Loss of oil on climb on both engines, Boeing 737-400, G-OBMM

Micro-summary: **This Boeing 737-400 lost nearly all the oil in both engines on climb.**

Event Date: **1995-02-25 at 1205 UTC**

Investigative Body: **Aircraft Accident Investigation Board (AAIB), United Kingdom**

Investigative Body's Web Site: **http://www.aaib.dft.gov/uk/**

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1. Accident reports can be and sometimes are revised. Be sure to consult the investigative agency for the latest version before basing anything significant on content (e.g., thesis, research, etc).

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Boeing 737-400, G-OBMM: Main document

Aircraft Accident Report No: 3/96 (EW/C95/2/3)

Report on the incident to a Boeing 737-400, G-OBMM near Daventry on 25 February 1995

Contents

Fss.aero modifications: (1) Fixed formatting problems (every fifth word or so was combined with the following word; (2) eliminated PDF "return to contents" tags, since we now have the Bookmarks function in PDF files.

- Air Accidents Investigation Branch
  Aircraft Incident Report No: 3/96 (EW/C95/2/3)

Registered Owner & Operator	British Midlands Airways	
Aircraft Type	Boeing 737-400	
Nationality	British	
Registration	G-OBMM	
Place of Incident	Overhead Daventry	
	Latitude	52°20' North
	Longitude	001°10' West
Date and Time	23 February 1995 at 1205 hrs	
	All times in this report are UTC	

Synopsis

The incident was notified to the Air Accidents Investigation Branch(AAIB) at 1245 hrs on 23 February 1995 and an investigation began the same day. The investigation was conducted by Mr D FKing (Investigator in Charge), Mr R W Shimmons (Operations), Mr C G Pollard (Engineering) and Ms A Evans (Flight Recorders).

The incident occurred when the aircraft was climbing to cruise altitude after a departure from East Midlands Airport en-route for Lanzarote Airport in the Canary Islands. Following an indicated loss of oil quantity and subsequently oil pressure on both engines, the crew diverted to Luton Airport; both engines were shut down during the landing roll. The aircraft had been subject to Borescope Inspections on both engines during the night prior to the incident flight. The High Pressure (HP) rotor drive covers, one on each engine, had not been refitted, resulting in the loss of almost all of the oil from both engines during flight. There were no injuries to any crew or passengers. The aircraft was undamaged; both engines were removed and examined as a precautionary measure.

The investigation identified the following causal factors:

1. The aircraft was presented for service following Borescope Inspections of both engines which had been signed off as complete in the Aircraft Technical Log although the HP rotor drive covers had not been refitted.
2. During the Borescope Inspections, compliance with the requirements of the Aircraft Maintenance Manual was not achieved in a number of areas, most importantly the HP rotor drive covers were not refitted and ground idle engine runs were not conducted after the inspections.
3. The Operator's Quality Assurance Department had not identified the non-procedural conduct of Borescope Inspections prevalent amongst Company engineers over a significant period of time.

(4) The Civil Aviation Authority, during their reviews of the Company Procedures for JAR-145 approval, had detected limitations in some aspects of the Operator's Quality Assurance system, including procedural monitoring, but had not withheld that approval, being satisfied that those limitations were being addressed.

Fifteen safety recommendations are made.

1. Factual Information

1. History of the incident
2. Aircraft dispatch and flight

The flight crew reported for duty at 1055 hrs at East Midlands Airport to prepare for a charter flight to Lanzarote in the Canary Islands; departure was scheduled for 1155 hrs. On arrival at the aircraft, at approximately 1100 hrs, the crew commenced their normal pre-flight checks, during which they noted that the hydraulic power circuit breakers had been left open. The first officer went down onto the apron and asked the despatching engineer why they were not set. The engineer had reviewed the Technical Log before starting his refuelling and pre-departure checks and had seen that Borescope Inspections of both engines had been carried out during the previous night. These had been signed off as being completed satisfactorily. The engineer informed the first officer that, so far as he could see, there was no reason for the circuit breakers to be left open, so the first officer returned to the flight deck and closed them. With no outstanding items in the Technical Log, and after completing the normal prestart checks, the crew started both engines. All engine parameters were checked as normal and G-OBMM left the stand at 1150 hrs. All the flight deck indications were normal during the taxi out to the runway and the aircraft was lined up on Runway 27 for take-off. The first officer was the designated handling pilot for the flight to Lanzarote and, using full power, he commenced the take-off roll, at 1157 hrs.

During the climb, the commander was carrying out the normal non-handling pilot duties; these included monitoring of the engine instruments which initially indicated no problems. However, as the aircraft was climbing through approximately Flight Level 140, the commander noted that both engine oil quantity gauges were indicating about 15%; the indications were also fluctuating and continuing to decrease. As the crew were discussing this problem, both engine oil pressures began decreasing. Coincident with this, GOBMM was transferred to London control on 131.12 MHz and, at 1204 hrs, the commander contacted London. The London Controller stated that he had positively identified the aircraft and confirmed the clearance to Flight Level 210. Shortly after this, at 1205 hrs, with the oil quantities continuing to decrease and the oil pressures now below 13 psi, the commander informed London that he had engine problems and wished to return to East Midlands Airport. The controller immediately cleared GOBMM to level at Flight Level 180 and to turn left onto a heading of 010°M. By now, the oil quantities were indicating zero and the oil pressures were still decreasing. The crew informed Air Traffic Control (ATC) of the deteriorating situation and a "Mayday" was declared. As the aircraft was turning left onto the designated heading, the ATC controller informed the crew that Luton Airport was the closest diversion and asked them where they wished to go. The commander then declared that he was diverting to Luton and the controller cleared G-OBMM to roll out on a heading of 120°M, and to commence a descent.

The commander assumed the role of handling pilot, and the first officer was allocated the tasks of re-programming the Flight Management Computer and operating the radio. Radar and Flight Data Recorder (FDR) information indicate that G-OBMM levelled at Flight Level 180 at 1205.28 hrs and remained level for only 17 seconds before commencing a descent. During the descent and recovery to Luton, the ATC controller assisted the crew by minimising transmissions but ensuring that he passed them all essential information such as continuous descent clearances and weather information for Luton. Within the aircraft, the flight crew were working together to ensure that the aircraft was configured for the approach to Luton. The commander was using idle power and had made the decision that they would be making a Flap 15 landing. He decided on this flap setting because he was very conscious of the need to minimise power requirements due to the engine oil situation; both oil low pressure lights had illuminated 40 seconds after leaving Flight Level 180.

The commander had called the senior cabin attendant to the flight deck and fully briefed her on the situation, including the fact that they were making an immediate diversion. In turn, the senior cabin attendant briefed the cabin crew and the cabin was quickly prepared for landing; the commander had already briefed the passengers that he was diverting to Luton. The approach was direct and uneventful, and the crew was given priority and all requested assistance by London and Luton ATC agencies. G-OBMM touched down on Runway 26 at Luton at 1214 hrs; touchdown speed was at the crew's assessed target of 170 kt and at the normal touchdown point. Immediately after landing, the commander selected idle reverse power and used maximum automatic braking; with the landing roll under control and after transferring electrical power to the Auxiliary Power Unit, the first officer, on instruction from the commander, closed down both engines at approximately 120 kt. The aircraft came to a stop on the runway and was quickly attended by the Luton Airport Rescue and Fire Fighting Service (RFFS). The flight crew maintained radio contact with ATC but were unable to establish radio communications with the RFFS on the 121.6 MHz frequency; however, verbal contact with them was quickly achieved through the open flight deck window and the commander took the decision not to carry out an emergency evacuation.

The RFFS remained on the scene and the passengers began disembarking through the front left door using the aircraft airstairs. Once the commander had disembarked, he noted that the cowls of both engines, and the underside of both wings and flaps immediately behind the engines were covered in engine oil.

1.1. History of the maintenance during the previous night

The aircraft was scheduled to undergo Borescope Inspections of the turbine sections of both engines, which was required every 750 operating hours. This was to be performed, by the Airline's Line Maintenance organisation, during the night of Wednesday/Thursday 22/23 February.

The Line Engineer in charge of this night shift had also been on duty on the previous night. When he had made the handover to the day shift, on Wednesday 22nd, he had left a loose note for the day shift leader expressing his concern about the manpower expected to be available over the Wednesday/Thursday night relative to the predicted workload, which he knew to include the two 750 hour Borescope Inspections. However, when he came back into work, at about 1930 hrs on the Wednesday evening, he found that the manpower of the shift had not been supplemented. Instead of the nominal shift complement of six, there were only four on duty that night, two of whom, including the shift leader, were doing extra nights to cover shortfalls.

Although the Line Engineer was in charge of the shift, he knew that he had to do the Borescope Inspections himself as he was the only Line Maintenance engineer within the Company, at East Midlands Airport, with the necessary authorisation. Since this inspection was to be done in hangar T2, some distance from where the bulk of the Line Maintenance work was done, but close to the Base Maintenance hangar, he elected to do this inspection first. Therefore, after organising the Line night shifts work, he picked up the inspection paperwork from the Line Office and went to the aircraft. The package of paperwork contained everything that he, as a Line Maintenance engineer, would have expected.

Hanger T2, used for this inspection, was partially occupied by the engine and propeller workshops but one end was largely vacant. This hangar space was, however, insufficient to accommodate the Boeing 737-400, G-OBMM, completely. When the Line Engineer arrived at the aircraft, at about 2030 hrs, it had been pulled into the hangar so that the doors could be partially shut to almost touch the fuselage sides just ahead of the tailplane. Although the airstairs were extended, the slats and flaps were retracted and there was neither electrical nor hydraulic power available. As he needed no aircraft power and anticipated no other tasks being undertaken on the aircraft until the inspections had been completed, he elected not to disable those aircraft systems, which the standard procedures required, before starting to prepare the engines for inspection.

The borescope equipment was kept in the tool store in the Base Maintenance hangar, about 200 yards across an apron from T2. Since the Base Maintenance night shift did not start until 2100 hrs, the Line Engineer decided to prepare one engine (the left, or No 1) for inspection before going across to Base Maintenance for the inspection equipment. He thought that it was about 2115 hrs when he went across to the Base Maintenance hangar. He asked the night shift Base Maintenance Controller for the borescope equipment and for someone to assist him, as the HP spool of the engine needed to be turned by a second person whilst he did the inspection.

The Base Maintenance Controller (night) had recently been on leave for a week and had returned to work on the night before (Tuesday). The length of his leave had been limited by the fact that his night shift Foreman was scheduled to go into hospital. His normal supervisory and inspection staff on the night shift, in addition to himself and the Foreman should have consisted of four airframe and engine (A & C) Licensed Inspectors, supplemented by three Licensed Technicians. On his return from leave, however, in addition to the foreman, three of his Inspectors were also absent for various reasons, leaving himself and one Inspector, supported by the Licensed Technicians, to supervise the work of the shift.

On coming into work on the Wednesday evening, the Controller had noticed the tail of G-OBMM sticking out of hangar T2 and reflected that it would impede access to an ATP propeller which was being built up and which he knew he would need later during the night. On arriving in his office at about 2045 hrs he noted, in his shift handover brief, that G-OBMM was due to have 750 hour Borescope Inspections done by Line Maintenance that night. He had two ATP aircraft in Base Maintenance, one of which was undergoing a short service and was required for operations at mid-day the following day and the other undergoing more protracted maintenance, some of which was held up due to a spares shortage.

Shortly after arriving in his office, he got a request from Ramp Services to remove a Boeing 737-500 from the Line as it was in the way, but he was not able to do this immediately as he did not have suitable manpower available. Soon afterwards, the Line Maintenance engineer who had been preparing GOBMM for its inspection came in to ask for the borescope equipment and assistance.

British Midland Company rules required staff to perform a minimum of two 750 hour Borescope Inspections in a twelve month period in order to keep their Company Authorisation. The Controller had recognised that, because of the scarcity of opportunities, he was in danger of allowing this authorisation to lapse which would, as he saw it, adversely affect his usefulness to the Company. He was also aware that Line Maintenance had only four, of the nominal complement of six, on shift that night and that they had eight aircraft to deal with. With both these facts in mind, he assessed that his remaining Inspector and the Licensed Technicians should, if properly organised, be sufficient to supervise the required overnight Base Maintenance workload. So, he offered to take over the Borescope Inspections personally if the Line Maintenance engineer could take over the moving of the 737-500 from the Ramp to Base. This offer was accepted and the transfer of the task was noted, at 2200 hrs, in the Airline's Line Maintenance Controller's log.

The Line Engineer gave a verbal brief to the Base Controller of where he had got to in the preparation of the engines for the inspection. This brief included the facts that the aircraft was 'dead' (ie without electrical or hydraulic power and had no-one else working on it); that one engine (the No 1) had been fully prepared for inspection and the inspection paperwork pack was with the aircraft in T2. As the Line Engineer had not gone to the Base Hangar with any intention other than that of continuing the task he had started, there was no written statement or annotation of a work stage sheet of where he had got to in the inspection process. In fact, on the Line Maintenance paperwork provided, there was no suitable place to note it and, procedurally, additional paperwork should have been raised. The Base Maintenance Controller was, however, content with the verbal brief that he had received.

Having taken on the inspection, the Controller then selected a fitter to assist him in the task. This fitter was not licensed but had been in the Company for three years and the Controller believed him to be reasonably competent and conscientious; he had also had some previous experience of assisting in this type of inspection. The Controller had to use his own key to gain access to the borescope equipment, because the storeman was also absent that night. With the fitter, he drew, prepared and checked the equipment and gathered together the other tools needed for the task. The checking of the borescope equipment was a task which would normally have been done by the storeman.

From this point there is a divergence in the recollection of the passage of time between the three individuals concerned. The Line Engineer thought that he had handed over the job, moved the Boeing 737-500 aircraft and returned to the Line engineering area by about 2200 hrs. The fitter believed that he went immediately, at about 2140 hrs on the instructions of the Controller, to the aircraft in T2 and started to open the cowlings of the No 2 engine. He then waited until the Controller joined him in T2 before continuing the task. The Controller, however, believed that they both went to T2 together sometime around midnight, after he had spent a considerable time organising the Base Maintenance activity for the night with a view to minimising the number of interruptions to the inspection.

The Controller took with him his personal copy of the borescope training manual which he had annotated with various dimensions to assist him in judging sizes through the probe. When he got to T2 he looked through the workpack for the job. Although it was not familiar to him, being Line Maintenance paperwork, and rather less than he was used to because there were no Boeing task cards attached, he considered it unnecessary to draw any additional reference material (§1.17.2). He then checked the state of preparation of the engine, by referring to his personal notes on the Borescope Inspection procedure, and found it satisfactory. At the same time he pointed out, to the fitter, the borescope plugs which had been loosened on the No 1 engine. He also mentioned the HP rotor drive cover, which conceals the means of turning the core engine, which had been removed from the Accessory Gearbox (AGB) and was hanging on its lanyard. He then instructed the fitter to prepare the No 2 engine in the same manner. The fitter was happy that he could do this without reference to any manuals and he had confidence that the Controller knew what he wanted to be done and would provide any necessary guidance.

Whilst the fitter was preparing the No 2 engine, the Controller started the inspection of the No 1 engine, looking at those parts which did not need the engine HP spool to be turned. When he had finished this part of the inspection, he called the fitter across to turn the HP spool so that he could inspect the required turbine blades. His recollection is that the fitter had not quite finished preparing the No 2 engine by that time, although the fitter's recollection is that he probably had. The Controller thought that they had just about finished the inspection of the No 1 engine turbines by the time the cleaners and Line Maintenance crews arrived to prepare the aircraft for the following day's flying. Amongst the Line Maintenance crew was the engineer who had originally been going to do the inspection.

At this time the Line Maintenance crew experienced some difficulty in getting the ground electrical power they required onto the aircraft. The Ground Power Unit (GPU) which the cleaners had brought with them would not plug into the type of electrical sockets in T2. The Line engineer, therefore tried to start the aircraft's Auxiliary Power Unit (APU) to provide the power. This proved reluctant to start and he eventually resorted to using another, diesel powered, GPU to boost the aircraft's battery power and start the APU. He then shut down the GPU to avoid filling the hangar with diesel fumes.

After the APU was started, the Controller and Line Engineer had a discussion about whether they should trip out the engine ignition and hydraulics circuit breakers. The Controller believed that he said that he felt it was unnecessary from his point of view, as he had no intention of working on the aircraft with electrical and hydraulic power systems active. The Line engineer pulled the circuit breakers anyway and felt confident that the Controller was aware of this. Once the APU had been started, both the Controller and the fitter returned to the Base Maintenance hangar. The Controller recollected that this was at his meal time, about 0100 hrs, but the fitter thought that it had been for a tea-break at 2300 hrs. The Line engineer thought that the time was about 0145 hrs, which would have been when the Controller recalled that he and the fitter had returned from his meal. The Line engineer had no clear recollection of the movements of the Controller and fitter whilst he was in the hangar assisting the cleaners with their power problem and doing the daily inspection. However, he believed that at the time he arrived in the hangar, the borescope equipment was beside the No 2 engine and the No 1 engine cowlings were still open.

Whilst the Controller was over in Base Maintenance for his meal he was confronted with an accumulation of ATP and other problems which he had to resolve before returning to T2 to continue the Borescope Inspection. When the Controller and fitter did return, the Line Maintenance crew and cleaners were still there with the APU still running. The fitter's recollection is that they had completed the inspections by this time and that he put in earplugs because of the APU noise before starting to restore the No 2 engine to its normal configuration, having just finished restoring the No.1 engine before the meal break.

However, the Controller's recollection was that at this time he began to transfer the results of the inspection of the No.1 engine from his rough notes onto the proper inspection sheets. He believes that only after the APU had been shut down and power removed from the aircraft did he continue with the remaining inspections which had to be done on the No 1 engine fan case and that this occupied the time until the fitter had finished preparing the No 2 engine. He believes that he then started the inspection of the No 2 engine and instructed the fitter to start 'plugging up' the No1 engine. Whilst inspecting the No 2 engine, the Controller asked the fitter to assist by turning the No

2 engine HP spool, interrupting the restoration of the No 1 engine. The Controller then completed the No 2 engine inspection and transferred the results of his inspection to the inspection sheets. He then went into the adjacent propeller shop to see how the build of the ATP propeller was progressing. Whilst there he was drawn into a discussion on the relative difficulty of building up propellers on a workshop stand rather than on an installed engine.

Having done this, he then returned to Base Maintenance to check the turbine damage which he had found during the inspections against the limits laid down in the Aircraft Maintenance Manual (AMM). In passing, he instructed the fitter to carry on putting both engines back to their normal state. When he returned to Base Maintenance he again became embroiled in problems encountered on the work being done on the ATP. Whilst in the Base workshop he saw the fitter consulting the AMM about the torques for the inspection plugs which inclined him to be satisfied with the fitter's approach to the task.

The Controller recalls that, when he returned to T2 to inspect the re-instatement of the engines to their normal condition, he encountered the Line engineer who was just finishing with the aircraft and asked him to confirm which borescope plugs he had removed from the No 1 engine. The Line engineer, however, believes that it was shortly before the cleaners had finished their work when he was about to shut down the APU and return to the Line, that he rehearsed with the Controller which plugs he had removed from the No 1 engine. They found that one, at about the 3 o'clock position on the HP turbine case, was still loose and not wire locked. The Controller pointed out this omission to the fitter who was then re-instating the No 2 engine and asked him to rectify it.

The Controller then inspected the No 1 engine and, after telling the fitter, who was working on the No 2 engine, that he would be back soon, went again to Base Maintenance to arrange for the transport of the ATP propeller from T2 to Base Maintenance workshops. Having arranged for the moving of the propeller, the Controller then became involved in further ATP problems in Base Maintenance, together with problems of Health and Safety and Union matters. When he returned to T2, he rechecked the inspection plug which had been missed previously and then inspected the No 2 engine which the fitter had finished by that time.

When the Controller was satisfied with both engines, he and the fitter closed up the reverser ducts and fan cowlings, packed up all the equipment and returned to Base Engineering with all the paperwork. The Controller then called Line Engineering and asked for the Technical Log to be brought over to Base Maintenance so that he could enter up the work. He also requested someone to move the aircraft out of the hangar T2 so that he had access to the ATP propeller.

Shortly afterwards, the Line engineer arrived with the Technical Log, thanked the Controller for taking the job on, and assured him that the aircraft would be moving straight away. The Controller then turned his attention to the ATP propeller as he considered that the Borescope Inspection had been completed. Since the task had been scheduled as a Line Maintenance task, none of the normal double checks of the paperwork, built into the Base Maintenance procedures, was activated.

The Line engineer removed the aircraft from the hangar but left it outside T2 at that time and then returned to the line. Sometime later, when he heard that the Technical Log had been filled in, he sent someone over to Base Engineering to collect the Log.

1.1.3. The dispatch of the aircraft as seen by Line Engineering

When the Line Engineering day shift came in at 0730 hrs, the shift leader noted from the Technical Log that Borescope Inspections had been carried out on both engines of G-OBMM during the night and that it had to be collected from where it was parked outside T2. About an hour before the aircraft's scheduled departure, he went across with a tug and driver and found the aircraft, closed up outside the hangar. This was as he would have expected it to have been after an idle ground run test of the engines which, although he personally did not have a borescope inspection authorisation, he thought should probably have been done after the Borescope Inspections. He tried, unsuccessfully, to start the APU and they then towed the aircraft up onto the line. After further unsuccessful attempts he eventually started the APU using a GPU and, after allowing it to run for a while, shut it down again and left the aircraft. As he did so, one of the ramp staff gave him the landing gear ground locks for stowage on the flight deck and when he returned to the Line Office he signed for their removal in the Technical Log.

After he had returned to the Line Office, he was informed of the aircraft fuel load for the sector and sent one of the Line Engineering staff to supervise the refuelling and give the aircraft the pre-departure check for its first flight of the day. This second engineer had also read the Technical Log and took it with him to the aircraft. Having instructed the refuellers, he began his pre-departure check. Almost immediately he was approached by the First Officer who asked him whether there was any reason why the hydraulic power circuit breakers were not set. The engineer, from having read the Technical Log, knew that the borescope inspections had been done and signed off as complete, replied that it was probably an oversight and that the Technical Log did not indicate any reason why they should not be reset.

Just before being approached by the first officer, the engineer had found the hatch of the Electrical and Electronic compartment (E and E bay), located just behind the nose landing gear, unexpectedly open. After the first officer had returned to the flight deck, the engineer made a thorough examination inside the bay before closing it up. He then continued with the pre-departure check and oversight of the refuelling whilst the baggage was being loaded onto the aircraft. When the check and refuelling were complete ,the shift leader was given a debrief on the check and signed up the Technical Log. The engineer then took the log to the crew on the flight deck.

When he arrived on the flight deck, the captain expressed some dissatisfaction with the fact that the hydraulic circuit breakers had not been reset after the completion of the borescope inspections. During this discussion it was also noticed that the engine ignition breakers had not been reset either. Following this, the ignition circuit breakers were reset and the captain accepted the aircraft; the engineer then returned to the line office whilst the aircraft was taxying out and departing.

On his return to the line office, he remarked on the ignition circuit breakers not being reset to the shift leader who wondered how an engine run had been done with the ignition disabled. The Line Engineers were discussing this issue when they were informed by telephone that the aircraft had landed at Luton with oil pressure indicating zero on both engines.

1.2 Injuries to persons	There were no injuries to any persons.

1.3. Damage to aircraft	Nil
1.4 . Other damage	There was no other damage.

1.5. Personnel information

1.5.1

Commander	Male, aged 42 years
Licence	Airline Transport Pilot's Licence
Instrument Rating	Renewed on 7 December 1994
Base check	19 November 1994
Line check	12 July 1994
Medical	Class 1 valid until 30 June 1995
Flying experience	Total all types - 11,200 hours Total on type - 2,700 hours Last 90 days - 125 hours Last 28 days - 57 hours
Duty time	17 hours rest prior to commencing duty at 1055 hrs on 23 February 1995

1.5.2

First Officer	Male, aged 25 years
Licence	Commercial Pilot's Licence
Instrument Rating	Renewed on 21 May 1994
Base check	20 November 1994
Line check	3 June 1994
Medical	Class 1 valid until 30 June 1995
Flying experience	Total all types - 2,218 hours Total on type - 1,625 hours

	Last 90 days - 143 hours
	Last 28 days - 48 hours
Duty time	17 hours rest prior to commencing duty at 1055 hrs on 23 February 1995

1.5.3

Base Maintenance Controller	Male, aged 45 years
Licences	CAA Airframe (A) Licence (Without type) 1977 CAA Engines (C) Licence (Without type) 1983
Relevant Authorisations	Boeing 737, CFM56-3, Borescope Inspection
Engineering experience	RAF airframe fitter 1966/76 Air Training Group (TOPS course) 1977 With previous employers -as fitter to 1980 -as inspector to 1983 With this Airline -as fitter to 1984 -as inspector to 1985 -as foreman to 1987 Base Maintenance Controller (nights) from 1987
Recent duty pattern	Permanent night shift worker, had been on leave for 1 week until Monday 20 February. Returned to work on Tuesday 21 February

1.5.4

Base Maintenance Fitter	Male, aged 23 years
Licence	none
Relevant Authorisations	none
Engineering experience	With previous employers - apprentice to 1991 With this Airline - as fitter from 1992
Recent duty patter	Permanent night shift worker, previous weekend had been 'short' (2 night off) and his week had started on Monday 20th February

1.5.5

Line Maintenance Engineer(1) Deputy Chief Supervisor)(2)	Male, aged 33 years
Licences	CAA Airframe (A) Licence (Without type) 1987 CAA Engines © Licence (Without type) 1988
Relevant Authorisations	Boeing 737, CFM56-3, Borescope Inspection (only Line Engineer so authorised at EMA)
Engineering experience	RN -Aircraft engineering mechanic 1980/85 With previous employers - as fitter to 1988 -as Line Maintenance engineer from 1988 With this Airline from 1989
Recent duty pattern	On 3rd consecutive 12 hour night shift following two day shifts. (see §1.17.5 for shift pattern description)

1.6. Aircraft Information

1.6.1 Leading particulars

Type	Boeing 737-400
Constructor's number	25177
Year of manufacture	1991
Engines	2 CFM56-3C Turbofan Engines

1.6.2. Aircraft weight and centre of gravity

The maximum structural take-off weight of G-OBMM, published in the BMA Operations Manual was 67,000 kg; however, the take-off weight from Runway 27 at East Midlands Airport on 23 February 1995 was limited by the maximum landing weight at destination of 56,245 kg. This produced a take-off limit of 65,464 kg. Take-off weight at East Midlands Airport was 65,050 kg.

The assessed landing weight at Luton was 63,800 kg. This was substantially greater than the maximum structural landing weight of 56,245 kg but the crew had no choice with the emergency they experienced, having no fuel dump facility. The Company Operations Manual accepts that there may be occasions when an immediate overweight landing will be required and includes advice to make as gentle a landing as possible. The Company manuals were consulted to extract the landing performance based on the weight of G-OBMM and the weather conditions. Additionally, Boeing Commercial Airplane Group were asked to provide information on landing performance based on the same parameters. Both sets of figures are detailed at §1.6.3

The aircraft was correctly loaded within its centre of gravity limits.

1.6.3. Scheduled landing performance

The Landing Distance Available (LDA) from the UK AIP for Runway 26 at Luton is 2,075 metres.

Based on a Flap 15 landing at 63,800 kg and a surface wind of 270°/23 kt, figures extracted from the Aircraft Flight Manual (AFM) give a landing distance of 1,295 metres.
Boeing Commercial Airplane Group provided landing information based on a headwind component of 18 kt and a landing weight of 63,800 kg using Flap 15. The figure from the AFM reflected an unfactored field length of 1,365 metres and the figure from the Performance Engineer's Manual (PEM) reflected an unfactored landing distance of 1,387 metres; this later figure included an airborne distance of 305 metres and a landing roll of 1,082 metres.

1.6.4. Relevant engine inspection requirements.

The Maintenance Schedule to which the Airline was working required that the engine turbine sections were borescope inspected every 750 flight hours. At the same time an Engineering Order issued by the Airline required that an inspection of the low pressure turbine borescope plugs, recommended by the engine manufacturer in a Service Bulletin, was to be performed. The Borescope Inspection was specified in the Company Exposition (See §1.17 1 - Operation under JAR-145) as being a Line Maintenance function.

Borescope Inspections involve looking at components within an engine using an optical probe. The probes are inserted throughports in the engine case and can be rigid or flexible, the choice depending on the difficulty of obtaining a satisfactory view of the required features. Some of these ports are the attachment points of functional devices which intrude into the engine (eg igniters or temperature probes) but on more modern engine designs there are usually several purpose made ports.

The Borescope Inspection which was performed required, amongst other things, an examination of the blades of the HP turbine. To do this, the rotor of the core engine (N2 rotor) had to be turned so that every blade would pass one of the two Borescope Inspection ports available on the engine at this position. To turn the N2 rotor, access had to be gained to a shaft within the AGB, and this shaft turned either by a hand lever or by a pneumatic motor. The forward end of this shaft, which had a square drive socket in it, was normally concealed behind a cover which was bolted to the pad on the AGB on which the drive motor, if used, would be mounted. The cover had two O-ring seals which were a tight fit into the hole in the drive pad and its removal involved using three of its five attachment set screws as jacking screws. This cover was identified by a variety of descriptions in the aircraft and engine manufacturers publications but will be described as the 'HP rotor drive cover' throughout this report.

The proper procedure for the Borescope Inspection, as laid out in the aircraft manufacturer's Task Cards and detailed in the AMM, included a number of preparatory and restorative actions which were necessary either for the safety of personnel working in this aircraft zone or for assurance that everything had been correctly completed. The stages of the inspection procedure, including the actions involved at the preparatory and restorative phases as laid out in the task cards are summarised below (underlined), with the significant elements of their respective AMM references described.

A. Prepare for the Borescope Inspection

This section of the procedure listed the equipment and consumable materials required for the inspection but new O-ring seals for the HP rotor drive cover were not mentioned here. A list of references to the AMM was also provided and the requirement for new O-rings was contained within one of these. The references were made in the task card where they were appropriate and a brief indication of what they contained is given in the following description.

The following warning was also contained in the preparation section:-

WARNING: DO THE DEACTIVATION PROCEDURE FOR THE THRUST REVERSER TO PREVENT THE OPERATION OF THE THRUST REVERSER. THE ACCIDENTAL OPERATION OF THE THRUST REVERSER CAN CAUSE INJURIES TO PERSONS AND DAMAGE TO EQUIPMENT.

(1) Do the deactivation procedure for the Thrust Reverser for ground maintenance

(AMM ref 78-31-00/201):-

Open three circuit breakers (CBs) on a panel on the flight deck. Then open the two air-conditioning equipment bays in the main wheel well and, for each engine, move an Isolation Valve handle and install a lock pin.

(2) Open the right and left fan cowl panels

(AMM ref 71-11-02/201):-

Deactivate Flaps and Slats:- Open two CBs on a panel on the flight deck, move 'Alternate Flap' switch to 'Arm', open and lock a 3rd CB and then put 'alternate flap' switch to 'Off'.. Then go to the aft bulkhead of the main wheel well and check that the override lever on the trailing edge bypass valve is in the No 2 position.
Open the fan cowls to expose the AGB.

(3) Open Thrust Reversers

(AMM ref 78-31-00/201):-

This phase of the procedure involves work around the nacelle only and exposes the case of the core engine.

(4) If it is necessary, turn and index the N2 rotor

(AMM ref 72-00-00/201):-

Remove the HP rotor drive cover from AGB and discard the two O rings. Install a drive motor or turning bar.

Note:- This AMM reference was reproduced, although not subject to amendment, in the Borescope training manual.

(5) If you turn or index the N1 rotor, do these steps:

Instructions on how to identify and align the zero index mark on the N2 turbine

(6) (7) Connect power supply to Borescope & connect the fibre light cable

(CFMI NDT Manual ref 72-00-00, part 7)

B Conducting the Inspections

(AMM ref 74-21-02/401-removal of igniter plugs)

Open igniter system CBs and remove igniter plugs.

The inspection of the turbines and nozzles is effected by an authorised operative. For the turbine blade element of the inspection, the N2 rotor has to be turned. If a bar is used to turn the rotor (as in this case), an assistant is required.

C Put the Airplane Back to Its Usual Condition

(1) If you turned the N2 rotor, refer to AMM 72-00-00/201
The task card has this exact wording which instructs the operative to read an AMM reference which relates to the engine. The reference itself details the fitting of new O-rings on the HP rotor drive cover, reinstallation of the cover onto the AGB and the requirement to perform an idle power ground run of the engine. The way the task card is written implies that this test should be performed with both the fan cowls and the reverser ducts open but the main reference contains a sub-reference in the AMM which indicates that the reverser ducts should be closed.

The Borescope Inspection training notes, which the Controller used, were not intended to be other than a training aid and carried a specific warning that they should be used for that purpose only. The training manual did contain AMM references which, despite not being updated, contained the information which referred to fitting new seals on the HP rotor drive covers, installing the covers and performing a post-inspection engine run to check for oil leaks. It did not, however, contain the two capitalised warnings which appeared in the then current revision of the AMM. These were as follows:-

CAUTION: DO NOT INSTALL THE COVER ON THE AGB WITHOUT A NEW O-RING. IF THE COVER IS INSTALLED WITHOUT A NEW O-RING, THE ENGINE CAN HAVE OIL LEAKAGE. THIS CAN CAUSE ENGINE FAILURE.

and after instructing the reader to lubricate the O- rings with engine oil -

CAUTION: DO NOT OPERATE THE ENGINE WITHOUT A CORRECTLY INSTALLED COVER ON THE N2 ROTATION PAD. IF THE COVER IS NOT INSTALLED CORRECTLY, THE ENGINE CAN HAVE OIL LEAKAGE. THIS CAN CAUSE ENGINE FAILURE.

(2) On The Borescope Equipment

Details disconnection of the equipment

(3) Close the Thrust Reversers

(AMM ref 78-31-00/201)

(4) Close Fan Cowl Panels

(AMM ref 71-11-02/201):-

Reactivate Flaps and Slats - Restore all levers and CBs to original positions.

(5) Do the activation procedure for the thrust reversers

(AMM ref 78-31-00/201):-

Restore all levers and CBs to original positions

1.6.5. Twin engined aircraft maintenance practice

Boeing, Customer Services Division, issued Service Letter 737-SL-05-004 titled Dual System Maintenance Recommendations on 17 July 1995, some five months after this incident. Having observed the benefits experienced by operators who had used conservative maintenance policies in line with Extended-range Twin-engine Operations (ETOPS) practices, this Service Letter carried the following "Suggested Operator Action":-

Operators are encouraged to institute a program by which maintenance on similar or dual systems by the same personnel is avoided on a single maintenance visit. Operators may choose to schedule maintenance on similar or dual systems using different personnel or during separate maintenance visits,

The Operator, in July 1995, issued an amendment to the Borescope Inspection Procedures in the Procedures Manual which included:-

Maintenance Practices

When carrying out Borescope inspections the following Maintenance Practices are to be adhered to, prior to releasing the aircraft to service.

a. Aircraft in service are to only have Borescope inspections carried out on one engine prior to flight. A minimum of one flight must occur before a Borescope Inspection is carried out on the second engine.

b. Aircraft undergoing base maintenance may have Borescope Inspections carried out on both engines, but a "Vital Point" Inspection must be carried out on both engines to ensure correct installation of all blanks and ports removed as part of the Inspection. (Refer to Procedure 3-2-45 Duplicate Inspections)

All Maintenance Manual requirements are to be complied with and both the engine run(s) and "Vital Inspection(s)" are to be recorded in accordance with Company requirements.

1.6.6. Airline History of Borescope Inspections

Following this incident the Airline conducted an internal inquiry to establish the general practice followed by its line engineers in the completion of the 750 hour Borescope Inspection. This inquiry revealed the following:-

With respect to the fitting of new O-rings on the HP rotor drive cover, a mismatch was found between the number of new O-rings drawn from stores relative to the number of engines inspected. This mismatch indicated that the O-rings were routinely re-used rather than replaced. It is presumed that the 'old' O-rings were inspected and judged to be in a satisfactory condition to continue in service. The AMM makes no mention of this practice being allowable or acceptable but the Quality Assurance (QA) system, as operated at the time, did not have a ready means of detecting this regularly perpetrated non-standard and erroneous practice. The only check conducted by QA was to examine the signed statement that the job had been completed according to the AMM.

With respect to the execution of post-inspection engine runs, the Airline questioned all their Line Engineers who had Borescope Inspection Authorisation as to whether or not they habitually did a post-inspection engine run to check for leaks. The result of this survey showed that only about half the engineers did the required engine run.

As a result of these findings, the Airline incorporated changes to the Borescope Inspection paperwork. Work packs were modified to include MAVIS cards (see §1.17.2) which had been amended to contain specific mention of the O- ring seals and the engine runs.

1.7. Meteorological information

1.7.1. Synoptic situation

There was a fresh to strong westerly airstream established over the area.

1.7.2. Landing information

The weather at Luton at the time of landing was good. The surface wind was 270°/23 kt, the visibility was in excess of 30 km, the cloud was scattered at 3,000 feet agl, the QNH was 1004 mb and the temperature was °C.

1.8. Aids to navigation

Not relevant.

1.9. Communications

VHF communications were generally satisfactory. Tape recordings were available of transmissions on the London and Luton ground-to-air and ground-to-ground frequencies, and console telephones.

The only communications problem that was experienced was on the common fire frequency of 121.6 MHz. On the ground at Luton, ATC could hear the aircraft and fire crew transmissions, but the aircraft and fire crew could not establish communication with each other on that frequency. However, the flight crew were quickly able to establish voice communications with the fire crew through the open flight deck window.

1.10. Aerodrome and approved facilities

Not relevant.

1.11. Flight Recorders

1.11.1. Flight Data Recorder (FDR)

The FDR was a Sundstrand model UFDR Part No 980-4100-DXUN, Serial No 7915. The FDR system was intended to operate when either engine oil system was pressurised or the air/ground sensor was in the air mode. In this case both engines had lost oil pressure and so the recorder switched off at touchdown when the air/ground sensor operated.
The flight data was downloaded by aircraft engineering personnel onto a Copy Recorder from the UFDR, which was left on the aircraft for engine runs performed later that evening. It was then removed and taken to AAIB the following day.

1.11.1.1. FDR Replay

A satisfactory readout of the UFDR was performed using the AAIB replay facilities. Analysis of the data for the incident flight showed that the data terminated at around 2,000 ft on approach. This data was followed by a record of the engine ground runs which were performed after the incident, and then 25 hour old data.

When the copy tape was first replayed it yielded 60% bad data, making analysis of the readout difficult, and it was not possible to determine whether this data contained the landing. This copytape was then replayed by AAIB using both the original Copy Recorder and the AAIB replay facilities, and this yielded 95% good data for the incident. Analysis showed that this data ended when the aircraft touched down, giving incident data for 116 seconds additional to that recovered directly from the UFDR. The copying process appeared to have repositioned the tape in the UFDR incorrectly after the down load, allowing the final approach data to be overwritten by the engine ground runs.

1.11.1.2. Interpretation of FDR data

Figure 1 at Appendix A contains some of the recorded parameters for the complete flight. The indicated oil quantity on each engine was recorded once every 64 seconds; this showed the quantity to be 25 pints (14.2 litres) on each engine at start-up, this remained constant during the taxy but began to reduce as power was increased for take-off. The recorded oil quantity reduced to around 2 pints (1.13 litres) on each engine as the aircraft was climbing through FL 110, at around 270 kts CAS. The power levers were retarded at FL 178, 306 kts CAS and the oil quantity dropped to zero at the same time as the master caution illuminated.

The aircraft descended continuously from FL 180 with both engines at Flight Idle until 2,000 ft on approach when power was increased on both engines to about 65% N1, Flap 1 selected and the rate of descent reduced. Flap 15 was selected at 600 ft agl, 187 kts CAS and the aircraft speed just before touchdown was 166 kts CAS.

The aircraft flight path from the FDR data together with relevant ATC transmissions is contained in Figure 2 at Appendix A.

1.11.2. Cockpit Voice Recorder (CVR)

The CVR, a Sundstrand Model AV557, Part no 980-6005-076, Serial Number 11917, was replayed without removing the tape from the unit. Analysis showed that the recording duration was about 10 minutes in total, and contained only the final approach and landing.

The method of operation of this recorder is to record 15 minutes of data on four tracks travelling in one direction; when the End of Tape (EOT) sensor detects a small hole in the tape the unit reverses direction and records a further 15 minutes of data travelling in the opposite direction. The incident tape contained a slit which caused the EOT sensor to reverse the direction of the tape prematurely, thus reducing the recording duration. The rest of the tape was checked, and contained no signal. The reduced duration of the recording would not have been detected by the unit Built in Test Equipment (BITE).

1.12. Examination of aircraft

There was no overt damage to the aircraft.

After landing at Luton, the underside of the wings and the flaps in the region of each engine was found to be covered in an even film of oil. The contents of each engine oil tank was drained and measured and it was found that there was 1.34 litres in the left engine and 1.4 litres in the right. The nominal maximum oil contents was 17 litres.

A rigorous, on wing inspection of the two engines revealed no apparent damage but they were both changed as a precautionary measure and sent for strip examination to establish the condition of their main rotating assembly bearings.

The strip examination revealed that the bearings were in a condition similar to that expected at routine overhaul.

1.13. Medical and pathological information

Not applicable.

1.14. Fire

There was no fire.

1.15. Survival aspects

There was no need for the use of any aircraft emergency equipment and the passengers disembarked normally.

1.16. Tests and research

Following the incident, the engine manufacturer conducted a test to confirm that engine oil loss occurred if the HP rotor drive cover was not fitted and the engine was run at ground idle.

This test showed that if the engine was motored over on the starter, with the ignition switched off, a very fine oil mist was emitted from the open hole in the AGB case. If however, the engine was started and run at ground idle, as is required by the AMM following the Borescope Inspection, a significant outflow of oil occurred.

1.17. Organisation and management information

1.17.1. Operation under JAR-145

The Airline's aircraft maintenance organisation was approved to work according to the conditions of JAR-145. JAR-145 lays down the Requirements (JARs) for the functions which maintenance organisations must undertake and the interrelationships between the various requirements. In its 2nd section are detailed the Acceptable means of Compliance and Interpretations of the Requirements (ACJs). Amongst these are items specific to the establishment and operation of a Quality Assurance system and these, and the relevant extract from the British Midland Company Exposition are given at Appendix B

In order to be awarded JAR-145 approval, an aircraft maintenance organisation has to write a Company Exposition and Procedures Manual. This describes, in considerable detail, the way in which the Company intends to perform each of the necessary functions and who is to be the responsible person or office to ensure that they are correctly executed. This Exposition must then be submitted, in the case of UK maintenance organisations, to the CAA who are the National Authority.

The CAA first analyse and approve the Exposition as a theoretical description of an acceptable way to operate an aircraft maintenance facility, including its QA systems. Having approved the Exposition and Procedures Manual as a document, the CAA then should investigate the organisation to assure itself that they are able to work in the manner described. Once the CAA is satisfied that the Company can operate in accordance with its Exposition they, as the National Authority, grant JAR-145 approval.

A requirement was laid down that all organisations carrying out maintenance on aircraft used for Commercial Air Transportation were to be in compliance with JAR-145 by 31 December 1994. About three years before that date, the CAA had started to monitor the British Midland maintenance facilities and organisation with a view to highlighting the changes which would have to be made in order for them to comply with the new regulations.

Amongst the topics of concern to the CAA, of specific relevance to this investigation were a lack of presence of Quality Assurance engineers during 'out-of-hours' working (ie during night shifts) and a lack of evidence that quality audits were addressing compliance with procedures. The issue of 'out-of-hours' QA was a matter of persistent concern for about two years. However, a procedure, issued by the Operator in June 1993, specifying intermittent and isolated night audits by QA engineers apparently satisfied the CAA's concerns in that the matter was not raised again. Similarly, the concern of the CAA on the matter of procedural monitoring appears to have been addressed to their satisfaction when the operator declared that modified audit paperwork, emphasising procedures, was being re-issued and would be in use by December 1994. It appears that the CAA deemed the organisation and its procedures satisfactorily complied with the requirements of JAR-145 insofar as approval had been granted two months before this incident.

JAR-145 approval renewal was to be dependent upon a continual monitoring process in which all functions were to be checked at least once during a two year period and found to work satisfactorily. In the particular case of British Midland, the local CAA office at East Midlands Airport was responsible for the initial recommendation for JAR-145 approval and was to perform the subsequent continual monitoring over the rolling two year cycle. This functional monitoring was to be effected by a sampling process, generally based around the opportunities afforded by normal audit visits and at specific times, to aircraft undergoing maintenance or repair.

One of the items monitored by the CAA was that there were sufficient manpower hours available within the Company to do specific tasks. They did not, however, check that the necessary man-hours for particular tasks were available from appropriately qualified staff, this being considered a Company management function. Neither did they audit the way in which work was being performed to ensure that it was being done in strict accordance with the procedures laid down in the AMMs; this being considered a matter for the Company's own QA staff. They did, however, make spot checks of the currency and correctness of authorisation qualifications of inspectors engaged in particular tasks.

1.17.2. Airline maintenance documentation

a) General

At the time of the incident, the Airline maintenance staff in Line and Base Maintenance were issued with different styles of worksheets to support the same tasks. Although the Company Procedures Manual Vol. 2 (Procedure 2.5.7.) did not indicate clearly that there should have been any difference, it was inferred by an absence of references to the MAVIS system in the descriptions of how a Line Maintenance work pack was constituted. This had resulted from an appreciation of the different working environments in which the two types of maintenance were normally performed.

When aircraft went into Base engineering, it was anticipated that a large number of different tasks would proceed simultaneously. It was also anticipated that any of the tasks might require a change of personnel part way through as a result of shift changes or the need to suspend a partially completed task. Tasks falling to Line Engineering, however, were more likely to be isolated and pursued by an individual or small team and completed during a single shift. Thus, in broad terms, most scheduled maintenance tasks were performed in Base engineering; whilst some routine inspections, minor maintenance and most of the rectification of defects which arose during the day-to-day operation of an aircraft, fell to Line Maintenance.

The form of documentation used by Base Engineering to specify and act as a progress record for Base Maintenance tasks had been evolved within the Company over a number of years. The maintenance planning system in use had been developed by the Airline, for use with its specific aircraft types, from a commercially available general maintenance planning software package. It was known as MAVIS and the planning department used it to produce a computer generated job card, or sets of cards, for each task to be performed at a particular maintenance interval. The system could also be used to produce a job card for a specified individual task. This card was intended to act as a combined job description card, staging record sheet and task certificating document.

Wherever possible, the MAVIS card contained all the information and references needed to complete a task but, in the case of jobs involving many sub-tasks of which this Borescope Inspection was an example, it carried a standard phrase, "SEE FULL TEXT", to indicate that the engineer would need to make reference to other documents. The MAVIS job card/s constituted the first sheet/s of a package for a task which might include a manufacturers task card, giving a more detailed description of the task, and any necessary inspection record sheets. If a number of tasks was to be performed in one zone of the aircraft, the documents for all the jobs in that zone would be put into a folder with an index of the tasks.

In Base Maintenance, the workpack would be expected to be supported by text extracts from the AMM, illustrations from the Illustrated Parts Catalogue and other information which would be needed to complete the task. This would be placed at workstations around the aircraft undergoing maintenance by the dock control staff. Specific information on dimensions, forces and torques would be excluded from the workpack, so use of the most recent standard of this information could be assured by continuous updating of the AMM alone. The planning procedure for Base Maintenance work started six weeks before the activity.

It was this standard of paperwork, with all the additional information placed at hand near to the aircraft being worked on, with which the Base Maintenance Controller was familiar.
The Line Maintenance task paperwork, however, was only generated shortly before the maintenance input was planned and was subject to change resulting from operational requirements. The Line Maintenance job cards gave a very brief description of the task to be performed and, when preplanning had been possible, gave minimal details of Task card and AMM references. The 750 hour Borescope Inspection of the turbines was specified as a Line Maintenance job and, as such, the maintenance planning department had created a package of working papers specifically for use by Line Maintenance personnel.

b) 750 hour Engine Borescope and Hot Section Inspection

The documentation supplied to Line Engineering, for this inspection, consisted of a folder containing eight items of task paperwork with an index of the individual items. These were:-

ï The inspection job cards, one for each engine, with their necessary inspection record sheets and certificates of release.

ï Copies of the previous inspection record for each engine (for reference) ï A Company engineering order and record sheet for each engine

ï A certificate of release to service for the aircraft with a copy of the procedure for its completion.

The job card carried references to the Task Cards and AMM sections relevant to the work but copies of these documents were not provided. The accepted system of working in Line Engineering, was that if an engineer wished to have additional information beyond that on the job card they could extract it from the Line Maintenance library.

The Line Engineer who had intended to do the inspection was familiar with the task and did not feel it necessary to draw additional information paperwork.

Neither the inspection job card, which was included in the normal Line Maintenance work pack, nor the MAVIS card, available as part of a Base Maintenance work pack for this job, contained any mention of the restorative work requiring completion signatures. Furthermore, neither these documents nor the Boeing Task Card contained any intimation of the warnings, highlighted in the AMM references, that airworthiness would be jeopardised if correct procedures were not adhered to whilst executing the restorative tasks.

1.17.3. Quality Assurance (QA)

The airline, in common with most others, had in recent years moved from a system of Quality Control to one of Quality Assurance. These two concepts are fundamentally different in approach.

A traditional Quality Control system required specialist inspectors whose function was to physically check and certify that all steps of tasks had been correctly executed, according to the appropriate manual. When strictly applied, this meant that the work had to be stopped after any stage which it would not be possible to inspect if the next stage were started, or when the next stage was critically dependent on the previous one being correct, until an inspector had certificated it.

Quality Assurance changes the emphasis from independent checks to operatives having responsibility for the quality of their own work. As a result there has been a general movement within the industry to develop an acceptable way of having maintenance engineers (other than type rated Licensed Aircraft Engineers) self certificating except when duplicate inspections are still required. This has led to the current situation in many operating companies where maintenance engineers, having obtained a CAA licence without type rating, are then granted specific authorisations of varied scope by the Company. These authorisations allow such engineers to certificate their own work and to inspect and certificate the work of non-authorised staff. The foundations of a successful QA programme are comprehensive, well considered working procedures which are fully adopted. The need to audit the efficacy of this mode of working has led to a major part of the role of the QA Department being to examine all the paperwork generated and to ensure that the legal requirements of certification have been met. Quality Assurance, as applied by the airline at the time of this incident, followed this model.

The universal method, adopted by the aircraft operating industry, of showing that jobs, or parts of jobs, have been satisfactorily completed is for an authorised person to sign and/or stamp against a declaration that it has been done. It is this mark which is used as proof that a job has been done when it is no longer visible and the collection of all such declarations, related to one aircraft, are considered proof of its state of repair. With the traditional, separate inspection function or the current self-certification system, a complete set of signed off job cards, and duly authorised deferments if any, is required to show that a maintenance input is complete and an aircraft fit to fly.

If, during an audit, QA engineers observed any anomaly in the way a job had been certified or described in the task documentation,they would have been expected to check the certification process with the engineers who had performed the tasks, and possibly conduct a physical re-inspection of the aircraft itself.

It was also within their remit to re-inspect a randomly selected area of an aircraft in order to audit the effectiveness of the inspection and certification system. Quality Assurance was normally only a day shift activity and such audits would nearly always have been done during the day shift although they had been done at night on a small number of occasions.
This auditing was mainly directed at the Base Maintenance function but was sometimes done on the Line Maintenance at East Midlands, the home base, by means of unannounced spot checks. QA staff considered it difficult to emulate this surprise element whilst auditing Line Maintenance at outstations, owing to the need to get security passes, however, the required audits of outstations were performed during routine visits.

A number of the QA Department personnel did not, at the time of this incident, understand from their terms of reference that they had a remit to observe tasks in progress, with a view to detecting any procedural laxity. Neither did they think they were responsible for reviewing task description cards (MAVIS, see §1.17.2 Airline maintenance documentation) to ensure that the procedures themselves were sound.

The determination of what constituted a complete set of job cards for the required work, and the generation of those cards to check the work against, was the function of the maintenance planning engineers; what constituted a completed job was evidenced by the receipt of all those cards, with the required work duly signed for, by the QA Department engineers.

1.17.4. Training

The airline had its own engineering training establishment which ran aircraft specific courses to familiarise maintenance engineers with the types operated. These courses were intended to ensure that the Company's engineering skills were matched to their requirements and not to assist individuals towards obtaining CAA licences, that being considered a matter for self study.

The airline also ran courses on their procedures and certification requirements. These courses not only taught the details of the procedures but stressed the need to adhere to them rigorously, using the staging sheets (MAVIS) and correct techniques as described in the manuals.

1.17 5. Maintenance shift patterns.

The Base and Line Maintenance staff worked on different shift patterns.
The Line Engineering staff were divided into four shift groups, each of nominally six personnel.

However, one group had been under-strength by one for 18 months. The establishment for each group comprised a supervisor, his deputy and four licensed fitters, to cover airframe avionic and electrical trades.

These groups worked 12 hour shifts on an eight day rotating cycle consisting of two day shifts, then two nights and then four days off. The shifts started at 0730 hrs and 1930 hrs. As a result of staff absences, due to leave, sickness or training etc, it was normal for most of the engineers to work more than the four allotted shifts over an eight day period. Consequently some juggling of the manpower was needed in an attempt to ensure that shifts were adequately manned for the expected workload. Frequently, however, shifts were worked with less than the full establishment of engineers.

Unlike the Line, Base Maintenance operated a fixed shift system where staff were rostered permanently for either days or nights. Only in circumstances of short term exigency would staff be asked to work other than their allotted shift, although they could expect to be required to work overtime in an extended length shift, from time to time.

The night shift worked from 2100 to 0700 hrs and the personnel had alternate long (three night) and short (two night) weekends.

1.18. Additional information

1.18.1 Quick Reference Handbook (QRH)

There were two QRHs on the flight deck of G-OBMM readily accessible to the flight crew. Additionally, in Company with the other mandatory items, there was a copy of the BMA Operations Manual Volume 9; this volume detailed and provided an expanded explanation of the emergency procedures.

Actions in the event of low oil pressure were as follows:

Accomplish this procedure when the engine oil pressure is below 26 psi, or when the amber LOW OIL PRESSURE light is illuminated. The amber LOW OIL PRESSURE light illuminates at a pressure below 13 psi.

If engine oil pressure is in the yellow band with take-off thrust set:

DO NOT TAKE-OFF.

Oil pressure in the yellow band is normal at low thrust settings.

If oil pressure is at or below the red radial:

Accomplish the ENGINE FAILURE AND SHUTDOWN checklist.

1.18.2. Form and Purpose of Aircraft Maintenance Manuals (AMMs)

When aircraft were generally simple by today's standards, their Maintenance Manuals were also similarly less complicated than more recent examples. They then contained only descriptions of the philosophy and manner of functioning of the various aircraft systems, together with the dimensions and tolerances required to maintain or overhaul those systems. Such manuals did not, as a rule, contain detailed instructions of how to do the various tasks except in circumstances where a deviation from normal or standard practices was required or when a particular sequence of actions had to be undertaken.

Over time, a standardised format (ATA) was developed, and has been generally adopted, in which the various subjects and systems are categorised (and sub-categorised) and all information relevant to any category appears in the appropriate chapter. The AMM of a typical modern transport aircraft now requires several large volumes which are subject to continual amendment.

As aircraft have become more complex it has become necessary to give more detailed descriptions of how maintenance tasks should be performed. It has also been deemed necessary to include, within the descriptions of how the work should be done, warnings concerning every conceivable risk involved in its execution. This has resulted in the inclusion of tracts of text, often lengthy, which break up the sequence of relevant maintenance activity description. Thus, the proportion of the total text directly related to doing the work has diminished and the task of finding specific and relevant information, more protracted.

The pursuit of a particular piece of aircraft maintenance can normally be expected to require preparatory and restorative work elements related to gaining access to, and completing, the required work. Some of these elements will almost certainly involve systems or structure not directly related to the main task except by physical proximity. In more modern aircraft, these 'sub-tasks' may of themselves be quite complex and require a section of descriptive text for themselves. Thus, to avoid considerable repetition, as the same sub-tasks may be required for a number of main tasks, they are treated as modules and appear in the AMM task descriptive text as cross-references. This generally leads to a requirement to refer to a number of different chapters within the Manual in the pursuit of a single main task. This is frequently further complicated by the modification and Service Bullet in status of an individual aircraft affecting the selection of relevant modules.

To enable maintenance engineers to concentrate on the main task, without having to do basic searches through the AMM to check on the way to do this ancillary work, several manufacturers have developed job specific task cards. These are adjuncts to the AMM and, therefore, do not supplant it. They include the flow of the whole work requirement for a particular job with references to the relevant modules within the AMM.

The manufacturers task card for this 750 hour Borescope Inspection was laid out along these lines but it was noted that, in general, the AMM references were supported by cryptically brief descriptions of what the references contained.

The operator had ensured that both the Aircraft Maintenance Manuals and the Task Cards were available, either as hard copy or on microfilm reader/printer, to all maintenance personnel at any time. It should be observed, however, that whilst there was normally support, in the form of planning personnel, available to provision such material during the daytime, there was no such assistance available at night.

1.18.3. Lighting in hangars

Both of the Base Maintenance personnel involved in the Borescope Inspection remarked that the lighting in the part of T2 that they were using was poor compared with that in the Base Maintenance hangar.

Hangar T2 was not normally used for night Base Maintenance work and had not been included in operator"s JAR-145 approval. It was not equipped with the standard low voltage electrical socket outlets which would have been suitable to power the lead lamps available to Base Maintenance staff. The two individuals who did the Borescope Inspections were aware of the deficiencies in the general lighting and electrical supply in T2 and so took torches with them for additional illumination.

T2 was considered to be part of the Line Maintenance facilities and, for the Line Engineers, represented a considerable improvement from their normal outdoor maintenance environment where they were used to working by torchlight alone.
During the course of the investigation a series of measurements of the light intensity in various locations in both the Base Maintenance and T2 hangar were made. In order to get a realistic appreciation of the actual working conditions, a Boeing 737-400 aircraft was placed in T2 and the engine cowlings opened. Comparative sets of light intensity readings were taken in the general areas of the Base Maintenance hangar and T2 and under the opened engine cowls of aircraft in each place. The observations of light intensity in 'lux' were as follows:-

Location where light intensity was measured	Base Maintenance	T2
In general workspace	450 - 700 lux	150 - 200 lux
Under opened engine cowling	200 lux	< 20 lux

Although there are no specified requirements for lighting levels in aircraft maintenance hangars, some recently issued FAA guidelines for lighting levels contains the following:-
Lowest recommended level: 150-200 lux Should only be used for infrequently used areas
Normal recommended level: 750-1,000 lux Adequate for many normal maintenance tasks

1.18.4. Shift patterns - tiredness

A review of existing literature on shift work and its management was conducted recently by the School of Aviation Medicine (SAM) at DRA Farnborough. This covered the human factor aspects of shiftwork patterns, alertness and mood effectors. Several databases were used in its preparation and it generally limited itself to consideration of English language papers, with priority being given to literature published after 1980. This paragraph is a precis of the points relevant to this investigation which were discussed in that review.

The main problem in the management of shift work, is to cover the night-time hours when alertness is naturally low. Poor performance at night was also found to be associated with an increased risk of accidents, the consequences of which, like the nuclear reactor disasters at Chernobyl and Three Mile Island, may be serious.

There were many features which characterise individual shift systems. Key factors identified by the review included, length of shift,timing of shift, how long workers stay on one shift, how they are moved to a different shift, and the provision of time off. The main body of evidence suggested that night shifts lasting for longer than 8 hours should be avoided when alertness is a critical issue and 12 hour shifts were found to be associated with a higher risk of accidents than 8 hour shifts.

The normal circadian rhythm, which is driven by a biological 'clock' in the brain, has a considerable effect on performance at work. It is entrained to the 24 hour clock through environmental synchronisers, the pattern of light/dark being the major one. This, in association with information such as the timing of meals and activity, ensures that the individuals remain entrained to a 24 hour cycle. Many physiological and psychological variables have their own rhythms within this cycle including; body temperature, sleep tendency, cognitive performance and alertness.

The internal circadian rhythm has been studied by monitoring physiological rhythms such as deep body temperature. It has been found that under a normal, diurnal, sleep/wake environment, body temperature varies approximately as a sinusoidal curve over a 24 hour period. In this the minimum deep body temperature occurs in the early hours of the morning, rises to its highest values in the evening and then falls back rapidly, over the late evening, to the early morning low.

At night, performance on most tasks is impaired, including particularly those which require sustained attention, monitoring, scanning, tracking and logical reasoning. The rhythm of performance closely follows that of body temperature and changes in performance can be quite large (15% of the daily average have been observed). For an individual who starts work in the evening, even if initially fully rested, performance may fall to very low levels as the duty extends through the night. The final hours of the night shift, therefore, are liable to be a particularly difficult period for shift workers.

Under normal patterns of sleep/activity, environmental cues have a fixed phase relationship with the internal circadian rhythm. During shift work the whole range of external synchronisers, except the natural light/dark cycle, is rapidly moved and this is followed by a much slower shift of the internal rhythms. This slow adaptation of the internal circadian rhythms affects the majority of physiological and psychological rhythms and may result in many of the problems which shift workers encounter. A single night shift is not sufficient to move the circadian rhythm to a night orientated pattern and complete adaptation to night working is rarely achieved. Observation also indicates that any adjustment made is rapidly lost during days off.

It was observed that shifts which rotate at least every two to three days appear to be more satisfactory, since they reduce cumulative sleep loss, help to maintain the circadian rhythm on a diurnal orientation and are less socially disruptive. However, another recent review concluded that a permanent night shift system was superior, and should be implemented for night work. There was little information, in the papers reviewed, on the time required to recover from successive night shifts. However, it is important to provide sufficient time to recoup any sleep debt incurred during the schedule, and at least two consecutive days off appear to be needed.

This review considered other factors affecting the ability to adjust to shift work. Workers over 40 years of age were more likely to have less tolerance to shift work and could be particularly vulnerable to sleep loss and decreased alertness. It was also observed that individuals could be classed as morning types or evening types, and that morning types and those who were rigid in their sleeping habits were less suited to shift work.

To assist adaptation during long periods of night work, bright light exposure during the night and avoidance of early morning daylight have been shown to increase alertness during the shift and improve daytime sleep. The intensity of light necessary to have a significant effect is around 2,500 lux for three hours or 1,000 lux for eight hours given at the appropriate time of night for three consecutive nights. Similarly, the timing of exercise may allow more rapid adjustment to shift work but further studies are required before their use can be recommended.

1.18.5. Occurrences of the HP rotor drive cover not being refitted.

Since the introduction of the CFM56-3 engine onto the Boeing 737, amongst all operators, there have now been nine instances recorded of HP rotor drive covers being left off after access to the HP rotor turning mechanism. On two of these occasions, the subject incident being one, refitting of both covers was overlooked. None of the incidents occurring before this one had involved UK operators.

Following the first five notified events, one of which involved both engines, a modification involving the attachment of the HP rotor drive covers to the AGB by means of a wire lanyard was introduced. The modified cover was introduced by Service Bulletin (CFM563/3B/3C) 72-500 dated 10 April 1990 (revised April 92) and had the status of recommended but optional. The intent was to keep the covers in view whilst they were removed and, thereby, reduce the likelihood of their not being refitted.

Since the introduction of the Modification there have been a further four incidents including this event involving G-OBMM. Both the engines installed on GOBMM were fitted with the modified covers.

1.18.6. Other Maintenance Related Incidents

This is the third serious occurrence stemming from a maintenance error to be made the subject of an AAIB Formal Investigation in the last five years. The other two incidents, which had involved aircraft of other operators, were the result of errors and omissions committed during night maintenance. Another major feature in common with this incident was the failure of the maintenance staff to comply with the requirements of the AMM.
These other incidents were the subjects of the Air Accident Reports 1/92 and 2/95. The following are extracts from the synopses of those two reports.

a From AAR 1/92 Report on accident to BAC 1-11 G-BJRT, 10 June 1990.

The accident happened when the aircraft was climbing through 17,300 feet on departure from Birmingham International Airport en route for Malaga, Spain. The left windscreen, which had been replaced prior to the flight, was blown out under effects of the cabin pressure when it overcame the retention of the securing bolts, 84 of which, out of a total of 90, were of smaller than specified diameter. The commander was sucked halfway out of the windscreen aperture and was restrained by cabin crew whilst the co-pilot flew the aircraft to a safe landing at Southampton Airport.

The following factors contributed to the loss of the windscreen:-

A safety critical task, not identified as a 'Vital Point', was undertaken by one individual who also carried total responsibility for the quality achieved and the installation was not tested until the aircraft was airborne on a passenger carrying flight.

The Shift Maintenance Manager's potential to achieve quality in the windscreen fitting process was eroded by his inadequate care, poor trade practices, failure to adhere to Company standards and use of unsuitable equipment, which were judged symptomatic of a longer term failure by him to observe the promulgated procedures.
The Operator's local management, Product Samples and Quality Audits had not detected the existence of inadequate standards employed by the Shift Maintenance Manager because they did not monitor directly the working practices of Shift Maintenance Managers.

b From AAR 2/95 Report on incident to Airbus A320 G-KMAM, 26 August 1993

The incident occurred when, during its first flight after a flap change, the aircraft exhibited an undemanded roll to the right on takeoff, a condition which persisted until the aircraft landed back at London Gatwick Airport 37 minutes later. Control of the aircraft required significant left sidestick at all times and the flight control system was degraded by the loss of spoiler control.

The investigation identified the following causal factors:

1. During the flap change compliance with the requirements of the Maintenance Manual was not achieved in a number of directly relevant areas During the flap removal the spoilers were placed in maintenance mode and moved using an incomplete procedure, specifically the collars and flags were not fitted. The re-instatement and functional check of the spoilers after flap fitment were not carried out.
2. A rigorously procedural approach to working practices and total compliance with the Maintenance Manual was not enforced by local line management.
3. The purpose of the collars and the way in which the spoilers functioned was not fully understood by the engineers. This misunderstanding was due in part to familiarity with other aircraft and contributed to a lack of adequate briefing on the status of the spoilers during the shift handovers.

1.19. Useful or effective investigation techniques

None new.

2. Analysis

2.1. Introduction

Following Borescope Inspections on both engines, G-OBMM was returned to service with the HP rotor drive covers not refitted on either engine. The result was that, shortly after take-off, engine oil from both engines was progressively released overboard and the flight crew were faced with a possible imminent double engine failure. Assisted by the prompt and effective actions of ATC, the flight crew coped exceptionally well with an unusual and potentially catastrophic emergency and

the aircraft made a safe landing.
The emergency primarily arose from a lack of adherence to engineering procedures.

The flight

2.2.1. The despatch of the aircraft

Having towed the aircraft to the line, his attention remained focused on the APU starting problem. Shortly after he had got the APU to start he left the aircraft to continue with the more immediate requirements of despatching other aircraft which had to depart sooner than G-OBMM.

As a result, it was not until after the fuel load became known and the second Line Engineer had gone to the aircraft, to supervise the refuelling and start his pre-departure checks, that minor discrepancies in the status of the aircraft were first observed. By this time, the flight crew had arrived at the aircraft and, whilst going through their flight deck checks, noticed that the hydraulic power circuit breakers were open. Initially, the flightcrew left the circuit breakers as they were and brought the situation to the attention of the Line Engineer who was involved in the pre-flight check.

The engineer, who had just discovered the forward Electronic and Electrical compartment (E & E bay) door open, told the crew that Borescope Inspections had been carried out the previous night, during which it would have been normal practice for those circuit breakers to be opened. He also told them that the inspections had been signed off in the Technical Log as having been completed and that he saw no reason why the circuit breakers should not be reset. Since it is not particularly unusual to find some minor discrepancies during an aircraft acceptance, this explanation satisfied the flight crew and they closed the breakers and continued with the rest of their preparations before engine start.

Meanwhile, the engineer, having inspected and secured the door of the E & E bay, completed his pre-departure check and went to the flight deck to give the Technical Log to the captain. At this point it was discovered that the engine ignition circuit breakers had also been left open; these were also closed.

After the aircraft had been despatched and he had returned to the Line Maintenance office, the engineer remarked on the open circuit breakers to his supervisor. As they reflected, they began to realise that there were several anomalies which cast doubt on their initial interpretation, that how they had found the aircraft was consistent with their understanding of how it should have been, had the maintenance been correctly completed.
The question raised is whether these anomalies should have alerted the flight crew or the Line Engineers to doubt the aircraft's readiness for flight. It is possible that these issues could have raised their suspicions and led to some further investigation. However, taking into account the pace and diversity of events which occur during the pre-departure phase of an aircraft operation, it is not surprising that neither of the groups involved connected the various clues, especially considering the random timing of when they became aware of each individual factor. This sequence was further confused by the fact that the open E & E bay door was almost certainly not a consequence of the Borescope Inspections. As there is no requirement to enter this bay for any part of that procedure,

even if carried out to the letter of the Task Card instructions, it was more likely a consequence of the difficulty in starting the APU.

These factors aside, the single most powerful reason for their not questioning the readiness of the aircraft was the signature, in the Technical Log, against the paragraph which showed that the Borescope Inspections had been completed according to the requirements of the AMM. Both groups would have had faith that the system of checks, which is built into the maintenance procedures, had worked, as it does in the overwhelming majority of instances. Even if any further investigation had been initiated there is no guarantee that the nature of the maintenance oversight would have been detected.

2.2.2. Conduct of the flight

With the first officer as handling pilot, the commander's duties were to monitor the aircraft instruments and to liaise with ATC; regardless of who is handling the aircraft, the commander retains overall control of the flight. The commander first became aware of a problem as G-OBMM was climbing through approximately FL140, when he noted low oil quantity indications for both engines. This early awareness reflected close attention to his duties and was a significant factor in the successful conclusion to the flight. He advised the first officer of the situation and then noticed that both engine oil pressure gauge indications had reduced to the yellow band; by now, the oil quantity gauges were indicating zero. These were confusing indications, particularly since the two oil systems are completely separate, and could have lead the commander to assume some sort of indicating error. Even though he could not diagnose the cause of the problem, he recognised the potential dangers and immediately advised ATC, at 1205 hrs, that G-OBMM was in difficulty and might need to return to East Midlands. This was a sound decision, heading towards a suitable airfield whilst attempting to determine the extent of the emergency. ATC replied by informing him of his present position and clearing him to level at Flight Level 180. The subsequent good co-ordination on the flight deck and between G-OBMM and ATC was obvious from the fact that, in just over one minute the aircraft was established on a direct heading for Luton Airport. In that time, the relative positions of Luton and East Midlands had been discussed between the crew and ATC and a decision made to divert to Luton. The validity of this decision was subsequently corroborated by examination of the FDR information and the ATC recordings showing that Luton was the closest suitable airfield. Furthermore, the nature and seriousness of the emergency was quickly understood by the ATC Controller, and the need for an expeditious descent and routeing was accepted.

Both the ATC Controller and the flight crew had to maintain a significant workload to enable a safe landing to be made. Examination of the ATC recordings indicate how effectively these duties were carried out. The Controller arranged direct routeing and continuous descent towards Luton and ensured that the crew were passed all the essential information for their approach. Within the aircraft, the workload remained high. By now, the commander had taken over the handling duties, made the necessary decisions about the approach and informed the senior cabin attendant of the emergency and imminent landing. He maintained control of the aircraft and, after consultation with his first officer, made the decision to carry out a Flap 15 landing at Luton. The commander was particularly conscious of two aspects. Firstly, the landing weight was going to be high but he was confident that the landing distance available was well within the distance in which the aircraft could stop. Secondly, his engine instruments indicated zero oil quantity for each engine and therefore he wanted to minimise power requirements during the rest of the descent and approach. As a compromise, he elected to make a Flap 15 landing. This decision can subsequently be justified by the performance calculations at §1.6.3 and by the evidence of the minimal damage to the engines. Moreover, this decision was made at a time when the crew had many other aspects to consider and were under significant stress because of the unknown factor of how long the engines would continue to run. Finally, as stated in §1.18.1, the action listed in the QRH for this emergency is to carry out the engine failure and shutdown check but this assumes that only one of the two engines has a low oil pressure. In the situation the crew were in, there was no advantage to them in closing down either or both engines.

Throughout the approach to Luton, the liaison on the flight deck, and between ATC and G-OBMM remained good. The commander maintained close control of the situation and ensured that the cabin crew and passengers were aware of the diversion. The first officer gave the commander full support and ensured that the navigation equipment was set up for the approach to Luton and that all the necessary checks were completed. Finally, ATC on all frequencies but particularly on the initial London frequency, provided all the assistance that G—OBMM required but with no extraneous distractions. The aircraft landed at Luton at 1214 hrs, only 9 minutes after the commander became aware of the emergency. Once on the ground, the crew retained sufficient awareness to ensure that the landing roll was under control before closing both engines down in accordance with the QRH. The aircraft was stopped on the runway and was met by the Luton Rescue and Fire Fighting Service (RFFS). There was good communication maintained between ATC and G-OBMM but radio contact could not be established between the aircraft and the RFFS on frequency 121.6 MHz. However, the flightcrew did not prolong the attempt to establish radio contact as the RFFS was quickly alongside the aircraft and communication was achieved through the open flight deck window. Subsequently, there was no fault found with the radio equipment on the fire vehicles or the aircraft. Furthermore, the RFFS make practical checks on frequency 121.6 MHz each week and, since the incident involving G-OBMM, have used it successfully with aircraft in other incidents. It is possible that an incorrect selection may have resulted in an initial failure to make contact and that the proximity of the aircraft and RFFS offered an immediate and obvious alternative, thereby making further attempts with the radio unnecessary.

2.3 Conduct of the maintenance

2.3.1. The allocation of the Borescope Inspections.

In the airline's Company Procedures Manual Vol. 5 (Procedure 5.2f of Routine Line Check Requirements), the 750 hour Borescope Inspection was one of a list of routine scheduled inspections and checks specifically designated as Line Maintenance tasks for Boeing 737s. A review of these inspections shows that all were of the type which would occur at a considerably higher frequency than the main scheduled maintenance cycle of six-monthly and annual checks performed by Base Maintenance. A further characteristic of the tasks classified as line checks was that they were all capable of being performed overnight with relatively little demand on logistic support. Therefore, with good planning, the tasks could be completed without taking an aircraft out of service.

In general, the nature of scheduled Line Maintenance tasks is that they are isolated and are intended to be pursued to a finish, without diversion or change of personnel. The non-scheduled rectification work, which also normally falls to Line Maintenance, requires a similar single minded approach if disruption to operational schedules is to be minimised. An adjunct of this is that many of the tasks which fall into the Line Maintenance environment have an element of aircraft preparation, to get it into a safe and suitable state in which to do the task, and likewise an element of restoration to flying condition after the task is completed.

By contrast, Base Maintenance usually involves the pursuit of many separate tasks in parallel. Although some may be relatively small and capable of being done in a single shift without any change in personnel, a number, which probably constitute the bulk of the work, will require several work shifts. In the process of receiving an aircraft into Base Maintenance therefore, there is usually a complete package of tasks to deactivate the aircraft so that, generally, any individual system or part may be worked on safely. Similarly, during the recomissioning process after maintenance, there is another work package specifically directed at ensuring that the aircraft is systematically reactivated and functionally tested. Because of this, the elements of aircraft preparation and restoration would not, at the time they are done, be necessarily associated with the execution of any particular individual task which may have been completed at several days remove and by different personnel.

It would, therefore, be generally true that Line Maintenance personnel are used to performing stand alone tasks, any of which they would expect to associate directly with selective system deactivation, reactivation and testing. Similarly, it would be normal for Base Maintenance personnel to consider the processes of aircraft system deactivation and reactivation as distinct tasks in their own right. These activities might not be linked directly with any part of the maintenance work package performed, which could include some Borescope Inspections. It would not be true, however, to say that Base Maintenance personnel never did isolated tasks any more than it would be true to say that Line Maintenance personnel were never exposed to tasks requiring more than one shift or having to do several tasks in parallel.

It can, none the less, be seen that the 750 hour Borescope Inspection, as a stand alone task, is of the type which falls more naturally into the Line Maintenance category. It is a relatively short procedure and clearly best performed as a single, uninterrupted task. In practical terms it can also be more easily placed with Line Maintenance because its frequency does not coincide with the normal Base Maintenance cycle. If categorised as a Base Maintenance task it would be likely to cause organisational difficulty in scheduling hangar space for the short period required for this task alone.

Thus the allocation, in the airline's Company exposition, of the 750 hour Borescope Inspection to Line Maintenance would appear to be both practically and philosophically correct. However, its nature would not preclude it from being done by suitably qualified Base Maintenance personnel, although it is likely that they would be less familiar with the specific details of the pre- and post-inspection procedures.

2.3.2. Manpower levels at the time of handover

a) Line Maintenance

The Line Engineer, who started the inspections, was the deputy shift leader and the only Line Engineer, at East Midlands, qualified to perform this Borescope Inspection. He had already extended his run of night shifts beyond the normal sequence to maintain the shift at an acceptable manning level. At the end of his previous shift, he had recognised, from the number of aircraft scheduled to be staying overnight at East Midlands, the relatively heavy Line Maintenance workload coming up the following night. This was of particular significance since his involvement with the Borescope Inspections would make him unavailable for any other work for a considerable proportion of the shift. It was his recognition of the developing situation which prompted him to leave a note to the effect that more man power would be desirable. However, his use of a loose note rather than an entry in the handover diary may have had the effect of making the request appear less urgent to the day shift supervisor.

In the Line Maintenance organisation, the shift supervisors were aware that their pool of available man power was restricted although it was theoretically possible for it to be supplemented from Base Maintenance personnel if their workload permitted. With the small numbers involved, any absenteeism, whether through sickness, attendance on courses or for any other reason, led immediately to understaffing of shifts, engineers working extra shifts or a combination of the two. Whilst running a shift short-handed might not be significant when the workload was light, when there was a heavy workload it would be deleterious. Each individual would be under pressure in order to complete the tasks within the shift and those working extra shifts would be prone to fatigue. It was commonplace for the night Line Maintenance shift to operate with less than the nominal six man complement of engineers.

On the night of the incident, the Line Engineer had started the Borescope Inspections with the intention of completing it himself. However, having had his earlier request for more manpower not actioned, he was almost certainly all the more receptive to the idea of handing the job over to Base Maintenance when the offer was made. His awareness of the criticality of the Line Maintenance manning level that night was demonstrated by the fact that he started the job with the intention of 'borrowing' the assistant he was going to need from Base Maintenance rather than increase the load on his own available manpower. There was no evidence to suggest that he had any knowledge of the manning status in Base Maintenance nor would it be expected that he should.

b)Base Maintenance

The Base Maintenance Controller should have been fully aware of his own manning difficulties, especially in the supervisory area; he had been required back from leave himself the previous night because his foreman was going into hospital. On the Wednesday night he knew that four of his five supervisors were absent as a result of sickness and leave. It would appear, however, that his concern about the impending lapse of his 750 hours borescope authorisation, coupled with the rarity of opportunities in Base Engineering to do the required inspections to keep it current, attracted him to undertake the inspections. His knowledge of the shortage of Line Maintenance staff related to their projected workload that night created his opportunity.

His self imposed need to retain his authorisation predominated when there should have been no doubt in his mind that, with the manning situation which prevailed, he would be fully occupied in managing the Base Maintenance area activity during that night's shift.

c) Line and Base Maintenance

There was not, at the time of this incident any system within the Company to flag up any anticipated mismatches between available and desirable manning levels at particular points in time. It was left to individual managers to judge whether or not their expected manpower needed supplementing and to request additional staff. It is clear, however, that any requests for additional manpower would require anticipation of such a need at least one day ahead. Furthermore, for a supervisor to make such a request would require him to acknowledge that he was not able to cope with a situation without assistance; something which he might be reluctant to do.

If the airline had had an effective system in place to monitor functionally related available manpower against planned workload, a shortfall of Line Maintenance engineers and Base Maintenance supervision would have been predicted. Such a system has become significantly more necessary in this era of minimum manning levels.

The remit of the CAA, under the requirements of JAR-145, to ensure that the airline had sufficient man-hours available to perform the required work was ineffective in these circumstances.
The regulations only task them with looking at available man-hours,unrelated to discipline, skill or authorisations at the time when the JAR-145 approval is initially granted. Subsequent to the granting of JAR-145 approval, the required frequency and depth of the sampling of manpower information does not enable them to take account of transient absenteeism. The absence of any requirement for the Company to maintain and supply, to the CAA, a record of maintenance staff attendance related to workload, precludes any retrospective audit of the situation. The Base Maintenance supervision situation which arose on this particular occasion was relatively short term and would only have been visible to the CAA if it had conducted a specific spot check on discipline related manning levels at that time.

This indicates that the sampling, by the Authority, of man-hours available within the Company, as is currently required by the regulations of JAR-145, is an ineffective procedure and should be reviewed. If aircraft maintenance companies were required to implement manpower monitoring systems it would be realistic for these to be monitored by the Authorities.

Whilst it must be accepted that it is the Operator's responsibility for ensuring that there is adequate and suitable manpower available for the necessary tasks to be undertaken, the Regulator must have available mechanisms for detecting shortcomings, in this area as much as in any other, before these shortcomings constitute a hazard to flight safety.
It is, therefore, recommended that:-

The Airline's Maintenance Organisation should introduce an effective system to monitor functionally related available manpower versus anticipated workload.(Safety Recommendation 96-29)

The CAA in conjunction with the JAA should review the requirements of JAR 145, relating to the monitoring of available manpower of maintenance organisations, to enable Authorities to retrospectively sample the availability of correctly qualified staff for the conduct of aircraft maintenance performed. (Safety Recommendation 96-30)

2.3.3. Handover of the task from Line to Base Maintenance.

Originally, the Line Engineer had gone to the Base Maintenance hangar with the intention of collecting the necessary equipment and an assistant and then returning to continue the task he had started. Therefore, it is not surprising that he had not at that point, made a written statement or annotation on a work stage sheet to show where he had got to in the task. It could be argued from a purist point of view that he should have done so for his own benefit because he had interrupted the flow of the work. However, there was no appropriate place in the Line Maintenance work pack to record the stage he had then reached and so a separate note would have had to have been written. During the investigation, it was clear that there was an expectation that some sort of handover statement should have been generated but, although the Procedures Manual hinted at it, that Manual defined no specific procedure to cover the transfer of a part completed job from Line to Base Engineering. It was, in effect, a standard practice for which no standard was written.

Conscious of the total amount of work which Line Maintenance had to do that night the Line Engineer readily accepted the offer and in the absence of any stage paperwork only gave a verbal handover to the Base Maintenance Controller. Thus he could dispose of the Borescope Inspections and get on with the other Line Engineering work he had with minimum delay. He felt that such a brief was adequate as the Base Maintenance Controller was a senior and well respected member of the staff, with the reputation of being highly competent, conscientious and possessing a considerable depth of knowledge of the aircraft types operated by the Company. It was clear from their statements that both the Line Engineer and the Base Maintenance Controller were satisfied, after their verbal exchange, that the existing state of the aircraft and the total requirement of the task were well understood by both.

It is clear, however, from a number of facts revealed during the investigation that the Controller did not fully appreciate what had been, or remained to be, done. He was unaware of the loosened plug, he did not renew the HP rotor drive cover O-rings and he did not complete idle power engine ground runs.

2.3.4. The conduct of the inspections

The Line Engineer had stated in his verbal brief to the Controller that the aircraft was 'dead'; a ' dead' aeroplane, in this context, being one with no live electrical or hydraulic systems. Working on an aircraft in this condition was a practice which was accepted in Line Maintenance, although not formally approved. The rationale seems to have been, that if it was anticipated that a task would be completed before anyone else was expected to work on that aircraft and use electrical or hydraulic power, the systems which the procedures require to be disabled to ensure working safety, were not disabled. Thus some time can be saved at the start and finish of the task. It was a way of working developed on Line Maintenance, to save minutes in tight operational circumstances. To operate the concept safely would require total awareness if anyone else were to approach the aircraft to apply power.

In this case the Line Engineer, anticipating that no other tasks would be started on the aircraft until he had finished the Borescope Inspections, elected not to disable the wing flap and engine thrust reverser systems. Although the amount of time that he might have saved by doing this was probably no more than about 15 minutes, clearly he thought that this might be significant in terms of what he perceived to be his night's workload. After he had passed the inspections over to the Controller, it was the latter's decision as to whether he continued to use the potential time saving characteristic of the 'dead' aeroplane or adopted the AMM procedure.

After doing other work on the line, the Line Engineer later returned to the aircraft as part of the team wanting to perform the Daily Inspection before the borescope task had been completed. Being alert to the concept that the aircraft status could need to change with circumstances, he recognised that a point had been reached when the 'dead aeroplane' had to be abandoned and the systems had to be disabled. It was this awareness which prompted him to disable the hydraulic and ignition systems part-way through the Borescope Inspections procedure for the Controller and assistant's safety. The Controller had not really wanted the systems disabled, not intending to work on the aircraft with power applied.

Working on a 'dead' aeroplane, as practised by Line Engineering, is largely alien to Base Engineering thinking. Aircraft in Base Maintenance are usually programmed for a considerable number of tasks to be executed simultaneously with groups and individual workers operating independently. Consequently it would be unthinkable not to carry out a safety procedure to totally deactivate the electrical and hydraulic systems in a rigorous and regimented fashion at the start of a block of work to ensure that no group was put at risk by another's activities. Although it might become necessary to reactivate electrical or hydraulic power during the progress of the work, the selective activation of only the necessary parts of these systems, together with the monitoring of groups whose activities might conflict, were standard practices to ensure safety.

During the time Line Maintenance were conducting the Daily Inspection and needed power on the aircraft, the Controller wrote up the inspections and had his lunch break. This self imposed break interrupted the flow of the task. As an immediate consequence, he appears to have not fully appreciated that the Line Engineer had deactivated the systems relevant to the engines. As he had not done this for himself and neither was he following a detailed procedure, when the time for restoration of systems was reached, he forgot to close the circuit breakers. He appeared to have been relying on his memory to complete the inspection task, which he had not done for some time, aided only by the Line Engineering job card, with its broad headings, on which to annotate his progress. This job description was too broad to refer to a break at a random point in the procedure and made no mention of the details of the preparatory and restorative sections of the task. As a result, the reinstatement of the systems was omitted along with the engine test runs and the reinstallation of the HP rotor drive covers with new seals.

There were several other facets of the execution of the task which indicated the relative unfamiliarity of the Controller with the task.

The Line Engineer, being familiar with the inspection, correctly and habitually removed and used an inspection access plug at about the 3 o'clock position on the turbine case. The Controller did not, even though it was one which the procedure on the Task Card indicated should have been used. Because he did not think he had to use it, the Controller had not noticed that it had been unlocked and loosened until he was finishing his post task inspection, when he invited the Line Engineer to go over his preparation of that engine. The opportunity to make this check was not planned at the time of the initial handover and hung on the chance that the two engineers met at the appropriate time and place.
The consequence of this plug falling out at some later time would have been to release a concentrated stream of hot gas into the space enclosed by the core fairing. It is not certain that a written handover note would have avoided this omission as it could well have noted 'necessary borescope plugs - wire locking removed- plugs loosened' or something along those lines.

The fitter operated throughout on the instruction of the Controller and ultimately it was the Controller who would certificate the inspections. However, it was the fitter who removed the HP rotor drive cover from the No 2 engine, a task requiring the use of three of the five attachment bolts to 'jack' the cover from its mounting pad. It was also the fitter who operated the tool through the aperture exposed by the removed HP rotor drive cover on each engine to turn the HP rotor. Having removed one cover and spent some time using the exposed drives it is surprising that when instructed to, "plug the engine up" or something similar he should completely forget the covers. Like the Controller he was not using any detailed procedure and appears to have operated on the basis that provided he did as asked, by the Controller, all would be well; even if he got something wrong the Controller would put him right. He operated as though he had relinquished all responsibility for his actions to the more experienced and senior Controller.

When the Line Engineer was asked to move the aircraft out of the hangar, it would have been clear to him that the engines could not have been run whilst the aircraft was still in the hangar. Thus an opportunity appears to have occurred, at this juncture, for him to remind the Controller that the engine idle ground runs still needed to be done. However, since he had passed the responsibility for the Borescope Inspections over to the Controller, the Line Engineer could reasonably consider that he no longer needed to monitor the requirements of the inspections.

It is worth considering whether routine work which can effect the airworthiness of the engine should be conducted on all the powerplant installations of an aircraft during one maintenance visit. It is true that a post inspection idle ground run of the engines would have detected that the HP rotor drive covers had not been refitted, but not all types of discrepancy would necessarily show up on such an engine run. The loose borescope plug is an example. It was only fortuitous that it was discovered in this case and if such an omission were to occur on both engines the airworthiness of both powerplants would be compromised.

Having observed the benefits experienced by operators who had used conservative maintenance policies, in line with ETOPS practices, Boeing issued a Service Letter, some five months after this incident. This encouraged Operators to avoid maintaining similar or dual systems by the same personnel on a single maintenance visit. British Midland do not, and never have, operated ETOPS aircraft; however,with the experience of this incident they have instituted procedures in line with the recommendations of the Boeing Service Letter.

It is therefore recommended that:-

The CAA, with the JAA, consider issuing advice to aircraft maintenance organisations that, where practical, work which can effect the airworthiness of an engine should not be conducted on all of the powerplant installations of an aircraft at one point in time by the same personnel. (Safety Recommendation 9631)

2.3.5. The familiarity of the Controller with the task and his adherence to procedures.
The Controller had only had one opportunity to do this Borescope Inspection in the preceding year, although he had done many in the more remote past. As he had no recent familiarity with the task it would have been reasonable to expect that he would, for his own confidence, have referred to the published procedures at every major stage.

The 750 hour Borescope Inspection of the turbines was specified as a Line Maintenance job and, as such, the maintenance planning department had created a package of working papers specifically for use by the Line Maintenance personnel who were familiar with the inspection. (see §1.17.2) The Base Maintenance Controller was aware that he was not familiar with the supplied workpack, noting in particular both the absence of the MAVIS cards for each of the tasks to be performed, with their inbuilt stage records and Certificates of Release to Service (CRS), and the Boeing Task Cards. He, nevertheless, judged the line paperwork to be sufficient and did not seek to support his recollection of the job by obtaining a copy of the Task Card, in which the work sequence was laid out in considerable detail and which was readily available to him.

He preferred instead to use his own set of Borescope Inspection training notes, which he knew to be an unapproved reference. He knew that the information in the notes was not updated, that they were not intended to be other than a training aid and that they carried a specific warning that they should be used for that purpose only. His reason for using these notes was that he had written some information into them which assisted him in determining the size of any defect he might find.

Despite the fact that the training manual was an inappropriate document to use as a procedure, it did contain AMM references. These, although not updated, contained the information which should, had he used it, have prevented his failure to ensure fitment of the HP rotor drive covers, complete with new seals, and have prompted him to perform post-inspection engine runs. These omissions almost certainly stemmed from both his unfamiliarity with the task through lack of recent experience and a misplaced confidence in his recollection of the task.

In using only a reference source which he knew to be unapproved, for a task with which he was not currently familiar, the Controller made it almost inevitable that he would deviate from the correct practices. In failing to use even that document to the limit of its potential for informing him, he made a number of serious omissions from the correct procedures, including failing to fit the HP rotor drive covers and not performing the engine run which would have revealed that omission.

It is therefore recommended that:-

The Airline's Maintenance Organisation should devise a common standard of task documentation for Base and Line maintenance activity. (Safety Recommendation 96-32)

The CAA, in conjunction with the JAA, review JAR-145 with a view to requiring a common standard of task documentation for Base and Line maintenance activity. (Safety Recommendation 96-33)

Following the investigation of an incident involving an Airbus A320, of a different operator, which took-off with four of the five spoilers on the righthand wing in the maintenance mode, the following recommendation (9441) was made:-

"The Civil Aviation Authority should formally remind engineers of their responsibility to ensure that all work is carried out using the correct tooling and procedures, and that they are not at liberty to deviate from the Maintenance Manual but must use all available channels to consult with a design authority where problems arise; if full compliance cannot be achieved the engineer is not empowered to certify the work."

The CAA response published in FACTOR 2/95 was :-

The Authority partially accepts this Recommendation. Joint Aviation Authority Regulation 145 Approved Maintenance Organisation Part 145.40 para a. states "The JAR-145 approved maintenance organisation must have the necessary equipment, tools and material to perform the approved scope of work".

Advisory Circular Joint (ACJ) 145.40 (a) para 1 states: "where the manufacturer specifies a particular tool or equipment, then that tool or equipment should be used unless otherwise agreed in a particular case by the quality department".

The use of type specific tools is recommended by the manufacturer in the relevant maintenance and overhaul manuals. Not all tools are essential, but in general the Authority does expect the necessary tooling to be used.

Deviation from the use of tools has to be agreed by the Quality Department of the JAR-145 organisation, not the Design Authority, who may however be consulted.

CAA Airworthiness Notice No 3 adequately addresses the responsibilities of Certifying Personnel. This document is issued to all CAA Licensed Aircraft Maintenance Engineers and CAA Approved Organisations. It is also readily available to all maintenance personnel in approved organisations. A further reminder will be issued to all AOC holders and JAR-145 approved organisations.

In the light of this further incident it is recommended that:-

The CAA review its response to recommendation 9441, in particular with respect to formally reminding engineers of their responsibility to ensure that all work is carried out using the correct procedures, and that they are not at liberty to deviate from the Maintenance Manual; if full compliance is not achieved the engineer is not empowered to certify the work. (Safety Recommendation 96-28)

2.3.6. The propriety of the Controller himself performing the inspections.

A highly significant feature of the way in which the Borescope Inspections were done was the fragmentation of the flow of the process. As was discussed earlier, this inspection was clearly of the type which would benefit from being done in isolation and without interruptions.

The Base Maintenance Controller held a Company Authorisation to do engine Borescope Inspections but his awareness that it was liable to lapse by disuse had made him uncomfortable as, amongst other considerations, he believed it would diminish his usefulness to the Company. Although such authorisations should not have been necessary for a person in his position within the Company, it is virtually an industry-wide practice for workshop line managers to retain, and keep current, any authorisations they had acquired and maintained before becoming managers. This may be because it is perceived as a way of demonstrating their continued competence to their staff, as an insurance against the unexpected, or for simple personal satisfaction. In order to get the experience to retain his authorisation, the Controller had seized and, to a degree, manufactured an opportunity to perform these inspections.

His self imposed urgency to retain his Company Borescope Inspection authorisation almost certainly led him to underestimate the likely demands of his primary duty, that of controlling Base Maintenance activity. Although he had attempted to anticipate the difficulties which might arise in the Base Maintenance work during that night, he had, in the event, to contend with a series of diversions and interruptions. These interruptions, he should have known, were an essential and predictable part of his normal work and would require him to consider matters which had nothing to do with the inspections, on which he needed to concentrate to the exclusion of all else, if he was to do it. In the event, not only did the flow of the task get interrupted by the Daily Inspection, but also by a string of issues associated with the remainder of the Base Maintenance activity. This was particularly the case because of the depleted Base Maintenance Inspection and supervisory staff that night.

The Controller, therefore, showed, what he afterwards recognised as, bad judgement in taking on the inspections in addition to his normal work. By doing so, he placed himself at a location physically remote from where he was needed, to do his normal work, and thereby compounded the difficulty of doing it in parallel with the inspections.

Managerial responsibility, in any line of work, inevitably has the potential to interrupt the natural flow of a particular 'hands-on' task which is being done by the manager. The more frequent or demanding the interruptions are, the more likely it is that the thread of this personally undertaken task will be lost or its full content forgotten. As such, any maintenance manager should recognise the need to avoid the responsibility for performing specific tasks, particularly if they are as safety critical as most aircraft maintenance.

It is therefore recommended that:-

The Airline's Maintenance Organisation should review its instructions to maintenance supervisory staff with a view to redefining their responsibilities and avoiding them undertaking tasks which are inconsistent with their managerial role. (Safety Recommendation 9634)

The CAA, when conducting reviews of maintenance organisations for JAR-145 approval should monitor the work definition for maintenance supervisory staff and ensure that it avoids them undertaking tasks which are inconsistent with their managerial role. (Safety Recommendation 9635)

2.4. Differences between Line and Base maintenance engineering

A consideration which may have been significant in this event is the fundamental difference between Line and Base Engineering in both outlook and way of working. It became clear, whilst interviewing the personnel involved in this incident, that the particular features which attracted them to one or other of the two sorts of maintenance were different.

The aspect which appeared to have attracted the Line Engineer to that discipline was the 'fire fighting' nature of the work, the relative lack of predictability of the more demanding unscheduled tasks. The need to work to short and tight deadlines was part of the challenge of keeping aircraft in service and on schedule by correcting faults quickly. By contrast, the aspect of Base Maintenance which attracted the Controller was the requirement to do more fundamental work, going much deeper into the structure and systems of aircraft.

One of the most frequent causes of deviation from correct maintenance practices and an acceptance of reduced standards, is the presence of a deadline. This may be exacerbated when combined with the perception that it will be difficult to meet. In the sense that these Borescope Inspections were jobs in a large workload for the Line Engineer automatically gave it a tight deadline and the way he started doing it was consistent with doing it in the shortest time. However, such deadlines being inherent in the Line Maintenance environment, the Line Engineer would be used to the pressures created and his relative lack of a need to supervise and control those under him would have allowed him to concentrate on the inspections.

For the Base Maintenance Controller, the Borescope Inspections had to be finished before he could move the aircraft out of the way and collect the propeller he required for another aircraft which was needed early the following morning. During the course of the night, the Controller experienced a number of delays and distractions, amongst which was the length of time that the propeller was taking to be built up. The interruptions which he suffered must, inevitably had an effect on his concentration on the Borescope Inspections and compounded the effects of his lack of recent familiarity with the job.

In his position as Night Base Maintenance Controller, his main role was the supervision of the work of others and as such he was unused to working, effectively alone.

2.5. The Airline history of Borescope Inspections

The Airline conducted an internal inquiry to establish the general practice of its engineers when conducting Borescope Inspections. This revealed a significant mismatch between the number of inspections conducted and the number of HP rotor drive cover O-rings used, indicating that contrary to the specific requirements and warnings in the AMM, O-rings were routinely being reused. In addition,a survey of engineers authorised for Borescope Inspections revealed that post inspection engine runs were frequently omitted. This is not only contrary to the direct requirements of the AMM but is also contrary to good engineering practice. The inquiries made in this investigation indicated that the non-procedural approach adopted by engineers engaged on the Borescope Inspections which led to the incident under investigation was far from unique.

If individuals or groups of individuals come to regard a non-procedural approach appropriate for one safety critical maintenance task, it is reasonable to suspect that they probably regarded a non-procedural approach appropriate for other safety critical maintenance tasks.

2.6. Quality Assurance (QA)

The Airline's Maintenance Organisation operated a QA Department charged with ensuring that the high standards required in aircraft maintenance in order to achieve acceptable levels of flight safety were maintained. The philosophy of QA places on the maintenance engineer doing a task, the responsibility for engineering quality into the task and ensuring that it is correctly completed. Many tasks involve a progressive masking of earlier stages as they progress, rendering impossible a final visual or physical check that it has all been done correctly. Consequently, the engineer conducting the task is often solely responsible for doing the work, 'inspecting' it and certificating that it has been correctly completed. This is not only consistent with the argument that quality can only be engineered into the task, not inspected into it, but also is more efficient by avoiding the delays associated with separate inspection or Quality Control. If duplicate inspections are required, of course, those delays must be borne anyway.

In such a system, the quality of work is more heavily dependent on the skill, good judgement and integrity of the engineers, than in the past. The key to operating such a scheme of QA lies, first,in the identification of the supervisors, engineers and technicians within the workforce who possess the necessary levels of these attributes. It is these people who, having been identified and authorised by the Company as fit people to issue certificates to say that work has been properly done, are, for most of the time, the sole guardians of standards of workmanship. The supervisors also have the duty of being the guardians who ensure that their engineers and technicians adhere to correct working practices as laid down in the AMMs.

Part of the requirements for recommendation of JAR-145 Approval was that the organisation demonstrated that it had a QA system, satisfactory to the Airworthiness Authority, capable of ensuring that all aircraft work was traceable and signed as having been correctly performed and completed. Thus, one of the principal functions of a QA department was a clerical one, being able to demonstrate that all the right documents were available and the aircraft was legally airworthy. It was normally only when there were anomalies in the paperwork that they had received, that the QA engineers were alerted to challenge the manner in which the work had been done and they might then go to the maintenance hangar to resolve the certification anomalies.

Some of the QA engineers did not understand their terms of reference to include a remit to roam the hangars to observe work in progress as a matter of course, nor were they prompted to do so. They did not, therefore, create opportunities to observe any deterioration in adherence to standards or proper practice and put corrective action in hand. Neither did they believe that they were responsible for reviewing task description cards to ensure that the procedures themselves were sound and correctly described. In this sense,their expertise as engineers was not used to monitor the quality of the work being done. Both of these tasks were, however, implicit in the description of the QA function as described in the Company Procedures Manual.

Ensuring that the method of working of a QA department is effective must be regarded as pivotal in ensuring that working standards of an aircraft maintenance organisation are maintained. In its remit to monitor the workings of a maintenance organisation to ensure its continued compliance with JAR145, it would be expected, therefore, that the CAA would take particular care that this facet of the whole organisation was sound above all others. Whilst the Procedures Manual description of the workings of a QA department might appear satisfactory, it is incumbent upon the Authority to ensure that a mechanism exists to detect, fairly readily, any variation between theory and practice whilst fulfilling its monitoring function. This would appear to be particularly important in instances where the Authority has been uneasy about the compliance of the operator's existing practices.
Although QA engineers were not habitually on the floor in the maintenance areas, the approach to QA adopted by the operator appears to have worked well when a reasonable number of engineers, particularly supervisors, were on duty, as was the case during the normal working day. In this situation there were plenty of people to assist, remind and with whom to exchange views. Furthermore, with the presence of other people with the same discipline, working nearby, peer pressure tends to constrain operatives to work in the known approved way. There were also all the support departments, including QA and Planning, fully manned, and all technical services available for consultation.
By contrast, night shifts tended to be relatively sparsely manned and it was more likely that people would be working in a more isolated manner. Furthermore, not only was there seldom any QA or Planning available at night, but the presence of any form of senior management was rare; this situation gives rise to the potential for a more relaxed and less procedural environment to develop unnoticed, except by results. In these circumstances, greater self discipline is needed amongst the engineers, and supervisory staff need to be more vigilant to deviations from correct practices. It is under these circumstances that the fragility of the self monitoring system is most exposed because the safety system can be jeopardised by poor judgement on the part of one person and it is also the time at which people are most likely to suffer impaired judgement. (see §2.8)

The airline's survey of Borescope Inspection history makes it clear that the QA department had not identified the frequent deviations from a procedural approach and failures to observe the requirements of the AMM over a considerable period of time. Equally, the monitoring conducted by the CAA had also failed to detect the same procedural lapses and deviations.

It is therefore recommended that:-

The Airline's Maintenance Organisation should redefine the role of the QA department with a view to achieving, for both day and night shifts, effective monitoring of working practices, ensuring adherence to promulgated procedures and monitoring of the quality of the engineering product. (Safety Recommendation 96-36)

The CAA, when conducting reviews of maintenance organisations for JAR-145 approval should monitor the function of the QA department to ensure that, for both day and night shifts, they are achieving effective monitoring of working practices, ensuring adherence to promulgated procedures and monitoring the quality of the engineering product. (Safety Recommendation 96-37)

2.7. T2 Hangar Facility

This hangar represented a very welcome working environment for the Line Engineer who was used to working outside much of the time. However, for the Base Engineering staff it was poorly equipped when compared with their usual working environment, particularly with respect to the lighting.

There are no regulations which lay down required standards for lighting levels. However, according to the guidelines recently published by the FAA, the Base Maintenance hangar lighting was of a level regarded as "adequate for many normal maintenance tasks", whereas T2 lighting was graded as "should only be used for infrequently used areas". Hangar T2 was only infrequently used for maintenance but the absence of any sockets compatible with their lead lights reduced the two Base Engineers to operating by torch light. This was particularly the case under the engine cowls in the area of the AGB where it was quite dark.

2.8. Physiological and psychological influences on performance

When reviewing the general performance of the Controller in the light of the findings of the SAM review of the literature related to shift working, a number of factors which were considered likely to affect the performance of individuals on night shift working can be seen to be relevant.

It would appear that, the time of night when the Controller made the offer to take on the inspections his judgement was unlikely to have been significantly impaired by disturbance of his circadian rhythm. It was in the relatively early part of the evening and, therefore, at a time when he could be expected to be alert, if not at his absolute sharpest. It would seem, therefore, that his decision to take on the inspections was one he would have made almost regardless of the time of day he made it and the possible reasons for that decision have already been discussed (see §2.3.6).

The Controller had just returned to night working the previous evening, following a weeks holiday during which he had been living as a normal, daytime orientated, individual. Although he was a permanent night shift worker, he would, over the period of his holiday, have reverted completely to being a day orientated person. It would be unlikely that he had re-adapted much to a night time orientation, from consideration of the number of nights he had been on shift. The bulk of the work of performing the inspections was done over the period during which his ability to sustain concentration and reasoning ability was likely to be diminishing; it culminated in his need to ensure the completion of the task, by final inspection of the restoration of the aircraft, around the time that his capabilities were likely to be at their lowest.

During this period he would also have been diverting his attention onto those other matters which had been competing for his attention as Controller, whilst he had been attempting to concentrate on the Borescope Inspections as an inspector.

Another factor which might have had some influence on his adaptation was his age, although up to the time of this incident he had not perceived any difficulties in coping with night working. The lighting level in the T2 hangar may also have had some influence, but it must be borne in mind that the review of factors affecting shift workers was cautious about the effects of bright lights improving adaptation to night working.

Night working was a feature common to this incident, the accident to BAC 1-11 GBJRT and the incident to Airbus A320 G-KMAM. The inference of these three serious night maintenance related incidents, combined with the research indications that judgement is generally likely to be impaired at night, is that the style of QA which places complete responsibility for maintaining standards on the individual, which was in force in all three cases, is particularly vulnerable for night working. The human factors research indicates that the QA and support infrastructure required for night work is proportionately greater than for day working, to guarantee the same standards of working integrity. This is contrary to what happens, support for the night shift is generally minimal compared with the day shift. This is of particular significance as, especially with short haul operations, the maintenance activity is concentrated at night.

2.9. Previous occurrences of the HP rotor drive cover not being refitted.

Although no UK operators had been involved previously, this incident was not the first time that HP rotor drive covers had been left off following a Borescope Inspection. Originally, after removal the cover was free to be put down anywhere and, with this standard of cover, refitting had been overlooked on five separate occasions. The engine manufacturer then introduced a 'recommended' modification, by Service Bulletin, to attach the cover by a wire lanyard. This meant that when the cover was removed it would hang down the outer face of the AGB.

The covers on G-OBMM had been so modified but were still not refitted and on three other occasions since this modification was introduced, single covers have been left off. Although the cover hangs down the outside face of the AGB it is a grey painted object against the grey painted, multi-faceted AGB and as such can be inconspicuous. Enhancing the conspicuity of the cover and the presence of the uncovered hole when the cover is detached, would be advantageous.

It is therefore recommended that:-

CFMI should review the HP rotor drive cover and lanyard modification with a view to making more conspicuous, the fact that the cover is detached from the Accessory Gearbox. (Safety Recommendation 96-38)

2.10. Maintenance Manuals and Task Cards

In the conduct of the two borescope inspections, neither the Controller, the fitter nor the originally tasked Line Engineer considered it necessary to draw any additional information, in the form of AMM extracts or Task Cards, to assist them in the conduct of the work. The only reference that the Controller made to the AMM was to ensure that the damage which he had observed during the inspections was within limits and the fitter limited himself to checking the correct torque for the borescope inspection plugs on the engine.

It would, at first sight therefore, seem that these documents played no part in the cause of this incident because they were not used as an aid to adhering to the correct procedure. However, it is worth examining some of the factors which may have disinclined the personnel involved from obtaining or using these documents to boost their knowledge of how the task should have been done, rather than use them only for minimal reference. It is also of value to consider how the minimal documentation used might be modified in this, and similar instances, to reduce the likelihood of similar omissions being perpetrated.

2.10.1. Engineers reasons for not drawing the supportive documents.

The fact that the Line Engineer was relatively familiar with the particular work, having done this inspection several times in the recent past, makes it less surprising that he did not try to obtain additional information. The Procedures Manual, in its description of what constituted a correct workpack for this inspection (designated a Line Engineering task) omitted mention of the Boeing Task Card as being part of that pack although it was clearly stated that the Line Engineer should be able to refer to this Task Card if he felt it was required.

It is difficult, however, to see how Line Engineers could be expected to be certain to remain procedural without this document. Although the Borescope Inspections had to be done relatively frequently over the whole fleet, they were done at the operator's several line outstations and by sub-contractors as well as at East Midlands. This meant that any one authorised individual would not do this inspection with great frequency and it would have been better, therefore, for there to have been no option but to have the Boeing Task Card as part of his work pack, along with copies of the included AMM references.

It is clearly stated, in JAR 145.65, that the maintenance organisation must establish procedures ' acceptable to the Authority' (CAA in UK) to ensure good maintenance practices and compliance with all requirements. The CAA had an opportunity to notice the omission of Task Cards from the Borescope Inspection work pack whilst reviewing the Company Procedures Manual before recommending the Company for JAR-145 approval.

The results of the operator's post-incident survey of 750 hour Borescope Inspections indicated that deviations from correct practice were not unusual in Line Engineering, particularly in respect of those procedures required by the AMM references within the Task Card. It was in not following these procedures that the performance of the Controller and fitter had its most serious shortcomings.

Having not done a 750 hour Borescope Inspection for about a year, it is surprising that the Controller did not feel it necessary to use the Task Card to remind himself of the complete procedure. A possible reason for him not having done this, before first going to the remote T2 hangar, may have been that he had expected the Task Cards and AMM extracts to be part of the normal workpack, in line with normal Base Maintenance practice. The Line Engineer would, understandably, not have pointed out these deficiencies because he was unused to having this supportive documentation as a matter of course.

Once the Controller and fitter had got to T2 and found that this supportive material was not available in the workpack, they would have had to return to Base Engineering or to have gone over to the Line Maintenance office to get it. It would be, in some measure, understandable for them to have a reluctance to recross the exposed apron area on a winter's night to obtain a description of what they were fairly confident they knew anyway.

However, during the course of the night, both of them had occasion to return to the Base Maintenance hangar a number of times before the task had been completed. Either could, therefore, have referred to or even drawn the task descriptive papers before the job was signed off. The question that should be addressed, therefore, is whether there might be any factors other than overconfidence in their memories, bad judgement or idleness which would dispose them to pass up these opportunities to refresh their memories on the proper and complete procedures

2.10.2. Clarity of the Maintenance Documentation.

Aircraft Maintenance Manuals and the associated Task Cards, or similar maintenance activity support documents generated by either the manufacturers or internally by the maintenance organisations (eg MAVIS), are primarily reference documents. Their content is continually amended and supplemented as the aircraft type, to which they refer, is developed during the timespan that it is in service. Paragraphs are added and sometimes highlighted (usually in capitalised script) as particular hazards which have been identified through experience, become prominent.

Also, as a result of changes in the social and working climates they have been augmented by non-task-specific health and safety warnings (also usually in capitalised script). The addition of these general caveats appears to have been largely driven by a perception, on the part of the producers of the manuals, that not to include them would expose them to accusations of non-fulfilment of a duty of care.

As a result of this continual amendment process, the thread of the task descriptive text in the manuals has been, in some measure, obscured. This effect is clear in the manuals produced by all manufacturers, not any one in particular. The result of this is that the recognition and abstraction of text directly relevant to and descriptive of the maintenance task becomes more time consuming. As a result, there is an increased likelihood that isolated pieces of important information, which are surrounded by highlighted warnings and other general information, will be missed.

There arises, therefore, a conflict between the requirement to maintain clarity in order to ease access to the information an operative needs to do the maintenance, and the need to warn of risks, both to the person and airworthiness, whilst doing the work. It seems reasonable to include warnings of hazards which arise specifically due to the performance of the particular task (ie pointing out the dangers of working close to a live thrust reverser) and where the work may affect airworthiness (ie the dangers inherent in not replacing the HP drive covers correctly). However, the repetitive inclusion of warnings relating to general working practices and hazards (ie risks involved when working with acetone) should be avoided to achieve clarity.

It must be accepted that many manuals are as they are, because they originated using old printing methods where revision is an onerous task. Those of more modern aircraft, however, do not appear to have benefited from the newer techniques available and have a very similar appearance. Although engineers who use them habitually are used to them and accept their format, they could be made much clearer by exclusion of the non-task-related information and the use of more 'attention getting' formatting.

2.10.3. Possible remedies.

The revision of any public transport aircraft's Maintenance Manual would be an extremely arduous and time consuming task. However, Task Cards and other job specific maintenance documents are more easily addressed.

A major factor in the non-execution of vital actions, in this case, was that, on the documents used for the quality audit, the job cards, there was no requirement to certify the elements of the restoration of the aircraft to its normal state. These elements all had warnings of potential airworthiness hazards associated with using incorrect procedures, but these warnings were all to be found in other documents, referenced from the Boeing Task Card. Even though the Task Card gave AMM numeric references, there was no indication that any of them included highlighted airworthiness safety warnings. Specifically, the Task Card does not mention either the dangers inherent in the re-use of O-rings or the need to do a post-inspection idle engine run to check for leaks. The absence of mention of these airworthiness hazards in the minimum task paperwork, denied the Controller the prompt which might have redeemed the situation.

Arising from this investigation, the Company's own investigation into how procedural their engineers had been in doing these Borescope Inspections indicated that such a prompt could have been significantly helpful for some time.

Whilst this investigation has focused on the documents relevant to the execution of this particular 750 hour Borescope Inspection, it is probable that there are other tasks which require elements of preparation for access, the restoration of which have airworthiness implications and for which no prompt or requirement for specific certification appear on the task specific paperwork.

It is, therefore, recommended that:-

The CAA in conjunction with the JAA review JAR-145 to require, where aircraft maintenance or inspection tasks require elements of preparation for access, and incorrect restoration of these preparatory actions might result in airworthiness hazards, these restorative actions are individually defined to be signed for as completed on the document which constitutes the Quality Assurance audit for airworthiness. (Safety Recommendation 96-39)

The CAA in conjunction with the JAA review appropriate JARs to require improvements in the clarity of presentation of maintenance instructions, in particular by the removal of non-task-specific information from the work descriptive text, by necessary revisions of existing documents. (Safety Recommendation 96-40)

The CAA should ensure that, when job specific Task Cards are produced by either a maintenance organisation or a manufacturer, any action which is required to be performed which has a particular airworthiness risk associated with it, should be described fully together with the potential risk and not just referred to in another document. (Safety Recommendation 96-41)

2.11. Parallels with subjects of previous reports

There are several features of this incident in which clear parallel scan be observed with the occurrences to both G-BJRT (AAR 1/92) and G-KMAM (AAR 2/95). In all three cases, there was a clear indication that promulgated procedures and requirements had not been observed.

The principal individuals involved were all engineers who had been highly regarded by their employers, who had judged them to be suitable to be entrusted with a supervisory role. They were, in effect, the monitors of adherence to good working practices by all the staff under their direction at the time the maintenance leading up to the incidents was being performed. They all were under the impression that what they were doing was for the benefit of their employer, helping to meet maintenance deadlines to permit on-time operations.

Given that these three incidents have occurred, any one of which could have developed into a serious accident, to CAA approved, industry respected organisations, it casts doubt upon the adequacy of the organisation and infra-structure which has developed to support aircraft maintenance. Although the recommendations stemming from these investigations are mainly specific to the events, their messages are probably of far wider relevance. The foundations of most of the current practices employed in aircraft maintenance were laid when the aircraft, the operating and commercial environments were very different from today. These industry standards covering all aspects of maintenance, including personnel licensing and authorisations, maintenance manuals and support documents, Quality Control versus Quality Assurance, equipment and facilities have all developed over time, but in these three events have been demonstrated to be fallible.

The significance of incidents as rehearsals for catastrophic accidents is sometimes recognised all too late; these three incidents have identified a wide range of common features conspiring to undermine the pursuit of quality in aircraft maintenance. Of particular significance, in all three of these cases, was the fact that the events occurred during night working. As has been discussed earlier in this report, studies have indicated that many people never adapt to night working and the attributes which appear to suffer most are concerned with logical reasoning, judgement and concentration. With this in mind, the level of monitoring and back-up which is required during night working, to achieve the same standards of quality as is acceptable during the daytime, should be proportionately greater than during the day. This is driven by the fact that not only are the maintenance staff operating at decreased vigilance levels, but the monitoring and support staff are similarly affected.

The existence of a satisfactory QA system is required (JAR 145.65) for a Maintenance organisation to be granted JAR-145 approval and their presence during all working is implicit in the requirements. However, the current requirements, as they were applied to this maintenance organisation for its JAR-145 approval, did not require that the QA system operated at night in the same continuous way that it did during the day. This lack of continuous presence of QA personnel, to ensure not only high standards of work but also adherence to procedures, was a major feature which this incident had in common with the other two incidents. The shortcoming was, therefore, in the interpretation and application of the requirement and not in the requirement itself.

It is, therefore, recommended that:-

The CAA review what they have heretofore regarded as acceptable arrangements for Quality

Assurance to meet the requirements of the regulations currently governing the conduct of aircraft maintenance within the UK, with the intent of ensuring that airworthiness is not compromised. This initiative has international significance and the CAA is urged to enlist support from the other JAA Authorities and the FAA in this comprehensive re-appraisal of aircraft maintenance practices. (Safety Recommendation 96-42)

3 Conclusions (a) Findings

1 The crew members were properly licensed, medically fit and adequately rested to operate the flight.

2 The commanders early awareness of a problem was a significant factor in the successful conclusion to the flight.

3 The commander took an early sound decision to head towards a suitable airfield whilst attempting to determine the extent of the emergency.

4 The Quick Reference Handbook did not provide the flight crew with a drill appropriate to their emergency, nor could it be expected to.

5 Good flight crew co-operation lead to a successful compromise approach configuration, balancing the aircraft configuration against the need to minimise power requirements.

6 Throughout the emergency, the flight crew coped exceptionally well with an unusual and potentially catastrophic emergency.

7 ATC provided prompt and effective assistance to the flight crew.

8 On landing at Luton Airport, the aircraft was above the maximum structural landing weight but within the performance limits for the existing conditions.

9 The aircraft was correctly loaded.

10 The aircraft had valid Certificates of Airworthiness and Maintenance.

11 Both engines had been subjected to a routine 750 hour Borescope Inspection during the night before the incident.

12 The Borescope Inspections were not carried out in accordance with the procedures detailed in the manufacturers Task Cards and the Aircraft Maintenance Manual.

Specifically:-

a The two HP rotor drive covers, one on each engine, had not been refitted after the Borescope Inspections.

b A post inspection ground idle engine tests, required by the Aircraft Maintenance Manual, had not been conducted.

c The entry in the aircraft Technical Log, relating to Borescope Inspections, had wrongly been signed as having been completed in accordance with the Aircraft Maintenance Manual.

13 The inspections had been scheduled as a Line Maintenance function, in accordance with the airlines standard practice, as declared in their Company Exposition.

14 It was commonplace for the night Line Maintenance shift to operate with less than the nominal six man complement of engineers.

15 The Base Maintenance Controller was aware that four of his five supervisors were absent as a result of sickness and leave.

16 If the airline had had an effective system in place to monitor functionally related available manpower vs. workload, a shortfall of Line Maintenance engineers and Base Maintenance supervision on the night would have been predicted.

17 The monitoring of man-hours available within the Company, required by the regulations of JAR-145 and conducted by the Civil Aviation Authority, was an ineffective procedure and should be reviewed.

18 Given the absence of four of his supervisors, the Controller should have been in no doubt that he would likely be fully occupied in the Base Maintenance area during that night's shift.

19 In order to retain his Borescope authorisation, the Controller seized and, to a degree, manufactured an opportunity to perform the inspections.

20 Conscious of the anticipated Line Maintenance work that night, together with a depleted shift, the Line Engineer readily accepted the Base Controllers offer to carry out the inspections.

21 Up to the time of the handover, the Line Engineer had intended to complete the tasks himself and he had not made a written statement or annotation on a work stage sheet to show where he had got to in the inspections.

22 In the absence of any stage paperwork the Line Engineer only gave a verbal handover to the Base Maintenance Controller.

23 The Company's Procedures Manual defined no specific procedure to cover the transfer of a part completed job from Line to Base Engineering.

24 Although the Night Base Maintenance Controller accepted the tasks on a verbal handover he did not fully appreciate what had been done and what remained to be done.

25 The Line Engineer, anticipating that no other tasks would be started on the aircraft until he had finished the Borescope Inspections, elected, contrary to the Aircraft Maintenance Manual requirements, not to disable the flap and thrust reverser systems.

26 The Night Base Maintenance Controller was unfamiliar with the limited line paperwork but did not support his recollection of the job by obtaining a copy of the Task Cards, in which the work sequence was laid out in considerable detail and which were readily available to him.

27 The Night Base Maintenance Controller used his own set of Borescope Inspection training notes, which he knew to be an unapproved reference.

28 In using only a reference source which he knew to be unapproved, for a task with which he was not currently familiar, the Night Base Maintenance Controller made it almost inevitable that he would deviate from correct practice.

29 As a result of the inadequate handover and the Night Base Maintenance Controller's lack of reference to either the Task Cards or the AMM, the reinstatement of the systems was omitted along with the refitting of the HP rotor drive covers with new seals and the engine test runs.

30 A highly significant feature of the way in which the Borescope Inspections were done was the fragmentation of the flow of the process. As was discussed earlier, this inspection was clearly of the type which would benefit from being done in isolation and without interruptions.

31 The Night Base Maintenance Controller showed, what he afterwards recognised as, bad judgement in taking on the inspections in addition to his normal work.

32 Any maintenance manager should recognise the need to avoid the responsibility for performing specific tasks, particularly if they are as safety critical as most aircraft maintenance.

33 A Company Inquiry revealed that maintenance staff had regularly completed Borescope Inspections in a non procedural manner, failing to replace the HP rotor drive cover O-rings or to conduct an idle engine run, both specifically required by the Aircraft Maintenance Manual.

34 The operator's Quality Assurance system had not identified frequent deviations from a procedural approach and failure to observe the requirements of the AMM over a considerable period of time.

35 The CAA monitoring system had been ineffective in identifying and making the operator correct the same procedural lapses.

36 The bulk of the work of performing the inspections was done over the period during which the Night Base Maintenance Controller's ability to sustain concentration and reasoning ability was likely to be diminishing.

37 The completion of the task, by final inspection of the restoration of the aircraft, occurred around the time that the Night Base Maintenance Controller's capabilities were likely to be at their lowest.

38 There had been eight previous instances when other operator's had left off the HP rotor drive cover following maintenance, after five of which the engine manufacturer issued a lanyard modification by Service Bulletin.

39 Both engines on G-OBMM had the lanyard modification incorporated but the covers remained insufficiently conspicuous when removed.

40 There are several features of this incident in which clear parallels can be observed with the occurrences to both G-BJRT (AAR 1/92) and GKMAM (AAR 2/95).

41 Serious incidents are frequently discovered, all too late, to have predicted catastrophic accidents; these three incidents have identified a wide range of common features conspiring to undermine the pursuit of quality in aircraft maintenance.

Causes

The following causal factors were identified:-

- (1) The aircraft was presented for service following Borescope Inspections of both engines which had been signed off as complete in the Aircraft Technical Log although the HP rotor drive covers had not been refitted.
- (2) During the Borescope Inspections, compliance with the requirements of the Aircraft Maintenance Manual was not achieved in a number of areas, most importantly the HP rotor drive covers were not refitted and ground idle engine runs were not conducted after the inspections.
- (3) The airline's Quality Assurance Department had not identified the non-procedural conduct of Borescope Inspections prevalent amongst Company engineers over a significant period of time.
- (4) The Civil Aviation Authority, during their reviews of the Company Procedures; for JAR-145 approval, had detected limitations in some aspects of the Operator's Quality Assurance system, including procedural monitoring, but had not withheld that approval, being satisfied that those limitations were being addressed.

4 Safety Recommendations

4.1 The CAA review its response to recommendation 9441, in particular with respect to formally reminding engineers of their responsibility to ensure that all work is carried out using the correct procedures, and that they are not at liberty to deviate from the Maintenance Manual; if full compliance is not achieved the engineer is not empowered to certify the work. (Safety Recommendation 96-28)

4.2 The Airline's Maintenance Organisation should introduce an effective system to monitor functionally related available manpower versus anticipated workload. (Safety Recommendation 96-29)

4.3 The CAA in conjunction with the JAA should review the requirements of JAR145, relating to the monitoring of available manpower of maintenance organisations, to enable Authorities to retrospectively sample the availability of correctly qualified staff for the conduct of aircraft maintenance performed. (Safety Recommendation 96-30)

4.4 The CAA, with the JAA, consider issuing advice to aircraft maintenance organisations that, where practical, work which can effect the airworthiness of an engine should not be conducted on all of the powerplant installations of an aircraft at one point in time by the same personnel. (Safety Recommendation 9631)

4.5 The Airline's Maintenance Organisation should devise a common standard of task documentation for Base and Line maintenance activity.(Safety Recommendation 96-32)

4.6 The CAA, in conjunction with the JAA, review JAR-145 with a view to requiring a common standard of task documentation for Base and Line maintenance activity. (Safety Recommendation 96-33)

4.7 The Airline's Maintenance Organisation should review its instructions to maintenance supervisory staff with a view to redefining their responsibilities and avoiding them undertaking tasks which are inconsistent with their managerial role. (Safety Recommendation 96-34)

4.8 The CAA, when conducting reviews of maintenance organisations for JAR-145 approval should monitor the work definition for maintenance supervisory staff and ensure that it avoids them undertaking tasks which are inconsistent with their managerial role. (Safety Recommendation 96-35)

4.9 The Airline's Maintenance Organisation should redefine the role of the QA department with a view to achieving, for both day and night shifts, effective monitoring of working practices, ensuring adherence to promulgated procedures and monitoring of the quality of the engineering product. (Safety Recommendation 96-36)

4.10 The CAA, when conducting reviews of maintenance organisations for JAR-145 approval should monitor the function of the QA department to ensure that, for both day and night shifts, they are achieving effective monitoring of working practices, ensuring adherence to promulgated procedures and monitoring the quality of the engineering product. (Safety Recommendation 96-37)

4.11 CFMI should review the HP rotor drive cover and lanyard modification with a view to making more conspicuous, the fact that the cover is detached from the Accessory Gearbox. (Safety Recommendation 96-38)

4.12 The CAA in conjunction with the JAA review JAR-145 to require, where aircraft maintenance or inspection tasks require elements of preparation for access, and incorrect restoration of these preparatory actions might result in airworthiness hazards, these restorative actions are individually defined to be signed for as completed on the document which constitutes the Quality Assurance audit for airworthiness. (Safety Recommendation 96-39)

4.13 The CAA in conjunction with the JAA review appropriate JARs to require improvements in the clarity of presentation of maintenance instructions, in particular by the removal of non-task-specific information from the work descriptive text, by necessary revisions of existing documents. (Safety Recommendation 96-40)

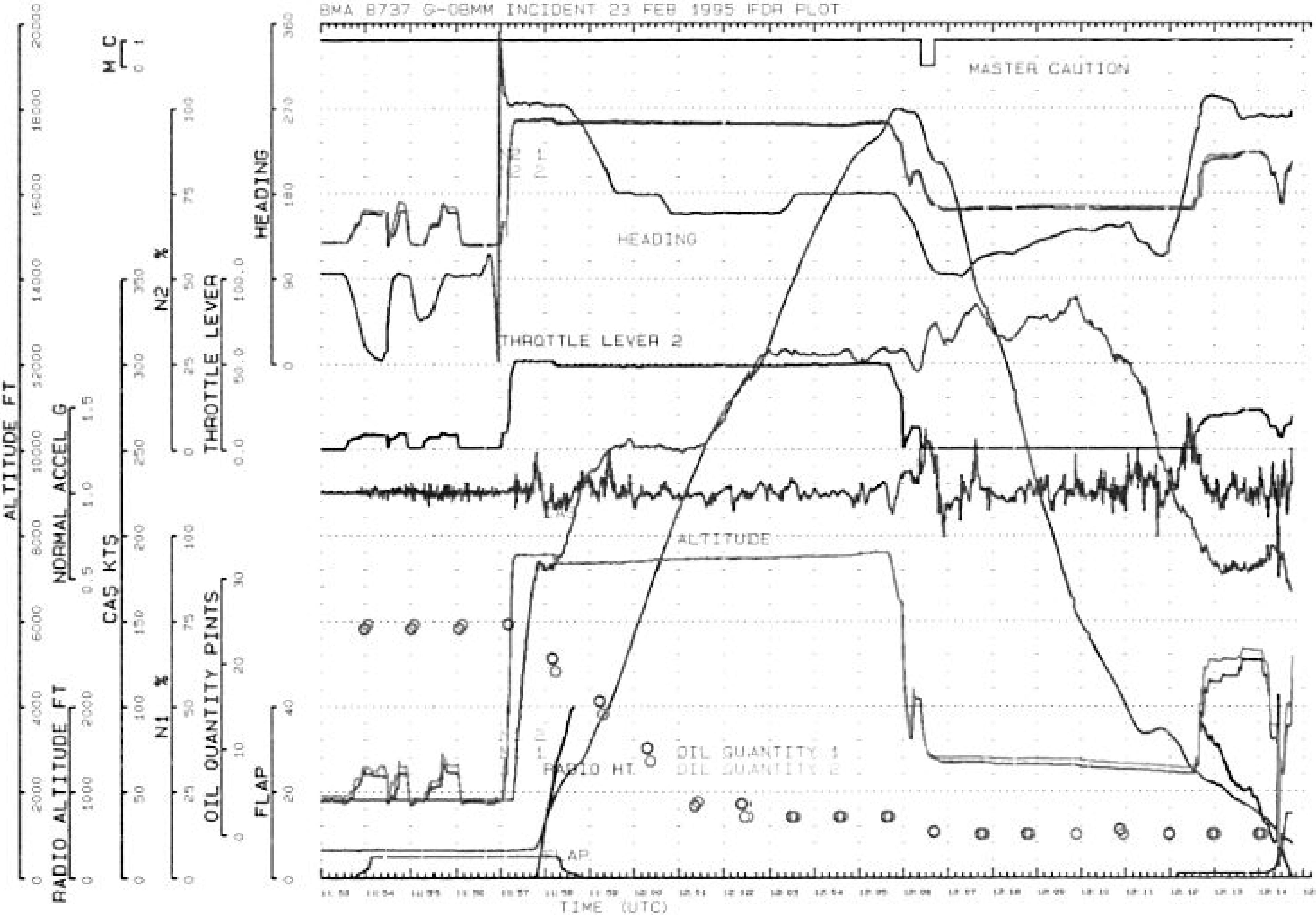
4.14 The CAA should ensure that, when job specific Task Cards are produced by either a maintenance organisation or a manufacturer, any action which is required to be performed which has a particular airworthiness risk associated with it, should be described fully together with the potential risk and not just referred to in another document. (Safety Recommendation 96-41)

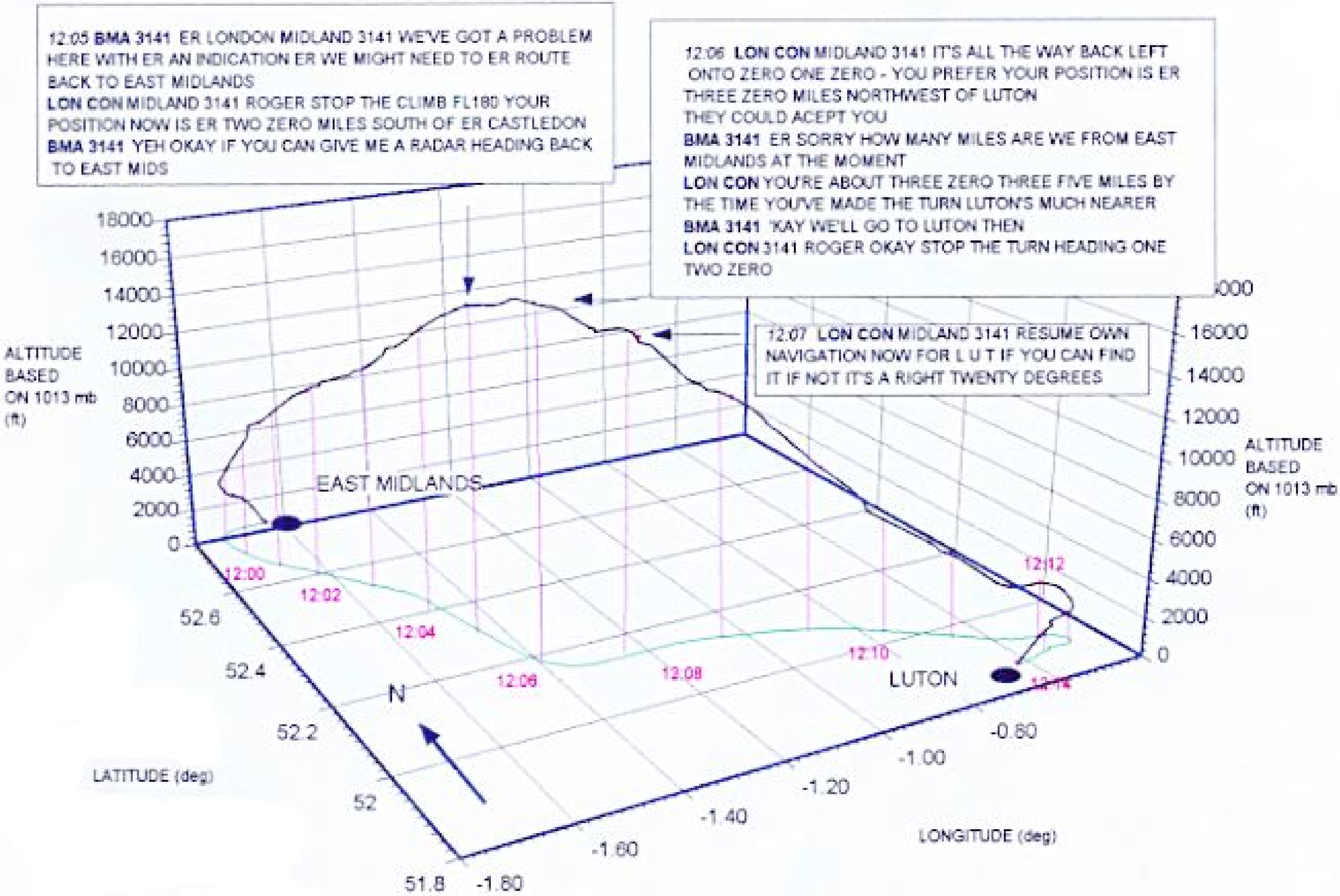
4.15 The CAA review what they have heretofore regarded as acceptable arrangements for Quality Assurance to meet the requirements of the regulations currently governing the conduct of aircraft maintenance within the UK, with the intent of ensuring that airworthiness is not compromised. This initiative has international significance and the CAA is urged to enlist support from the other JAA Authorities and the FAA in this comprehensive re-appraisal of aircraft maintenance practices. (Safety Recommendation 96-42)

D F King
Inspector of Air Accidents
Air Accidents Investigation Branch
Department of Transport

June 1996

APPENDIX A
Figure 1




12:05 BMA 3141 ER LONDON MIDLAND 3141 WE'VE GOT A PROBLEM HERE WITH ER AN INDICATION ER WE MIGHT NEED TO ER ROUTE BACK TO EAST MIDLANDS
LON CON MIDLAND 3141 ROGER STOP THE CLIMB FL180 YOUR POSITION NOW IS ER TWO ZERO MILES SOUTH OF ER CASTLEDON
BMA 3141 YEH OKAY IF YOU CAN GIVE ME A RADAR HEADING BACK TO EAST MIDS
12:06 LON CON MIDLAND 3141 IT'S ALL THE WAY BACK LEFT ONTO ZERO ONE ZERO - YOU PREFER YOUR POSITION IS ER THREE ZERO MILES NORTHWEST OF LUTON THEY COULD ACEPT YOU
BMA 3141 ER SORRY HOW MANY MILES ARE WE FROM EAST MIDLANDS AT THE MOMENT
LON CON YOU'RE ABOUT THREE ZERO THREE FIVE MILES BY THE TIME YOU'VE MADE THE TURN LUTON'S MUCH NEARER
BMA 3141 'KAY WE'LL GO TO LUTON THEN
LON CON 3141 ROGER OKAY STOP THE TURN HEADING ONE TWO ZERO
12:07 LON CON MIDLAND 3141 RESUME OWN NAVIGATION NOW FOR L U T IF YOU CAN FIND IT IF NOT IT'S A RIGHT TWENTY DEGREES
ALTITUDE BASED ON 1013 mb (ft)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
EAST MIDLANDS
LUTON
N
12:00
12:02
12:04
12:06
12:08
12:10
12:12
LATITUDE (deg)
52.6
52.4
52.2
52
51.8
LONGITUDE (deg)
-1.80
-1.60
-1.40
-1.20
-1.00
-0.80

Boeing 737-400, G-OBMM: Appendix B

Aircraft Accident Report No: 3/96 (EW/C95/2/3)

Report on the incident to a Boeing 737-400, G-OBMM near Daventry on 25 February 1995

Extract from British Midland Procedures Manual. Volume 1

Quality Objectives

1.1 The stated objectives of the Quality Assurance Dept. are to ensure that all JAA, NAA (UK CAA) and company requirements are complied with by maintaining a continuous check on the effectiveness of the maintenance organisation and also the procedures and system employed to achieve an acceptable high standard of continuing airworthiness.

1.2 These objectives are accomplished by a process of individual responsibility for the Quality of the work produced together with personal monitoring of performance and a formalised Planned Quality Audit Programme.

1.3 An individual will generate the highest Quality Levels whenever they perform a task correctly, in accordance with the prescribed standards. Inspection cannot achieve Quality, it can only ensure conformity.

1 4 Departmental Self Auditing is a function whereby a department will formally audit, investigate and sample its own products to ensure that any non-conformance is highlighted and that corrective actions are made as required in order to maintain the continued airworthiness of these products.

1.5 The key to Quality Control, therefore, is the principle of Formalised Self Monitoring. To be able to achieve this condition, both the individual and the department must have access to and be capable of using the standard procedures, as approved by the company and in accordance with the statutory and Manufacturer's requirements.

1.6 Overall Quality Assurance will be achieved by the monitoring and auditing of each department's adherence to approved standards and requirements and by the evaluation of data from all sources of company activity.

1.7 In order to achieve the Company's Quality Objectives, the Quality Assurance Department will carry a planned programme of audits on the following:

a) Aircraft - on Base Maintenance and Line Maintenance

b) Departmental - including Line Maintenance Control

c) Line Stations

d) Vendors, Overhaul and Repair Agencies

e) Quality Assurance

f) Computer System Audits - including IT Dept.

g) Sub-Contracted Organisations.

h) Secondary Organisations.

i) Test House - i.e. Metrology.

JAR 145.65 Maintenance procedures and quality system (See ACJ 145.65)

(a) The JAR-145 approved maintenance organisation must establish procedures acceptable to the Authority to ensure good maintenance practices and compliance with all relevant requirements in this JAR-145 such that aircraft and aircraft components may be released to service in accordance with JAR 145.50.

(b) In addition, the JAR-145 approved maintenance organisation must establish an independent quality system to monitor compliance with and adequacy of the procedures to ensure good maintenance practices and airworthy aircraft and aircraft components. Compliance monitoring must include a feedback system to the person or group of persons specified in JAR 145.30(a) and ultimately to the accountable manager to ensure, as necessary, corrective action. Such systems must be acceptable to the Authority.

ACJ 145.65(a) Maintenance Procedures and Quality System
(Interpretative Material)
See JAR 145.65(a)

1 The maintenance procedures should cover all aspects of carrying out the maintenance activity and in reality lay down the standards to which the JAR maintenance organisation intends to work. The aircraft/aircraft component design organisation standards and aircraft operator standards must be taken into account.

2 The maintenance procedures should address JAR 145.25 to 145.60 inclusive and the limitations of JAR 145.75 to 145.95 inclusive. The Appendix 2 example exposition contains typical procedures that are to be addressed.

ACJ 145.65(b) Maintenance Procedures and Quality System
(Acceptable Means of Compliance)
See JAR 145.65(b)

1 The quality system is in fact an independent system under the control of the JAR 145.30(a) quality manager looking at the JAR 145.65 (a) maintenance procedures and the correctness of the JAR 145.95 equivalent Safety Case process.

2 The JAA expects the quality system to review all maintenance procedures as described in the exposition in accordance with an approved programme or otherwise once a year in relation to each aircraft type maintained. The quality system should show when audits are due, when completed

and establish a system of audit reports which can be seen by visiting JAA staff on request. The audit system should clearly establish a means by which audit reports containing observations about non-compliance or poor standards can be actioned. The means ultimately should lead to the accountable manager.

3 A JAR-145 organisation claiming compliance with ISO 9002 at Issue 1 dated 1987.04.01 should mean that the organisation is in compliance with this paragraph, but the JAA will still need to be satisfied that compliance with this paragraph is established.