragms were intact, and the fuel metering mechanism was clear of obstruction and judged to have been in a serviceable condition prior to the accident.

A detailed examination of the exhaust system revealed the presence of several very small apparent cracks in the 'muffler', which had been opened up by the extreme deformation which occurred to this component in the impact. Metallurgical examination showed these crack like features to be associated with small regions of lack of fusion in the welding, occasioned during the manufacture of this component.

The magneto securing clamps were loose and, consequently, the magneto body could be rotated on its mount. As found, the magneto was positioned close to the limit of its range of adjustment. A loose magneto, resulting in incorrect ignition timing, has the potential to produce symptoms of the type reported by witnesses on the ground. Therefore, the magneto and associated clamping hardware was subjected to careful examination, which established that this feature was produced by the impact, and had not been pre-existing. Specifically, analysis of a series of microscopic witness marks at the clamp interfaces established that the clamps had loosened as a result of inertial forces during the accident, and that the magneto had been close to the centre of its adjustment range at the time of ground impact. The magneto was subsequently disassembled and examined internally for evidence of pre-impact abnormality.

Detailed magneto examination

The magneto installed on G-EKMW was a Teledyne Continental Motors (TCM) D-3000 series dual unit, in which duplicate electrical circuits are served by a common drive shaft, rotating magnet, and low tension contact points cam, all of which are housed in a common casing.

The magneto had been heavily sooted in the post-impact fire but had not itself been subject to significantly elevated temperatures. The LEFT side of the cover had partially broken away in the impact and the associated distributor casing, high tension (HT) harnesses and capacitor had separated with it. The LEFT side plastic distributor drive gear, situated inside the cover adjacent to the damaged region, had broken into several pieces. The spade connection at the LEFT side low tension contact points assembly, to which the LEFT capacitor earth wire had been connected, was pulled out of alignment by this wire as the capacitor was wrenched from its housing in the impact. In summary, all of the damage described thus far was consistent with being caused by the impact; in other respects, the magneto was internally free of impact damage.

With the cover removed, the input shaft was rotated manually by turning the impulse coupling, to check for continuity of mesh between the surviving RIGHT distributor drive gear and its pinion on the drive shaft. This confirmed the integrity of both the input pinion and the driven gear, but whilst conducting these checks it was noted that the low tension contacts cam did not rotate consistently as the input shaft was turned. Further investigation revealed that the cam retaining screw in the end of the shaft was loose and that the cam was not fully jammed down onto the tapered section of the shaft and was slipping[1].

Microscopic examination of the cam securing screw, in situ, revealed minor bruising on the sides of the slot in the head of the screw, evidently made by a screwdriver used to loosen the screw; no comparable bruises could

Footnote

[1] The contacts cam is mounted on its shaft by means of a taper, the drive being transmitted solely through friction developed at the taper interface by the interference fit between the cam and shaft. The function of the securing screw is twofold. Firstly, it provides the initial force required to 'jam' the cam down tightly on to its taper. The extent of this jamming is such that subsequent disassembly requires use of special tooling to lever the cam off its taper. Secondly, it maintains a preload on the taper, preventing the cam from working loose during subsequent operation of the engine, particularly during the step-loading across the taper which occurs during engine start when the impulse coupling comes into operation.

be found in a tightening sense. It was thus evident that the screw had been undone on at least one prior occasion. So as to permit the operation of the cam and associated contacts points to be checked, the head of the cam securing screw was index marked and tightened just sufficiently (approximately one quarter turn) to engage the cam on its taper and cause it to rotate consistently with its shaft. It was established that both contacts operated smoothly with no evidence of stiffness or binding, despite the LEFT 'moving' contact having been pulled slightly out of alignment with its fixed contact by wrenching of its capacitor lead during the impact.

Upon removal, the cam retaining screw was found to be undamaged and its condition was that to be expected of a previously used screw. Specifically, the remains of the integral nylon self locking patch on its thread were crushed down into the thread, and its lock washer was partially crushed, to an extent comparable with that of a new 'sample' screw after having been installed, correctly torque tightened, and then removed. There was no evidence of any additional locking compound on the thread, i.e. the type of compound applied in liquid form during re-assembly[2].

Detailed examination of the cam assembly and adjoining components showed that loosening of the cam retaining screw could not be attributed to impact forces, either directly or indirectly; or to thermal effects, as evidenced by an absence of heat damage on adjoining parts including oil impregnated felt pads in direct contact with the cam.

Relevant maintenance activity

Routine maintenance of the aircraft was carried out by a flying club at the pilot's local airfield, the owner of which had also helped him to source his aircraft prior to purchase. The most recent scheduled maintenance was a 150 hr/Annual inspection, carried out between 19 and 30 July 2004 at 794 total aircraft hours, some 25 hrs prior to the accident. Nothing of relevance to this accident was recorded during that inspection.

The magneto was due for a 500 hr inspection at 886 hrs. On 20 September 2004, at 818 hrs, it was removed from G-EKMW and sent to an EASA[3] Part 145 approved organisation[4] for this work to be carried out. Upon completion of the inspection, an EASA Form One Authorised Release Certificate was issued, dated 24 September, and the unit was returned to the aircraft's maintenance organisation who re-installed it on G-EKMW on 5 October 2004. The engine oil and filters were also changed at this time and, upon completion of satisfactory ground runs, the aircraft was released to service. The owner subsequently flew the aircraft to Jersey, apparently without problems; the accident occurred on the aircraft's next flight, the following weekend, during the takeoff for the return flight.

Magneto inspection

The EASA Part 145 organisation that carried out the magneto 500 hr inspection was a provider of overhaul, repair, and maintenance services, covering private and corporate aircraft, and aircraft equipment, including magnetos. It was established, from the technician who carried out G-EKMW's magneto inspection, that he had followed his usual practice when carrying out the work, which essentially comprised:

Footnote

2 This is not required by the current or previous issues of the Maintenance Manual.

Footnote

3 European Aviation Safety Agency.

4 International Aerospace Engineering, Cranfield Airfield.

- Disassembly
- Cleaning
- Visual inspection
- Checks of winding resistances etc.
- Re-assembly[5]
- Rig testing

Upon completion of this work, and after the unit had been rig tested and assessed as satisfactory, an Authorised Release Certificate was raised and signed by the EASA Part 145 organisation's Chief Engineer. This certificate included the statement:

> *'Above work carried out iaw with the maintenance manual 500 Hour inspection (SB643) & SB645 (AD96-12-07) carried out.'*

It was the technician's practice during D-3000 series magneto inspections (as distinct from overhauls) to replace only those parts which, in his judgment, warranted replacement based on their condition. With regard to the cam locking screw specifically, he would deem it necessary to replace this item if, upon inspection, he could find none of what he described as the wax-like lacquer (locking material) on its threads or if the spring lock-washer had become flattened. On this occasion, no replacement parts were used and none were billed to the customer. In this regard, the work did not comply with the requirements of the manufacturer's Maintenance Manual (MM) current at the time, which specifies replacement of a number of components including, inter alia, the points contact cam retaining screw. The technician was unaware that the current MM called for replacement of these items, and the cam retaining screw specifically, not only during an Overhaul but also during a 500 hr Inspection; or that the manual mandated replacement of the cam retaining screw in the event of it being loosened or removed, for whatever reason. He became aware of this only after it was drawn to his attention during the course of the investigation and after checking the MM for himself. He confirmed that, because of this misunderstanding, he had never replaced the cam screw or the other specified parts as a matter of course during Inspections, although he was aware of the requirement to replace cam screws during a magneto overhaul. However, it is understood that it was his normal practice, when installing the cam locking screw, to apply thread-locking compound to the screw threads prior to final assembly, notwithstanding the fact that this was not called for in the MM.

Maintenance manuals

Manuals held by the EASA Part 145 maintenance organisation

At the time of the 500 hr inspection, in September 2004, the applicable MM was Teledyne Continental Motors "Service Support Manual" No X42003-1, dated June 2004. The maintenance organisation did not have a copy of this version of the manual but held instead the previous version, No X42003, issued in July 1989, which they believed at that time was current. The maintenance manual against which the Authorised Release Certificate had been issued was therefore out of date by some four months.

The EASA Part 145 maintenance organisation also held a copy of a MM published in 1983 by Bendix, the original manufacturer of the D-3000 series magnetos. This was kept in the electrical workshop alongside the July 1989 manual, albeit marked by a coloured sticker to

Footnote

5 This included the use of a torque wrench to tighten the cam retaining screw to the specified torque, and a specially made pulley attached temporarily to the opposing end of the shaft to prevent it from turning against the applied torque.

signify that had been superceded. It was evident from its well-thumbed condition that the 1983 manual had seen extensive use in the workshop whereas, by comparison, the 1989 manual was relatively clean.

Relevant differences between the 1983, 1989, and 2004 versions of the MM

The following summarises the main differences between the various versions of the MM, insofar as they apply to replacement of the cam retaining screw.

Teledyne Continental Motors 'Service Support Manual' document No X42003-1, dated June 2004, Appendix 1[6]

X42003-1 mandates the replacement of a range of parts including the contact cam retaining screw and lock washer assembly, the threads of which incorporate a patch of plastic material to stiffen the threaded assembly and reduce the risk of the screw loosening in service. The instruction to replace this screw appears initially in the *Disassembly* section of the manual, where it features in a list of items *'...which must be replaced...'*. It also is referenced specifically in this same section of the manual in a note headed *'CAUTION',* which directs that this screw must be replaced *'...whenever it is loosened or removed'*. These instructions are reiterated, in broadly similar format and wording, in the '*Periodic Maintenance'*, *'Overhaul*' and '*Assembly'* sections of the manual.

Footnote

[6] Appendix 1 summarises the Instructions, Cautions and Warnings taken directly from the TCM X42003-1 Service Support Manual, regarding the removal, inspection and installation instructions pertinent to the cam securing screw.

Teledyne Continental Motors 'Service Support Manual' document No X42003, dated July 1989

This manual (the latest version held by the company at the time of the 500 hr inspection) contained similar instructions mandating replacement of the cam retaining screw to those found in the June 2004 version, summarised above. However, the form of words employed was different, and appeared to place less direct emphasis on the requirement to replace the cam securing screw, after disturbance, regardless of the underlying reason for that disturbance.

Bendix Overhaul Manual L-1176, July 1983

This manual covers overhaul and repair activities only, and apparently pre-dates any requirement for periodic inspection. It contains a single instruction to replace the cam retaining screw, contained in the '*Disassembly'* section, which states '*Discard the self-locking cam screw and washer assembly (14)'*.

Currency of the MM

The EASA Part 145 organisation's belief that its July 1989 manual (which was current until June 2004) was current at the time it issued the Authorised Release Certificate for the magneto, was founded upon:

- … the understanding that it had purchased, in early 2004, via TCM's website, a subscription service covering MM revisions/updates for the whole of 2004, and
- …the fact that no update had been received via the subscription service for the manual in question.

The TCM Ignition Systems Master Service Manual Publications Price List, of April 2001, for magnetos, lists the prices of all of their related publications. This list describes the 'Master Service Manual' by reference to Form No X40000. A renewal subscription is stated below this heading, referenced to Form No X40000SUB, and it was this to which the organization had subscribed, believing it to relate to the Master Service Manual. However, the TCM web site indicated that the reference X40000SUB related to Ignition Systems subscription services, Domestic and International, (January – December), generally. The organisation had not purchased a Service Bulletin set separately but had firstly purchased the Master Service Manual, to include the Service Bulletin Set and, by implication, their updates, together with the renewal subscription. The prices quoted in the April 2001 price list show that a Master Service Manual would cost US$105 and a renewal subscription, referenced X40000SUB, US$40. By contrast, a full set of Active Service Bulletins was US$10, a considerably lower amount. However, by the time of the 2004 renewal subscription, the cost of the Service Bulletin Set renewal had risen to US$50 and it was this cost that led them to believe that they had purchased more than the Service Bulletins[7]. In fact, the 'online' transaction receipt obtained for the purchase of the subscription service described the item purchased, for US$50, as a Subscription Service Domestic & International (January - December 2004), referenced to Part No X40000SUB, under the overall heading of 2004 Service Bulletin Subscription Renewal.

Footnote

[7] Also on the Price List was the statement '*Each Master Service Manual contains one copy of each of the following publications'*. A list then follows, which includes *'Active Service Bulletins'* referenced to form X40000SBS. A footnote is linked to this reference stating '*Service Bulletin set purchased separately will not be updated after initial purchase of set. Set includes all active service bulletins as of factory ship date'*.

The organisation remained unaware of the June 2004 manual's existence until informed during this investigation and, similarly, was unaware until that time that its subscription service from TCM did not cover MM updates.

Investigation into the underlying reasons for the organisation's confusion over the TCM subscription service, and its out-of-date MM, revealed a series of errors and omissions in the information posted on TCM's website which, coupled with the nature of the subscription provided, possibly explained both these misunderstandings. It also established that a number of other EASA Part 145 maintenance organisations had unwittingly used out-of-date manuals as a result of erroneous and misleading information on the TCM site, and identified further issues of concern which implied a systemic breakdown in TCM's control and distribution of technical documentation.

Additional information

The manufacturer's Service Bulletin 608, states,

> *'...If incorrectly torqued, there is a possibility that it [the screw] will "back-out", resulting in magneto malfunction. The use of a self-locking cam retaining screw reduces the possibility [sic] of "back-out" (by means of a nylon patch that creates an interface [interference] fit of the threads) in the event that incorrect torque is applied.'*

Service Bulletin 608 arose from the mandatory introduction of self-locking screws in 1979. The screw in question was of the self locking type.

Quality assurance issues

The EASA Part 145 maintenance organisation

Quality control within this organisation was the responsibility of a single, part time, Quality Manager working two days per week. The organisation's Quality Systems Procedures document, which underpinned, in part, its EASA Part 145 approval, set out:

- A schedule of 12 monthly internal audits covering its full range of activities, timetabled so that each area of activity was assessed and reported upon once in each 12 month period. At the relevant time, these audits were conducted by the Quality Manager. Each audit generated a report, which comprised a simple, single A4 page, document divided into three main sections: the first two sections were headed *'Remedial action required'* and *'Remedial action taken',* with attendant signature blocks for the Quality Auditor and Chief Engineer respectively; the third section showed the status of the report, *'Closed'* or *'Open'*.
- A schedule of quarterly external audits, each covering a cluster of related activities/areas. At the relevant time, these audits were carried out by an independent consultant retained by the maintenance organisation solely for that purpose. The reports issued by the consultant comprised a one page statement listing the date of the audit, the areas examined, and any findings made.

Internal audit

Of the twelve work areas scheduled for internal audit, two are of relevance to the 500 hr inspection carried out on the magneto from G-EKMW:

Technical Library

This area was scheduled for audit in September each year, and the audit comprised a spot check as to the currency and completeness of a set of manuals chosen randomly from the technical library. The most recent report of relevance, dated 18 September 2004, stated that control of incoming documents and registration of publications was '*Carried out as & when received*', and that *'Production of* [a] *new register* [is] *still in progress*'. The audit reports as *'satisfactory'*: FADs Volumes 1, 2 (CAP 473) & 3 (CAP 474); Mandatory A/C Mods (CAP 476); Bi-Weekly Issue No (2004/18); Air Navigation Orders; Airworthiness Notices; and the microfiche documents covering the Cessna 421C, 172 & 182 series aircraft. TCM manuals were not amongst the documents selected for audit on that occasion.

Electrical Workshop

This area was scheduled for audit in November of each year. The TCM Service Support Manual covering the magneto in question was actually held in the Electrical Workshop, not the technical library, so as to be available for immediate reference by the technicians concerned. The internal audit report for this area, carried out on 20 October 2004, assessed the following as *'Satisfactory*':

General housekeeping

Correct Equipment in use

Calibration of tools in date. Correct labeling. Correct storage

Library up to date

Correct and latest S.B's[sic], A.D's[sic] and manufactures[sic] information to hand

Correct signing and release of equipment

It is notable that the audit assessed the Library as being *'up to date'*, despite the 1989 issue of the magneto MM being some four months out-of-date at the time of the audit. (The MM in question, however, had been current for some 16 years.) No record appeared to exist as to what this audit actually constituted in practical terms, but the Quality Manager asserted that, whilst carrying out this audit, he telephoned the Technical Library of a major TCM distributor in the UK to enquire as to the issue date of their magneto MM. From the information he received in reply, he inferred that the 1989 issue of the manual before him was still current.

The investigation subsequently established that the UK based TCM distributor's manuals were also out-of-date at that time and remained so for a further four months, due to the errors and omissions apparent on the TCM website.

External Audit

- Technical Library. The most recent external audit report covering the technical library (together with personnel training records, and technical records) was dated 17 November 2004. The report stated simply *'There were no findings in this audit',* and made no specific reference to the technical library per se.
- Electrical Workshop. The 2004 external auditor's report covering the Electrical Workshops, dated 21 April of that year, also covered the maintenance areas, the hangar, the avionics workshop and two product items. The report made no specific reference to the Electrical Workshops, which the consultant involved explained was because "there were no non-compliance findings at that time."

Despite the work relating to magneto inspections not following the current MM procedures directly, some findings made were in relation to failures to make appropriate reference to MMs in paperwork which arose from a Cessna 310 Annual Inspection.

CAA Audit

In addition to the audits instigated by the maintenance organisation, the CAA surveyor responsible for their regulatory oversight carried out his own periodic audits.

His most recent audit of the organisation's work on magnetos was carried out in July 2003, when he looked at the servicing of a magneto, but of a different type from that fitted to G-EKMW. At that time he checked the test rig/equipment, and noted that the manual used in relation to that activity was X42002-1, which was current at that time; he made no formal findings or observations in relation to magneto servicing. Item five on the surveillance report recorded that *'it is not evident that a Library Register is available that shows details of publications used and their respective control numbers.'* The CAA have reported that the organization accepted this finding, in writing, and undertook to implement a library register. The organisation was also asked to ensure that their manuals were up-to-date by contacting the equipment manufacturers.[8] The CAA surveyor was subsequently given an assurance that a subscription service for renewals/amendments was in place. The organisation believed that it had complied with this advice by purchasing what was understood to be a current set of magneto manuals and Service Bulletins, together with update subscriptions to both.

Footnote

[8] When the CAA audit a company, they point out that examination of engineering activity is only to be carried out on a sample basis at each visit. Hence, a different aspect of the company's activities will be looked at in detail during each audit. They also advise that under the terms of an EASA Part 145 approval, the responsibility for ensuring that work is carried out correctly primarily lies with the approved company.

Electrical technician's training

The technician who carried out the 500 hr magneto inspection had significant experience of such work, extending back to the early 1980s. He had received training specifically on Bendix/TCM magnetos, whilst in the service of a previous employer, but that employer is no longer trading and the records covering this training are believed to have been lost or destroyed.

The training records held by his current employer showed that he had undergone a regular programme of training comprising, in all, some nine modules since the start of the record in 1999. These courses, which covered a range of subjects, were delivered in a mix of instructed and self-learn courses; the former method being used for technical training on specific types/makes of equipment, and the latter for training on more generalised topics. He joined the EASA Part 145 organisation in 1994 and completed a Human Factors Training JAR 145 JAA/CAA/FAA course in April 2003.

TCM Quality Control issues

TCM technical documentation

Current Publications Listing on the TCM website

TCM provides on its website a range of information, including the current amendment status and 'effective' dates of technical manuals and related data published by the company in support of its products, published in a document headed '*Current Publications Listing'*. This five page .pdf document, which is accessed via the '*Bulletins & Manual's* section of the site, lists the current document number, ie revision status, and amendment/issue dates for some 140 technical manuals and related publications (not including ADs/SBs), together with part numbers and descriptions of related documents and services. Page Nos 1 to 4 list the *'Document No*, *Application'*, and *'Date'* for approximately 140 engine manuals (*'Operators, Maintenance',* and *'Overhaul'* manuals*;* and *'Illustrated Parts Catalogue*s*'*) grouped by engine model. Page five lists similar details for TCM Publications, Videos, and Reference Manuals, including the series of Service Support Manuals covering TCM magnetos. The header section of each page is dated to show when the *'Current Publications Listing'* itself was last amended.

During this investigation, significant anomalies of relevance to the maintenance organisation's omission to update its D-3000 series magneto manual were identified in the *'Listing'*:

The listing's amendment date (the date shown in the header section) was March 2004, implying that:

- No changes had been made to the listing since March 2004
- None of the manuals or other documents in the body of the listing had issue dates later than March 2004
- In fact, page five showed the June 2004 version of the D3000 series magneto manual, document No X42003-1; all of the other publication dates were prior to March 2004.
- Inquiries showed that at least two other maintenance organisations dealing with TCM magnetos had been misled by the incorrect date in the *'Listing'* header: one, an agent and major overhaul agency for these magnetos, discovered its error in February 2005; the other, also an agent, was unaware of the revised manual's existence until informed by the AAIB.
- Part No X40000SUB was described as Subscription Service – Domestic & International

(January – December). The X40000 prefix to this part number is the same as the part number of the item immediately below it in the listing, "X40000", described as IGNITION SYSTEM MASTER MANUAL, implying that item X40000SUB is a subscription service for the IGNITION SYSTEM MASTER MANUAL updates. In fact, this item was a subscription for ignition system Service Bulletins, and did not cover manuals.

TCM's management of technical documentation

Because of the inherently transient nature of all web-based information, it was not possible to construct a full history of changes made to the TCM *'Current Publications Listing'* over time. However, a study of printouts from the *'Listing'* held on file by one EASA Part 145 organisation, who was also a UK distributor, provided several snapshots of its content over a period extending back to August 2004, ie shortly before the date of G-EKMW's 500 hr magneto inspection. These snapshots, together with related correspondence and other records held on file, revealed a series of long-term errors and omissions affecting the *'Current Publications Listing'*, and serious systematic problems with TCM's management and distribution technical documentation, exemplified by the loss of data integrity concerning the current status of its technical publications.

In February 2005, TCM were notified by fax and e-mail of the anomalous (March 2004) header date, together with anomalous entries pertaining to six of the (engine) manuals listed at that time. In its reply, dated 9 March 2005, TCM said it was unaware that the X42003 manual had been revised to X42003-1 June 2004, and asked for suggestions as to what the correct status should be.

TCM's response to notifications of omissions

In late September 2005, some seven months after TCM was notified of the incorrect (March 2004) header date in the *'Listing'*, this error remained uncorrected. Prompted by concern over this and other issues pertaining to the *'Listing'*, TCM's International Sales and Service Manager, based in the UK, attended a meeting at the AAIB where these issues were identified and discussed in detail. This meeting was followed up by an e-mail, in which the AAIB listed the specific issues of concern and requested that an appropriate person at TCM be tasked with taking appropriate action to rectify the situation. No response to this e-mail was received, and by early November 2005, the *'Listing'* posted on the web site was still showing the incorrect (March 2004) header date.

Of the six other errors reported to TCM in February 2005, only one of these had been corrected by early November 2005. The header date on the *'Listing'* at this time still had not been updated, and continued to show March 2004.

On 2 November 2005, prompted by an increasing concern over TCM's lack of action or acknowledgement of the issues of concern brought to its attention, the AAIB advised both the FAA and EASA of the situation and suggested that these organisations take appropriate safety action to ensure the published material was current. The FAA subsequently advised that, during an FAA meeting with TCM held during the week of 14 November 2005, these issues were discussed. The *'Listing'* was subsequently updated on 16 November 2005, and its header date amended accordingly; however, of the six anomalous entries relating to engine manuals brought to its attention originally in February 2005, only three had been amended.

Supply to customers of out-of-date (superceded) material

In November 2004, the UK based TCM distributor placed an order with TCM for the full set of magneto Service Support Manuals, part No X40000, for delivery direct from TCM to the distributor's end-customer based in Northern Ireland. Inquiries made in October 2005, on behalf of the AAIB, established that the set of manuals supplied included the out-of-date July 1989 X42003 D-3000 series magneto manuals, despite these having been superceded in June 2004 (some four months previously) by X42003-1.

Quality of spare parts distributed through the approved supply chain

Having been informed by the AAIB of its belief that the contacts points cam had become loose in flight, and having discovered that both the 1989 and 2004 versions of the magneto Service Support Manual mandated replacement of the self-locking cam retention screw, the EASA Part 145 maintenance organisation that inspected G-EKMW's magneto recalled those Bendix/TCM dual magnetos upon which they had carried out 500 hr inspections. This was for precautionary replacement of the cam retaining screw/lockwasher assemblies. To meet the associated demand for replacement parts, appropriate spares, including the self-locking screw assemblies, were sourced from an 'approved' supplier.

Whilst carrying out the recall work, it was noted that one of the newly sourced screws had no locking patch on its threads. This defective screw, together with the all of the other new screws and the old screw removed from the magneto in question, were forwarded to the AAIB for assessment. Visual comparison of the new screws, totalling 21 in all from two batches, showed that both the extent and the thickness of the locking patch on the threads varied significantly. This variation ranged from the previously identified 'missing', through 'marginal' to 'acceptable'. Variations were also evident in the thickness of the new spring lock washers, a thick and a thin variant; the latter being some 20% thinner, with a correspondingly reduced crush-depth.

Analysis

Sequence of events

The pilot's 'emergency' PAN/MAYDAY radio call included the phrase "rough running", twice, and this was confirmed by witnesses on the ground who reported hearing the engine making popping/backfiring noises as the aircraft reached about 200 ft in the climbout. The period of time over which the engine was heard to make these unusual noises could not be established exactly, but was unlikely to have been more than a few seconds.

Shortly after the radio call, the aircraft was seen to turn left, through approximately 90º, before the left wing dropped and the nose sliced down, following which it entered a steep descent into the ground. Examination of the aircraft's wreckage showed that the engine was stopped, or practically stopped, and that it was either in the incipient stages of a spin to the left or, possibly, that it was in the process of recovering from a spin to the left, at the time it struck the ground.

From an operational perspective, the pilot was forced into handling an engine problem at one of the most critical stages of flight, ie, shortly after takeoff, but too late to permit a landing immediately ahead on the runway distance remaining. He therefore had to decide whether to return to the airfield, or to attempt a forced landing in the area ahead of the aircraft. The ground in potential gliding range of the aircraft, from its maximum height of around 300 ft aal, contained few areas suitable for a forced landing and the pilot was likely to have been aware of this from his many previous departures off this runway. Had the engine been producing some power, returning to the airfield might have appeared to have been a realistic option, in lieu of the lack of suitable alternative landing sites ahead, but with the inherent risk that the engine might fail completely at any time. Had the engine ceased to produce any power prior to the turn back, the pilot would have been faced with an almost impossible decision. However, having initiated the turn back towards the airfield, it is considered likely that a subsequent loss of airspeed, arising from a further reduction or total loss of power, or increased angle of bank from a perceived need to tighten the turn, or a combination of the two, caused the aircraft to stall. What is beyond doubt is that the left wing dropped and the incipient spin would have been irrecoverable, given the height available.

Engine exhaust system

The minor defects in the welds of the exhaust system appeared to have allowed crack like features to have formed as the muffler was deformed in the impact. It was not established if, or to what extent, exhaust gasses might have leaked into the heating system or ambient cabin air from these areas but, if leakage had occurred, any concentration of carbon monoxide would have been very low and potential exposure time would have been relatively short. These minor defects were considered to have been present since manufacture and no evidence was discovered that the possible escape of exhaust gasses had caused problems to the pilot on previous flights. Despite the observation in the pathologists report that the toxicological analysis revealed the probability of an elevated level of carbon monoxide in the pilot's muscle tissue, the pathologist's opinion was that level of carbon monoxide saturation would not have produced any symptoms or decrement of performance, particularly at the low altitude of the flight. Therefore, carbon monoxide poisoning was not considered to have been a contributory factor in the accident.

The loss of engine power

Strip examination of the engine, its associated components and, as far as possible, its fuel system, failed to identify any pre-accident defects that would have caused the loss of power just after takeoff. Therefore, other possibilities were considered, including the possibility of water in the fuel and the condition of the dual magneto.

Possible water contamination of the fuel

Prior to the accident flight, the aircraft had been parked on the airfield during a period of unusually heavy rain. In common with many light aircraft, the integral fuel tanks on this aircraft were in the wings, with the filler cap assemblies on the top surface of the wing. Hence, there is potential for rain water to enter the fuel tanks, but this would be dependant on the fit of the caps, and the condition of the seals. During the examination of the wreckage, both filler caps were found to be in place and secure; both associated seals were judged to have been in good condition, despite one being slightly affected by the post crash fire. As there are no other apertures in the fuel system directly exposed to the elements, the possibility that rain water entered the aircraft's fuel system prior to the accident flight was considered remote. Water may form in a partially filled fuel tank as a result of condensation, but to produce a quantity that may influence the operation of an engine, usually requires generally low temperatures over an extended period, and infrequent use of the aircraft, which was not the case with G-EKMW. These factors were considered to mitigate against water in the fuel being a causal factor in this accident.

It is the normal practice to take a sample of fuel from the tanks and inspect for water, prior to the first flight of the day. It was not established if the pilot of G-EKMW carried out such checks generally or prior to the accident flight, but no evidence was discovered that water in the fuel had been a problem with the operation of this aircraft prior to the accident.

Magneto condition

In general, the magneto had been in good condition and appeared to have been well maintained. However, the examination of the magneto's remains identified that the contact points cam retaining screw was loose enough to permit slippage to occur between the cam and the shaft upon which it was mounted. It was established that the shaft, the cam and the cam retaining screw were all undamaged. Had the cam and retaining screw been correctly installed prior to the aircraft's impact with the ground, such that the cam was gripping the shaft as intended, then it is considered highly unlikely that the cam could have loosened due to impact forces without damaging the screw. Also, the nature of the forces experienced during such an impact would have precluded the screw from 'backing-off' by some 1 to 1.5 turns, the amount which would have been necessary to allow the cam to become free. Therefore, it was concluded that the cam and screw were loose prior to impact.

Dual magneto issues

The magneto in question was of the dual type, manufactured initially by Bendix and subsequently by TCM, in which two independent high-tension magneto inductive circuits are excited by a single magnet, rotating on a common drive shaft within a common housing. A single, four-lobed, cam mounted on the outer end of the common drive shaft operates a pair of independent low tension contact assemblies, one per inductive circuit. It follows that any loss of drive to the cam, whether partial or total (or indeed any other malfunction or failure affecting the common drive shaft/magnet assembly) will cause both LEFT and RIGHT sides of the magneto to malfunction. Consequently, it would not have been possible to restore power by using the magneto (ignition) switch in the cockpit to isolate the fault, an option which may have been available had the engine been equipped with two fully independent ignition systems.

Loose/slipping cam

Any slippage of the cam on its shaft with the engine running would have disrupted the ignition timing, most likely causing backfiring in the exhaust and spit-back through the induction system, all the while the engine was turning. This would be consistent with the symptoms reported by witnesses on the ground and the overall sequence of events, including the pilot's radio report of an engine problem. It was not possible to determinethe time period over which the slippage of the cam on its shaft occurred, but this was likely to have been short. The slippage could have been progressive as the screw began to loosen, but it is highly likely in any case that the engine would have ceased to produce any effective power almost immediately. (The aircraft appeared to witnesses to, initially, take off normally, with the onset of the problem occurring at a height of between 200 and 300 ft, very shortly after which, control of the aircraft was lost.)

Re-assembly of G-EKMW's magneto cam assembly, to check the fit of the taper using the cam retaining screw tightened to the specified torque, resulted in the cam jamming tightly onto the taper. Poorly-matched taper geometry can therefore be ruled out as a possible causal or contributory factor in the cam becoming loose. It seems likely, therefore, that since re-assembly, the cam was being held in contact with the shaft by the retaining screw with sufficient frictional force to enable it to rotate without slipping, but with insufficient force to cause it to jam onto the taper.

To provide additional security against the cam retaining screw 'backing off' in service, a modified self-locking screw, incorporating a nylon patch on its threaded section to create an interference fit, was introduced via Bendix Service Bulletin (SB) 608, issued in 1979. The '*Detailed Instructions'* section of the service bulletin included, under the heading *'CAUTION'*, the following instruction: *'If self-locking screw is removed at any time, always replace with a new self-locking screw and torque to the specified value.'* This instruction was incorporated, inter alia, into the maintenance manual, and was given increased emphasis in subsequent issues of the manual. Although the cam retaining screw on G-EKMW's magneto was of the (correct) type specified by the manufacturer, ie a self locking screw, it clearly was not a new item; bruising of the screws slot indicated that it had been undone on at least one occasion. The fact that it had been re-used, contrary to the requirements of SB 608 and MM instructions, meant that the self locking effectiveness of the screw would certainly have been reduced to some extent as a consequence.

The fact that the technician did not follow his usual, albeit non-authorised, practice of applying liquid locking compound to the screw's threads prior to final assembly, meant that any degradation of the screw's self locking capability, caused by its re-use, was not compensated for on this occasion.

Notwithstanding the fact that a previously used screw was installed, without additional locking compound, this type of magneto had been in widespread service, apparently satisfactorily, prior to the introduction of the modified screw in 1979. Unless unauthorised use of locking compound on these screws was widespread practice prior to SB 608, the fact that the original version of the screw (without the self-locking patch) apparently served, for the most part at least, in a satisfactory manner up to that time suggests that some other causal and/or contributory factors were involved for the cam screw on G-EKMW to come loose. Specifically, it suggests that the screw may not have been correctly torque tightened. The viability of this scenario is given credence by the background information given in Service Bulletin 608, which stated,

> *'...If incorrectly torqued, there is a possibility that it [the screw] will "back-out", resulting in magneto malfunction. The use of a self-locking cam retaining screw reduces the possibility [sic] of "back-out" (by means of a nylon patch that creates an interface fit of the threads) in the event that incorrect torque is applied.'*

The above quotation suggests that the self-locking feature was introduced primarily to prevent an inadequately tightened screw from backing out, the implication being that a correctly tightened screw, even without the revised locking features, would not normally back out in service.

On balance, should the screw have had even a minimal self-locking capability, and provided the screw had been correctly tightened at the time of installation, it is considered unlikely that it would have backed off almost immediately, and the cam become loose on the taper, so soon after its return to service. It is concluded, therefore, that the magneto malfunction was most probably caused by the instructions laid down in the appropriate D-3000 series Service Support Manual not being followed, specifically:

- Not torque tightening the cam retaining screw to the specified value and to a lesser extent
- Re-use of an old self locking cam retaining screw

In relation purely to outcome, ie, leaving aside the manual compliance issues relating to the technician's customary use of locking compound on the cam retaining screw threads, the fact that no locking compound was used, on this occasion, was considered to have been a contributory factor in the magneto malfunction.

The poor quality and variability exhibited by a number of new cam retaining screw assemblies examined by the AAIB, obtained via the legitimate supply chain, is a cause for concern and warrants investigation by TCM, withdrawal of substandard parts from the supply chain, and action to correct the quality control deficiencies which allowed such items to reach the market.

The 500 hr magneto inspection

The EASA Part 145 organisation's omission to update to the June 2004 revision of the manual relating to the magneto, which was issued several months before it carried out the 500 hr inspection, appears to have been a genuine oversight to which the following factors contributed:

- Long-term errors on the TCM website, pertaining to the status of its technical publications. (The maintenance organisation was not alone in holding an outdated version of the D-3000 series manual because of this.)
- A combination of confusing and misleading descriptive information on the TCM website relating to the purchase of subscriptions to receive Service Bulletin updates, which could be misconstrued as a subscription for maintenance manual updates.
- The omission on the part of the maintenance organisation to scrutinise the on-line receipt received for what it believed was a subscription to receive Maintenance Manual updates, but which the receipt actually stated was the Service Bulletins subscription service.

Significant differences between the 1989 and 2004 issues of the Maintenance Manual

Both the 1989 and 2004 versions of the D3000 series magneto MM clearly state that the cam retaining screw must be replaced at overhaul, inspection, or whenever it is removed or loosened for any reason. However, it is believed that this instruction is potentially nullified by the inherent requirement to slacken and tighten this screw at least once, and possibly on more occasions, before final tightening, as part of the procedure for setting the internal timing of the magneto. The assembly section of the manual gives instructions to 'loosely install the cam using an old screw', and on completion of internal timing instructions it instructs that the [final] 21-25 in.lbs torque be applied to a new screw. It is considered that the emphasis given to replacing the screw with a new item, after timing adjustments are complete, is insufficient and could readily be missed, notwithstanding the presence in this section of a 'caution' note requiring replacement if the screw is removed or loosened at any time.

The TCM web site is used by its customers as the principal source of up-to-date information about the status of its various technical publications, including MMs, ADs, and SBs. It is therefore essential, for the maintenance of air safety, that this information is timely, presented in a clear and consistent manner, and above all that it is free of errors and omissions. In the case of the information pertaining to the TCM D3000 series magneto Service Support manual X42003, dated July 1989, and its successor X42003-1, dated June 2004, this was not the case. The result was that, not only did the maintenance organisation which inspected the magneto from G-EKMW remain unaware of the revised 2004 manual until late 2005, but several other EASA Part 145 organisations in the UK (and possibly others worldwide) were similarly misled and continued to rely on manuals long after they had been superseded.

Whilst both the July 1989 and the June 2004 versions of the Maintenance Manual specified replacement, inter alia, of the cam retaining screw during 500 hr inspections, the form of words used in the 2004 version placed significantly greater emphasis on the requirement for these items to be replaced, regardless of the type of work being undertaken.

1983 Bendix Overhaul manual

Retention of outdated manuals carries with it significant safety implications. Arguably, the practice can be justified provided that such documents are held solely for exceptional reference purposes, and their location and use subject to appropriate oversight and control. In this case, however, both the 1983 and 1989 manuals were held in the electrical workshop, albeit with a coloured sticker affixed to the former to denote its uncontrolled status. The 1983 manual was not only immediately accessible for reference by workshop staff but its well-used condition, compared with the relatively cleaner condition of the 1989 version, suggested that it had seen significantly more workshop use than the 1989 version. At the time of the subject magneto's inspection, the 1989 manual should have seen some 15 years of use, whilst the 1983 manual should have been used for only some six years. This is considered to be inconsistent with the relatively 'well used' condition of the 1983 manual when compared to that of the 1989 edition.

Other evidence, of a circumstantial nature, also suggested that the 1983 manual may have enjoyed pre-eminence over the 1989 version. Specifically, the working practices used by the technician during his inspection of the magneto from G-EKMW are consistent with those laid down in the 1983 overhaul manual, issued when there was no requirement for 'inspections' per se, but were not consistent with the practices laid down in the 1989 manual covering inspections as well as overhauls.

In summary, it appeared that the work practices in use at the time the magneto was inspected were essentially those laid down in the 1983 manual.

Quality control issues

Training and work practices

The technician who carried out the inspection of G-EKMW's dual magneto reportedly received type-specific training on the magneto in question, but some considerable time after the modified cam retaining screw had been introduced by Service Bulletin 608 in 1979. The associated requirement, always to replace the self-locking cam retaining screw, whenever it was loosened or removed, should have been emphasised during that training. Because of the passage of time, and the loss of training records from that period, it was not possible to establish whether this actually occurred.

The technician was honest and straightforward when providing information during the investigation about his working practice, vis a vis replacement/re-use of the cam retaining screw, and the other items which the MM specified should be replaced. He simply followed his usual practice in the genuine but mistaken belief that replacement of the cam retaining screw was required only during magneto overhauls, ie, that it was not mandatory during magneto inspections. During the investigation, after re-reading the (out of date) 1989 copy of the maintenance manual provided by his employer, he realised his non-compliance for the first time.

In relation to the company's retention and apparent continued use of the 1983 manual it is possibly significant that, when the technician first worked on the type of magneto in question in the early 1980s, there was no requirement to carry out inspections per se. It appears that his work practices were established at that time, whilst carrying out overhauls, and that he appeared not to have studied the 1989 manual, or adapted his methods to meet the requirements for inspections. The fact that he was allowed to follow unauthorised and inappropriate procedures for so long raises questions regarding oversight of his work by his employer and, to some extent, of the system used for regulatory authority oversight.

Quality audits

The quality assurance policy of the maintenance organisation which inspected the magneto and, specifically, its audit procedures, were set out in the exposition document which formed, in part, the basis for its approval by the CAA as an EASA Part 145 Maintenance Organisation. The company's internal audit policy appears to have been comprehensive in terms of both its scope and frequency, and similar comments apply to its stated policy for external audit cover. However, in terms of their practical applications, none of these audits subjected the physical work being carried out to effective scrutiny.

Both the internal and external audits comprised a series of sample checks, the primary focus of which appeared to be directed towards the paperwork generated as a by-product of the engineering activity as opposed to critical scrutiny of the core engineering activity, ie, the various certificates generated, implementation of ADs, SBs etc and general housekeeping. Scrutiny of the 'paper trail' certainly had the benefit of being amenable to a pro-forma 'tick the box' approach in respect of both audit tasking and reporting, and this aspect of the audit process remains valid and necessary. However, there appears to have been little critical scrutiny of the core engineeirng activity per se. Similar observations are considered to apply to the CAA's periodic audits, carried out as part of its oversight function.

The lack of focus on the maintenance organisation's physical engineering activity is reflected in the CAA approved audit reports generated. Its internal audit reports comprised single sheet A4 documents, each of which covered as many as four areas of activity (departments). The information provided in these reports as to what was actually scrutinised was extremely limited, no information was given as to the methodology used and, from a third party's viewpoint, they provided very little insight as to the quality of engineering. Similar comments can be made about external auditor's reports, although these were somewhat more detailed, particularly in relation to the findings made, and they did provide some insights into the quality of the organisation's engineering activity.

With specific regard to the organisation's core engineering activity, it is of concern that the technician who carried out the 500 hr inspection on the magneto from G-EKMW had been carrying out similar inspections for at least 15 years without being aware that the relevant manual mandates replacement of the cam retaining screw…..*'whenever it is loosened or removed'*. It also calls into question the extent and/or effectiveness of any independent oversight which may have been applied to his activities, either directly by his line management or the various audit processes.

The CAA state that it is for the approved organisation to ensure that their authorised personnel work within the defined terms of reference, using the correct data etc. Also, the day to day responsibility for ensuring the competency of its staff rests with the EASA Part 145 approved company as it would be impracticable, and not required by the Regulations, for any regulatory authority to establish individual staff competencies. Their role is to satisfy themselves that the organisation has procedures in place to achieve this and, by sampling, that it has evidence that the organisation is following its internal procedures. However, this event highlights the intrinsic shortcomings of the quality assurance audit methodologies used, which focus heavily upon the processes/paperwork aspects of the work.

Process worksheets

The apparent lack of the correct torque having been applied to tighten the cam screw during re-assembly does not appear to have been the result of any inherent lack of skill or experience on the part of the technician concerned, or of the equipment he normally used. In the absence of any alternative, a likely explanation is that his sequence of work was probably broken at a critical point, possibly by some distraction or disturbance, and the final tightening of the screw was compromised or missed altogether as a consequence. The technician concerned, however, has stated the following:

> *'...I would never leave an operation incomplete, except for an evacuation of the hanger, or a person needed assistance in an emergency, and then on return I would start the operation from scratch. If asked to do another job, the task in hand would be completed to a stage where it could be left or the task would be completed before starting another job. I have often missed a tea break, part of a lunch break or stayed late to complete a job or task in hand.'*

The fact that the maintenance organisation did not make use of pre-planned process sheets, or worksheets, for magneto overhauls/inspections is considered to have been a factor in the omission to fully tighten the screw.

Had a properly set out work or process sheet been available for these activities at the time of G-EKMW's inspection, based upon and used in conjunction with the manufacturer's MM, then not only would it have:

- provided a framework for the series of operations to be carried out
- made provision for the technician to confirm and document completion of key stages
- listed the materials required, thus facilitating both provision of parts to the workshop and spares-provisioning back-office functions

but the very act of drawing up such a process sheet would, in itself, have required someone other than the technician to critically review the procedures specified in the manual[9]. This process of review would need to be undertaken afresh on each occasion the manual is updated, to ensure that any relevant changes in the manual are reflected in a revised process sheet. Furthermore, drawing up a suitable process or work sheet requires objective scrutiny of the manual, and any inconsistencies, apparent errors, or omissions in the manual itself are therefore more likely to be identified and followed up with the manufacturer at an early stage.

In summary, had the 500 hr inspection of the magneto followed a properly drawn up process sheet, a new cam screw (together with the other items listed in the manual for replacement) would have been provisioned automatically, and the key stage of final torque tightening of this screw would have been much less vulnerable to omission or error.

Footnote

[9] Once the 2004 issue of the relevant maintenance manual had been recieved by the organisation, it's Chief Engineer drew up such process sheets. He points out '*that had the up-to-date manual been communicated to them from TCM correctly*', such process sheets(s) would have been drawn up ealier.

Safety Recommendations

In consideration of the above, the following safety recommendations are made:

Safety Recommendation 2006-028

It is recommended that International Aerospace Engineering review their internal processes to ensure that they comply with the standards required under their EASA Part 145 approval focussing, in particular, on areas relating to the provision of maintenance information and staff training.

In response to this recommendation IAE has stated that:

'it believes that it does comply with the standards required under its EASA [Part] 145 approval. It continues to monitor such compliance as a necessary and ongoing element of its business.'

Safety Recommendation 2006-029

It is recommended that the Civil Aviation Authority review their quality audit programmes, which underpin its EASA Part 145 approvals of maintenance organisations, to ensure that such audits include adequate sampling and objective scrutiny of the physical engineering activities.

In response to this recommendation the CAA have stated the following:

'From a regulatory standpoint, CAA oversight and audit methodology is established to satisfy the EASA Part 145 Regulations. A review of the audit records completed over the last three years for this organisation shows that as well as regulatory compliance verification checks, audit samples of three examples from the product line were carried out on each visit'

It is not the regulators role to implement a quality audit programme to supplement that of the approved organisation'

The CAA have also stated that they recognise the utilisation of pre-planned work/process sheets, where appropriate, represents best practice, and the adoption of this practice is encouraged. However, they cannot require EASA Part 145 organisations to implement this practice if it is not specified within the Regulation. The following safety recommendation is therefore made:

Safety Recommendation 2006-030

It is recommended that the European Aviation Safety Agency (EASA) should amend the EASA Part 145 Regulation to require that EASA Part 145 approved maintenance and component overhaul organisations use pre-planned work/process sheets when carrying out work on safety critical components.

Whilst the extent to which the outdated manual actually contributed to the technician not replacing the screw could not be determined, there is no doubt that, if the 2004 version of the manual had been issued by the company to the electrical workshop prior to the 500 hr inspection, then that action alone ought to have prompted critical study of its content: ideally at a supervisory level, but certainly by the technicians involved in carrying out work covered by the manual. Had this taken place, the long-standing contraventions associated with re-use of cam screws should have been identified and rectified prior to G-EKMW's 500 hr inspection. The non-current D3000 series magneto Service Support Manual was therefore considered to be a causal contributory factor in the magneto failure.

The presence of errors and omissions on the TCM website was considered a major factor in the maintenance organisation's ability to update its D3000 series magneto manual, leading to the issue of an Authorised Release Certificate covering the 500 hr inspection on the basis of an out-of-date manual. The following safety recommendation is therefore made:

Safety Recommendation 2006-031

It is recommended that the Federal Aviation Administration require Teledyne Continental Motors to conduct a critical review of their processes for the support of maintenance organisations which maintain/overhaul their products, to ensure that concise and current technical data, and spare parts of acceptable quality, are always readily available.

In response to this safety recommendation, Teleydyne Continental Motors has stated the following:

- TCM will critically review its technical publication management system, and will maintain current publication status on-line
- TCM has reviewed and re-written the process to improve the release of approved documentation
- TCM uses Service Bulletins to expedite dissemination of updated technical information
- TCM encourages customer feedback regarding technical information in its technical publications
- TCM customers can receive 'kits' that include all the necessary replacement parts for magneto inspections or overhauls
- TCM takes steps to verify supply chain quality, is subject to FAA audits, annual reviews per AS9001 standard, and only uses approved suppliers/distributors.