AIRCRAFT ACCIDENT REPORT 2/2007

Air Accidents Investigation Branch

Department for Transport

Report on the serious incident to Boeing 777-236, G-YMME on departure from London Heathrow Airport on 10 June 2004

This investigation was carried out in accordance with
The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 1996

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Department for Transport
Air Accidents Investigation Branch
Farnborough House
Berkshire Copse Road
Aldershot
Hampshire GU11 2HH

February 2007

The Right Honourable Douglas Alexander
Secretary of State for Transport

Dear Secretary of State

I have the honour to submit the report by Mr J J Barnett, an Inspector of Air Accidents, on the circumstances of the accident to Boeing 777-236, registration G-YMME on departure from London Heathrow Airport on 10 June 2004.

Yours sincerley

David King
Chief Inspector of Air Accidents

Contents

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch
AMM	Aircraft Maintenance Manual
AMP	Approved Maintenance Programme
amsl	above mean sea level
APU	Auxiliary Power Unit
ATC	Air Traffic Control
BA	British Airways
BAMC	British Airways Maintenance Cardiff
CAA	Civil Aviation Authority
CAP	Civil Airworthiness Publication
CDU	Control Display Unit
CHIRP	Confidential Human Factors Incident Reporting Programme
CVR	Cockpit Voice Recorder
CWT	Centre Wing Tank
EASA	European Aviation Safety Agency
EICAS	Engine Indicating and Crew Alerting System
ER	Extended range
EU	European Union
EWS	Engineering Wide System
FDR	Flight Data Recorder
FL	Flight Level
FMS	Flight Management System
FTD	Fleet Team Digest
GOR	Ground Occurrence Report
hrs	hours (clock time as in 1200 hrs)
ILS	Instrument Landing System
IPC	Illustrated Parts Catalogue
ITC	Illustrated Task Card
JAR	Joint Airworthiness Requirement
kg	kilogram(s)
kg/min	kilograms/minute
km	kilometre(s)
LAE	Licenced Aircraft Engineer
lb	pound(s)
LDA	Landing Distance Available
m	metres
MEI	Maintenance Error Investigation
MEMS	Maintenance Error Management System
MEDA	Maintenance Error Decision Aid
MOE	Maintenance Organisation Exposition
MOR	Mandatory Occurrence Report
MPD	Maintenance Planning Document
NDT	Non-destructive Test
NTSB	National Transportation Safety Board
PQF	Planning Query Form
QAR	Quick Access Recorder
QDR	Quality Discrepancy Report
QEAN	Query for Engineering Advice Note
SAP	Systems, Applications and Products in Data Processing (a commercial software supplier)
SOP	Standard Operating Procedure
STA	Station
TR	Temporary Revision
TTL	Technical Team Leader
UTC	Co-ordinated Universal Time (the contemporary equivalent of GMT)

Air Accidents Investigation Branch

Aircraft Incident Report No: 1/2007 (EW/C2004/06/01)

Registered Owner and Operator:	British Airways PLC
Aircraft Type and Model:	Boeing 777-236
Registration:	G-YMME
Place of Incident	On departure from London Heathrow Airport Latitude: 51° 29' N Longitude: 000° 28' W
Date and Time	10 June 2004 at 1907 hrs All times in this report are UTC unless otherwise stated.

Synopsis

The incident was notified to the Air Accidents Investigation Branch (AAIB) on 11 June 2004. The AAIB investigation team comprised:

Mr J J Barnett	(Investigator-in-Charge)
Mr K Conradi	(Operations)
Mr S J Hawkins	(Engineering)
Mr C Pollard	(Engineering)
Mr A Foot	(Flight Recorders)

After takeoff from London Heathrow Airport a vapour trail was seen streaming aft of the aircraft. The flight crew diagnosed that the aircraft was probably leaking fuel from the centre wing fuel tank. They declared an emergency and decided to jettison fuel to reduce to maximum landing weight before returning to Heathrow. Their intention was to minimise heating of the brake units during the landing roll in order to reduce the risk of fire if fuel was to leak onto the wheelbrakes. After landing, the aircraft was met by the Airfield Fire and Rescue Service who reported some vapour emanating from the left landing gear but no apparent fuel leaks.

The fuel leak was caused by fuel escaping through an open purge door inside the left main landing gear bay, on the rear spar of the centre wing tank. The purge door had been removed during base maintenance at the operator's maintenence organisation in Cardiff, between 2 May and 10 May 2004, and had not been refitted prior to the aircraft's return to service.

The investigation identified the following causal factors:

1. The centre wing tank was closed without ensuring that the purge door was in place.

2. When the purge door was removed, defect job cards should have been raised for removal and refitting of the door, but no such cards were raised.

3. The centre wing tank leak check did not reveal the open purge door because:

   a. The purge door was not mentioned within the Aircraft Maintenance Manual (AMM) procedures for purging and leak-checking the centre wing fuel tank.

   b. With no record of the purge door removal, the visual inspection for leaks did not include the purge door.

   c. The fuel quantity required to leak check the purge door was incorrectly stated in the AMM.

4. Awareness of the existence of a purge door on the Boeing 777 was low among the production staff working on G-YMME, due in part to an absence of cross references within the AMM.

Following the incident, significant safety action was taken by both the maintenance organisation and the aircraft manufacturer to address issues discovered during the investigation. The AAIB made five safety recommendations.

1 Factual Information

1.1 History of the flight

1.1.1 The incident flight

The aircraft was scheduled for an 1845 hrs departure from London Heathrow Airport to Harare, Zimbabwe and the flight crew consisted of a commander and two first officers. The extra first officer was rostered to allow the pilots in-flight rest due to the length of the duty period. The flight crew agreed with the flight plan total fuel load of 101,017 kg, which included 18,989 kg to be 'tankered' to Harare and used on the return flight to Heathrow. This figure was calculated using the company's tanking SOP (Standard Operating Procedure) of landing at destination at 5,000 kg less than the maximum landing weight. On arrival at the aircraft, the extra first officer completed the external aircraft checks and noted that the fuel bowser was attached to the aircraft with refuelling not yet complete. The aircraft was filled with a total of 101,100 kg of fuel which included 43,400 kg in the centre tank (recorded to the nearest 100 kg).

After normal engine starts, the first officer, who was the handling pilot, taxied the aircraft to Runway 27L expecting to fly a Midhurst 3G Standard Instrument Departure. At 1903 hrs the aircraft took off and climbed straight ahead to 1,000 feet above the airfield before commencing its normal acceleration profile. Immediately after takeoff, the flight crew of an aircraft waiting to depart at the runway holding point reported a trail of 'smoke' (later identified as fuel) from the rear of G-YMME and a smell of fuel vapour. This was acknowledged by ATC and G-YMME's flight crew as the aircraft continued on its planned departure, climbing to 6,000 feet amsl. Because there were no abnormal indications on the flight deck displays and no abnormal symptoms visible from the flight deck, the pilots considered it likely that the aircraft was leaking fuel from its centre tank. This deduction was reinforced by further reports from the ground, and from other aircraft, of a two-mile long vapour trail from the rear of the aircraft (see Figure 1).

The flight crew decided to return to Heathrow but considered it prudent to jettison fuel beforehand to reduce to maximum landing weight. The intention was to minimise heating of the brake units during the landing roll in order to reduce the risk of fire if fuel was to leak onto the wheelbrakes. The flight crew declared an emergency and were transferred to a discrete frequency by ATC who then directed the aircraft over the sea during the ensuing 24 minutes of fuel jettisoning. With approximately 4,000 kg of fuel remaining in the centre tank, an ILS approach was made to Runway 27L. There were no reports of any fuel leaking during the approach. The aircraft landed at 2005 hrs with 'Autobrake 1' (the lowest autobrake setting) selected to minimise the wheel brake temperatures. The Airfield Fire and Rescue Service met the aircraft and reported some vapour emanating from the left landing gear but no apparent fuel leaks. As a precaution, the left engine was shut down and the aircraft taxied to Stand 406 where the passengers were disembarked normally.

Figure 1

Fuel stream visible from G-YMME during departure from Heathrow
(photo courtesy Steve Flint)

1.1.2 Post flight inspection

An engineer inspected the aircraft after it arrived at the stand. He noticed a few drips of fuel on the left main landing gear but none on the ground. After opening the left inboard main gear door, he detected a distinct smell of fuel. An inspection inside the gear bay revealed that the centre fuel tank purge door was not in place. The purge door was hanging on a lanyard inside the fuel tank and a plastic bag[1] was attached to the purge door opening. The bag contained fuel and the screws that would normally hold the purge door in place (see Figures 2 and 3).

1 The plastic bag was the same type as that used by both the operator's maintenance facility at Heathrow and by the operator's maintenance organisation in Cardiff.

Figure 2

View inside left main gear bay looking forward at the rear spar of the centre fuel tank. Purge door opening circled in red.

Figure 3

Purge door opening. Fuel and retaining bolts inside plastic bag. Purge door is hanging on a lanyard inside fuel tank. Purge door O-ring visible on lanyard.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	–	–	–
Serious	–	–	–
Minor / None	15	151	–

1.3 Damage to aircraft

The aircraft was undamaged but the centre wing fuel tank purge door was not in place.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 Commander: Male aged 50 years

Licence:	Airline Transport Pilot's Licence
Type Ratings:	Boeing 777
Instrument Rating:	Valid to 31 October 2004
Licence Proficiency Check:	Valid to 31 October 2004
Operator's Line Check:	Valid to 31 October 2004
Medical Certificate:	Class 1, valid to 30 November 2004, with no limitations
Flying Experience:	Total all types 14,600 hours
	Total on type 2,256 hours
	Last 28 days 64 hours
	Last 24 hours 0 hours
Previous rest period:	Off duty: 1815 hrs on 5 June 2004
	On duty: 1715 hrs on 10 June 2004

1.5.2 Co-pilot (Handling): Male aged 37 years

Licence:	Airline Transport Pilot's Licence
Type Ratings:	Boeing 777
Instrument Rating:	Valid to 31 July 2004
Proficiency Check:	Valid to 31 July 2004
Line Check:	Valid to 31 July 2004
Medical Certificate:	Class 1, valid to 30 April 2005, with no limitations
Flying Experience:	Total all types 5,650 hours
	Total on type 3,300 hours
	Total last 28 days 72 hours
	Total last 24 hours 0 hours
Previous rest period:	Off duty: 1115 hrs on 7 June 2004
	On duty: 1715 hrs on 10 June 2004

1.6 Aircraft information

1.6.1 General information

Manufacturer:	The Boeing Commercial Airplane Group
Type:	Boeing 777-236 (generically known as a Boeing 777-200 ER[2])
Aircraft Serial Number:	30306
Year of manufacture:	2000
Number and type of engines:	2 Rolls-Royce Trent 895-17 turbofan engines
Total airframe hours:	16,696 hours and 1,907 flight cycles
Certificate of Registration:	Valid
Certificate of Airworthiness:	Issued 15 April 2003 and valid

1.6.2 Aircraft weight

The aircraft's takeoff weight was approximately 276,000 kg which included a fuel load of approximately 101,100 kg. The aircraft's maximum landing weight was 208,652 kg.

1.6.3 Fuel quantity indication

During normal operation the Engine Indicating and Crew Alerting System (EICAS) displays the total fuel quantity and fuel temperature. If an imbalance between the left or right main tanks or a low level of fuel in any tank is detected, this display will automatically expand to show the fuel quantity in each tank. The Fuel Synoptic Display page on the flight deck's multi-function displays may be interrogated to identify fuel quantities in each tank at any time.

Whenever the aircraft's Flight Management System (FMS) detects a disagreement between the fuel totalizer and a calculated fuel quantity of greater than 4,080 kg for a minimum of 5 minutes, the Control Display Unit (CDU) displays a 'FUEL DISAGREE' message.

1.6.4 The maintenance organisation

G-YMME had recently undergone scheduled major maintenance at British Airways Maintenance Cardiff (BAMC), a sub-contracted maintenance organisation approved in accordance with EASA Part 145. Located at Cardiff International Airport, BAMC is a dedicated service and maintenance facility for

2 Extended Range.

British Airways' fleet of Boeing 747 and 777 aircraft. BAMC is a wholly owned subsidiary of British Airways and not a constituent part of the airline. In this report BAMC will be referred to as 'the maintenance organisation'.

1.6.5 Aircraft Maintenance Manual

The Boeing 777 Aircraft Maintenance Manual (AMM) contains the procedures and instructions on how to carry out maintenance on the Boeing 777. The maintenance organisation is required by regulation[3] to follow the procedures in the AMM unless they can demonstrate that their revised procedures result in equivalent or improved maintenance standards and they inform the manufacturer of the change.

The aircraft manufacturer also publishes maintenance task cards which contain the procedures and instructions extracted from the AMM for a particular task.

1.6.6 Centre wing fuel tank

The Boeing 777 aircraft has three fuel tanks, a left main wing tank, a right main wing tank and a 'center' tank, more commonly known in the UK as the centre wing tank (CWT). The 777 aircraft has one of two CWT configurations. The basic 777-200 model, sometimes termed the 'A' market model, has a CWT which occupies the left and right inboard sections of the wing with both sections connected via pipes that run through a 'dry' centre wing (see Figure 4). The 777-200 ER (Extended Range) model, sometimes termed the 'B' market model, has a larger CWT which occupies both inboard wing sections and the centre wing section (see Figure 5). Although all three sections are combined into one CWT and fuel flows freely between them, inboard wing ribs separate the sections. G-YMME was a 777-200 ER model and had this latter configuration with a larger capacity CWT and 'wet' centre wing.

The approximate capacity of each main wing tank on G-YMME was 29,322 kg; the capacity of its CWT was approximately 80,028 kg. These quantities are approximate because they assume a fuel density of 0.81 kg per litre, and fuel density varies with fuel temperature. The total fuel capacity was approximately 138,670 kg.

[3] European Aviation Safety Authority (EASA) Part 145.A.45 Regulation

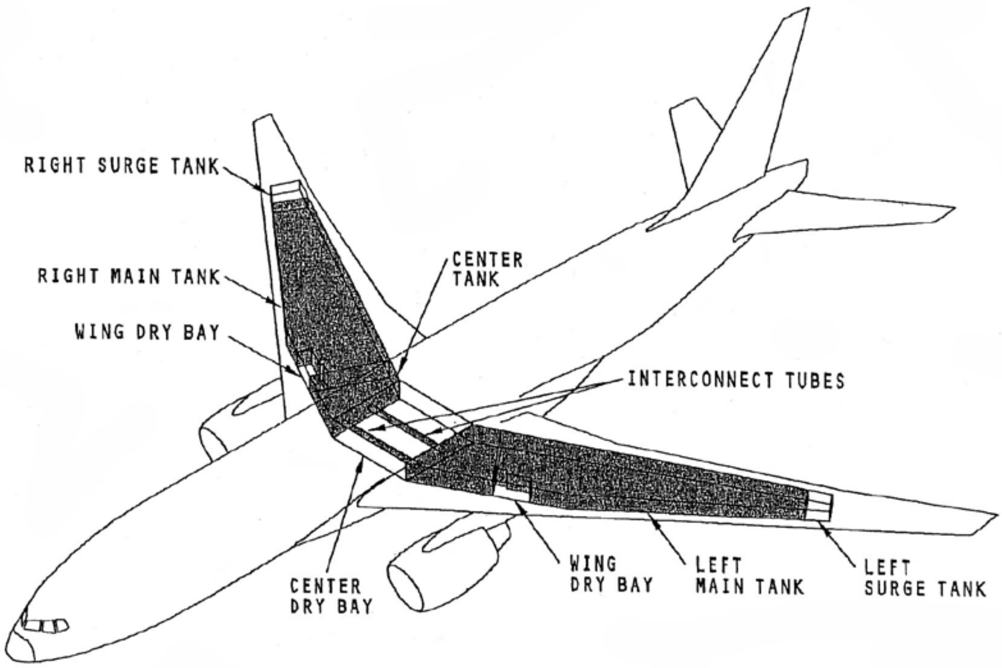


Figure 4

Boeing 777-200 (A-market) fuel tank configuration
(Copied with permission of The Boeing Company)

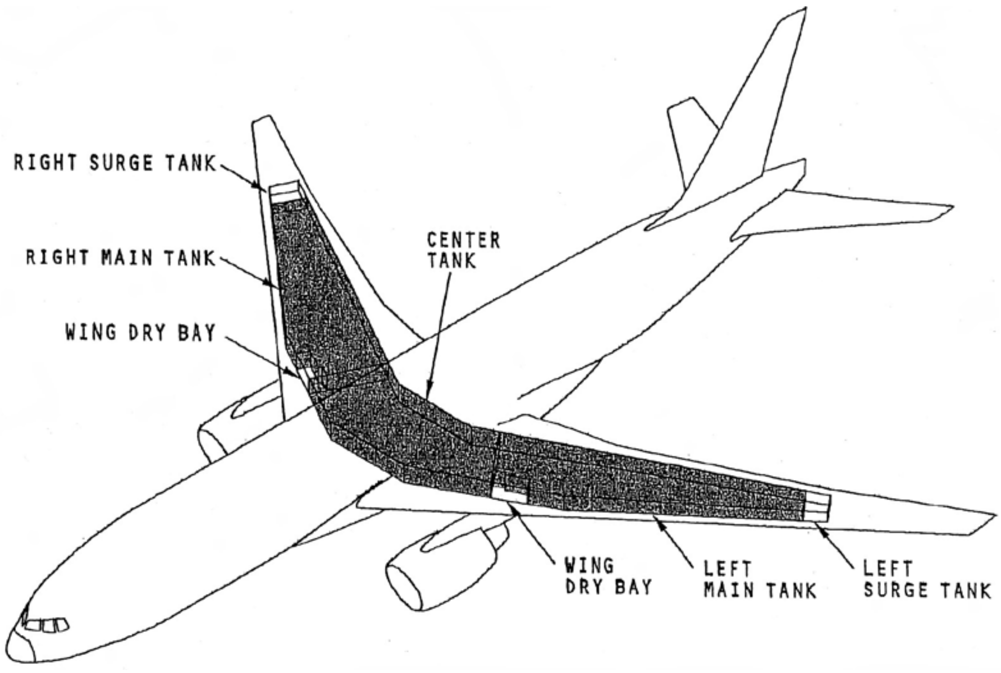


Figure 5

Boeing 777-200 ER (B-market) fuel tank configuration
(Copied with permission of The Boeing Company)

Access into the CWT can be gained via seven access doors. The central section of the CWT has one access door on its lower surface towards the front of the tank (door 139AZ), while the wing sections of the CWT each have three access doors on each side on the lower surface of the wings (see Figure 6).

Spanwise beams separate the centre wing section of the CWT into four bays (see Figure 6). Each spanwise beam has an opening to permit access between the bays. On 'B market' models such as G-YMME, these spanwise beam openings are closed-off with removable baffle doors (see Figure 7). The baffle doors serve to prevent rapid fuel movement (fuel slosh) between spanwise beams due to changes in pitch attitude or longitudinal acceleration. The basic 777-200 with a 'dry' centre wing does not have these baffle doors. The only other door that forms part of the CWT is the purge door.

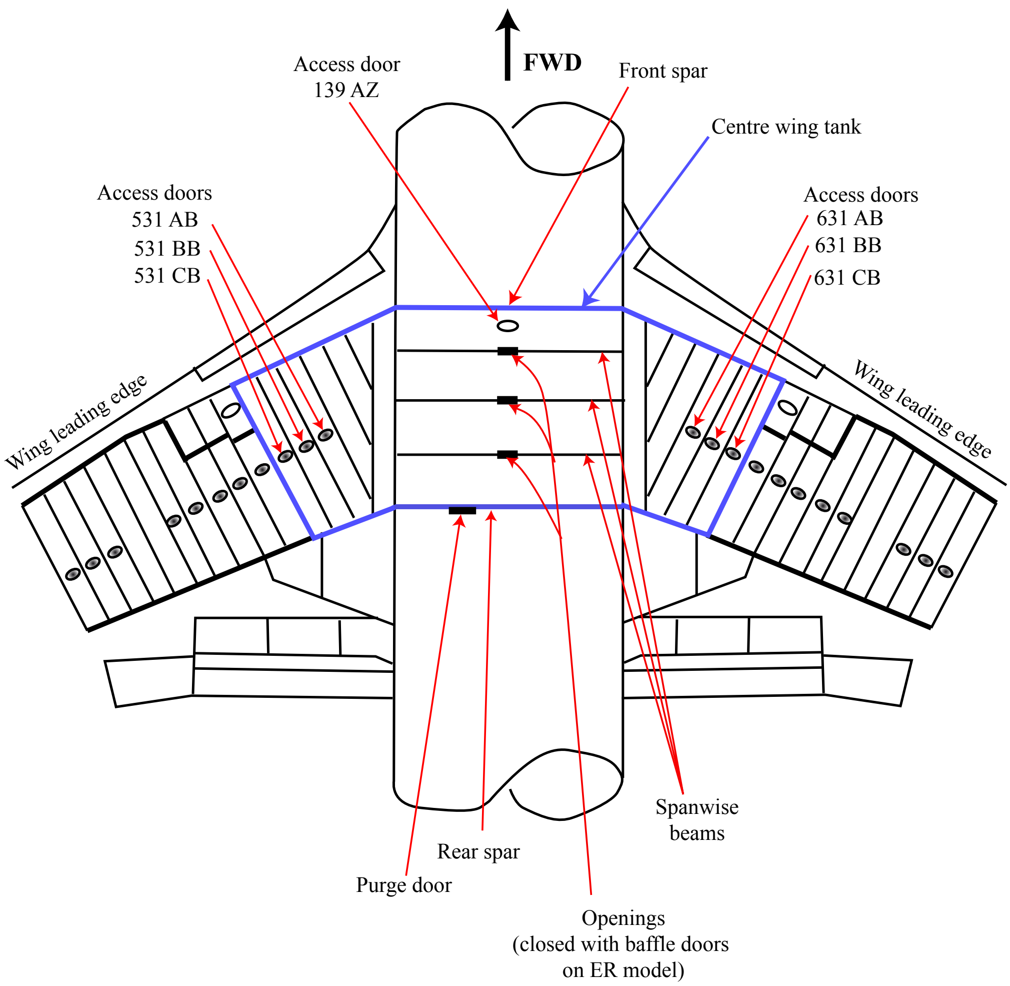


Figure 6

Boeing 777 centre wing tank configuration

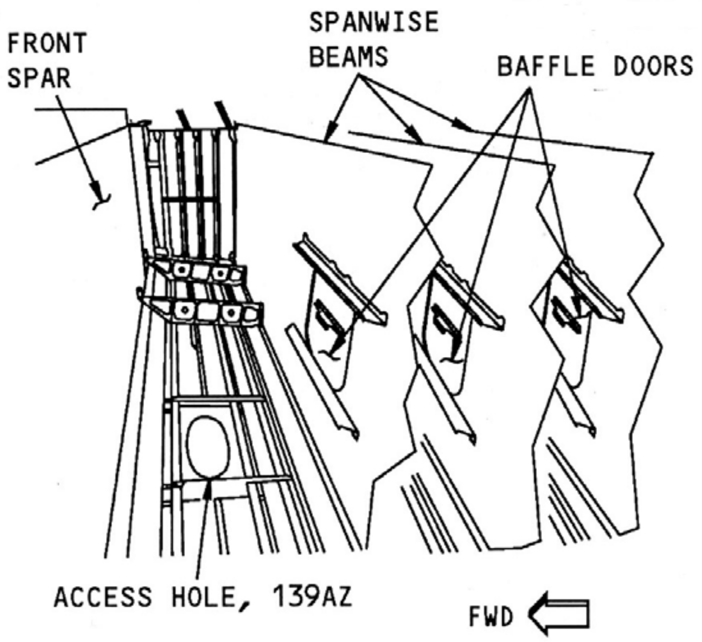


Figure 7

Baffle doors in the spanwise beam openings of the 777-200 ER
(Copied with permission of The Boeing Company)

1.6.6.1 The purge door

The purge door is located on the rear spar of the centre section of the CWT approximately 7 inches left of the aircraft centreline (see Figures 6 and 8). It can be accessed from inside the left wheel well or from inside the CWT. The purge door is a circular panel of approximately 4.5 inches diameter with 6 bolt holes around its circumference. It is a plug type door which is pressed into the purge door opening from within the tank (see Figure 9). The purge door opening has a diameter of 2.5 inches and is visible from the ground when the left inboard main gear door is open. For all normal operations this main gear door remains closed; it opens only briefly to permit the landing gear to extend and retract. The door can be opened on the ground to conduct maintenance inside the wheel well but it would not be normal to do this during a turn-around between flights. When the inboard main gear door is closed the purge door is not visible from ground level.

According to the Aircraft Maintenance Manual (AMM), during fuel tank maintenance *'The center purge door is used to remove fuel fumes from the center section.'*

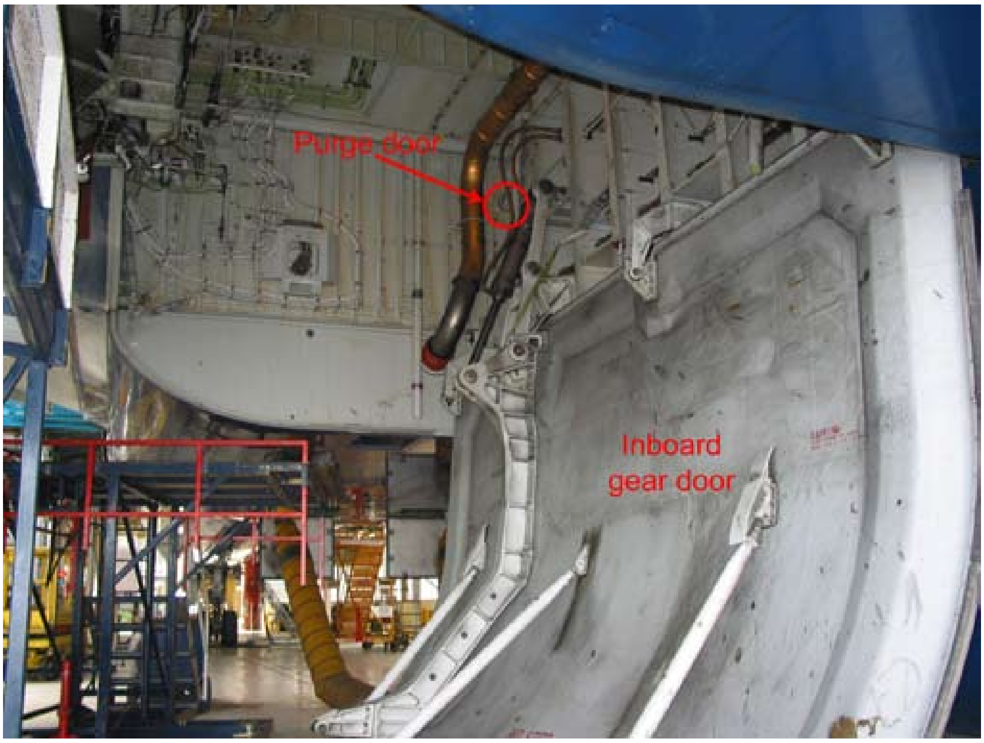


Figure 8

Purge door visibility with left main inboard gear door open

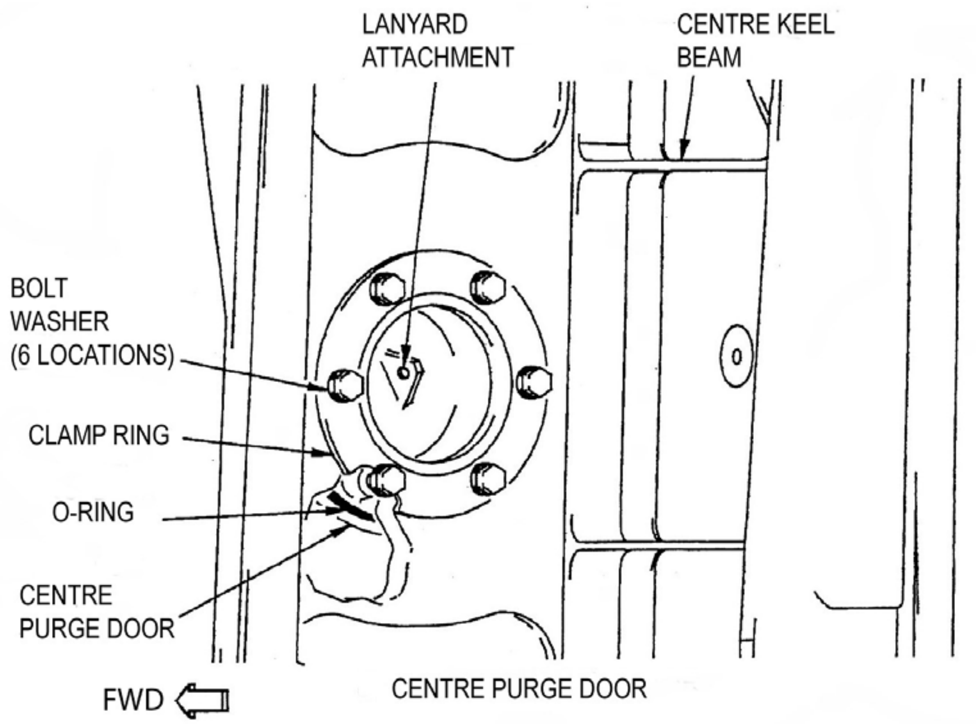


Figure 9

Boeing 777 purge door installation diagram
(Copied with permission of The Boeing Company)

1.6.7 CWT drain and purge procedure

To permit human entry into a fuel tank, the tank must be drained and the air inside the tank must be purged to reduce the fuel vapour level to an acceptable limit for health and safety. The bulk of the fuel inside the tank is pressure defuelled before draining is commenced. Draining is achieved by attaching two fuel bowsers to the sump drain valves on either side of the tank within the wing-to-body fairing, and then allowing residual fuel to drain by gravity.

The procedure in the AMM (ref 28-11-00-910-068, Rev 5 Sep 2003) used for purging the CWT was dependent upon the type of ventilation equipment the maintenance organisation had available. The organisation servicing G-YMME used a suction hose connected to an adaptor that could be secured into the opening of a fuel tank access door. When using this type of 'venturi' ventilation equipment the AMM called for all CWT access doors (six underwing CWT access doors and the access door on the belly (139AZ)) to be removed and then the suction hose to be secured to one of the wing openings. There was no mention of the purge door in the AMM's CWT purge procedure.

However, the AMM contained a separate stand-alone procedure entitled *Center Purge Door – Removal/Installation* (AMM ref 28-11-04) which detailed the procedure for removing the purge door and stated that the purpose of the purge door was to remove fuel fumes from the centre section. This procedure was not cross-referenced in the CWT purge procedure.

The CWT is effectively purged by sucking out the fuel vapour through one of the access doors while sucking in fresh air through all of the other open access doors. Since there are openings between all three sections of the CWT, the air can be drawn from one inboard wing section to the other. The CWT can be purged in this manner without removing the purge door. There is no data available to determine whether or not the efficiency of the purging process is affected by removal of the door.

1.6.8 Purge door removal procedure

The purge door removal procedure (AMM ref 28-11-04) called for the CWT to be defuelled and then a lanyard attached to the purge door. The procedure noted that the purge door could fall into the tank once the bolts were removed if the lanyard was not attached. After attaching the lanyard, the bolts, washers and clamp ring were to be removed (see Figure 9) and then the purge door lowered by its lanyard into the tank. The next step in the procedure called for the purge door to be physically removed from the aircraft by entering the CWT and removing the purge door from the lanyard. The procedure noted that it might be necessary to carry out the purge procedure before entering the tank to ensure a good flow of air. The O-ring seal on the purge door was then to be replaced prior to refitting the door.

This procedure differed from the purge door removal procedure for the Boeing 747 (described in section 1.18.4) which did not require complete removal of the purge door from the aircraft for purging[4]. The purge door could be left hanging on its lanyard inside the tank and then re-installed by pulling it back into position using the lanyard.

1.6.9 Fuel leak check procedures

Following the reinstallation of any fuel tank access doors and/or the purge door, the doors needed to be checked for leaks. The AMM contained a procedure for *'Fuel Leak Detection'* (ref 28-11-00-790-801, Rev 5 May 2003) and a specific subtask for finding leaks at fuel tank access doors. This subtask contained a table listing the fuel amounts required in each tank to leak-check specific doors - the higher the door's location in the tank the higher the level of fuel required to cover the door. According to the table, 30,900 kg of fuel was required in the CWT to leak-check the seven CWT access doors. However, the purge door, which is at a higher level in the tank, was not included in the table, nor was the purge door mentioned anywhere else in this procedure.

The previously mentioned purge door removal procedure in the AMM contained leak-check procedures specific to the purge door. The recommended leak check procedure was to use air pressure and a bubble solution but the alternative method was to refuel the CWT to a minimum fuel quantity that would cover the purge door and then carry out a visual leak-check with talcum powder applied around the seal. The minimum CWT fuel quantity stated in the AMM (Rev 5 May 2003) for this leak-check was 70,000 lb or 32,000 kg. However, following the incident to G-YMME, it was determined that this fuel amount was insufficient to reach the base of the purge door opening. The correct amount sufficient to reach the top of the purge door opening was 52,163 kg and the AMM has since been revised to reflect this figure (Rev 5 Sep 2004).

In both the general '*Fuel Leak Detection*' procedure and the '*Purge Door Leak Detection'* procedure it was stated that talcum powder should be applied to the seals to detect leaks rather than relying on a visual inspection alone. Since this incident the aircraft manufacturer has stated that using talcum powder is unnecessary following routine closure of a fuel tank access panel and it is only needed in the event of a suspected leak.

[4] This is potentially relevant because the organisation maintains Boeing 747 and Boeing 777 aircraft.

Since the leak-check procedures included a visual inspection of the doors for leaks, a visual inspection of the purge door would have revealed if it was in place or not regardless of the fuel amount used to perform the leak-check. However, uplifting 52,163 kg (the correct level to immerse the purge door) to the CWT would have revealed an open purge door, even if the visual inspection had been missed, because fuel gushing out of the open door would have been readily apparent.

1.6.10 Aircraft maintenance history

Maintenance records revealed that the last maintenance action carried out on the CWT prior to the incident flight was during the aircraft's 2C maintenance check[5] over the period 2 May to 10 May 2004. During the 31 day period between this 2C maintenance check and the incident flight, the aircraft flew 53 sectors but its highest recorded fuel load carried in the CWT was 26,800 kg – an amount half that required to reveal a leak from the purge door opening with the aircraft on the ground. In addition, during this 31 day period there was no record of the left main inboard gear door having been opened or any record of maintenance work inside the gear bay that would have required opening the gear door.

The fuel records showed that the previous occasion when G-YMME had carried more than 52,163 kg of fuel in the CWT was on 10 February 2003; therefore it was established that on that date the purge door was in place. A review of all the maintenance records covering the period between 10 February 2003 and 10 June 2004 revealed that the only occasion when entry to the CWT was required was during the 2C maintenance check between 2 May and 10 May 2004.

1.6.10.1 2C Maintenance check

All major maintenance checks, including the 2C maintenance check, on both the operator's Boeing 777 and Boeing 747 aircraft were carried out by the sub-contracted maintenance organisation. This organisation carried out a 2C maintenance check on G-YMME over the period 2 May to 10 May 2004. During this 2C check, access was required to the CWT to perform two tasks:

a) an internal structural inspection of the rear spar and

b) a special check of the bonding of the centre tank float switches.

[5] The 2C maintenance check is a series of maintenance tasks and inspections that is carried out on the Boeing 777 every 1,500 days, 8,000 cycles or 24,000 flying hours, whichever is soonest.

Task (a) was a scheduled maintenance task required to be performed at every 2C check and it required access to the centre section of the CWT. Task (b) was a special one-off check based on a service bulletin, which required access to the left and right inboard wing sections of the CWT. Before access to the tank could be gained to perform either task, the CWT needed to be defuelled, drained and then purged.

1.6.10.2 Job Cards

The maintenance tasks on the aircraft were controlled via job cards (also known as certification cards) which contained the instructions required to complete a particular maintenance task, such as drain the CWT. The job cards were structured by the maintenance organisation such that production staff[6] should be able to complete the job within 8 hours (ie within one shift). The data for the job cards was held in their electronic database known as 'Open Air'. A sample job card is included in Appendix 1.

The cards contained boxes for production staff to stamp. For each task one box was stamped for completion of the task and the adjacent box was stamped to certify that the task was completed correctly. When all tasks within a job card had been certified as completed, the top of the card was stamped to certify that the job had been completed. So that it was always possible to identify who performed a particular task, each Mechanic, Technician and Licenced Aircraft Engineer (LAE)[7] at the maintenance organisation had a unique stamp number. Certain simple tasks could be self-certified by Mechanics and Technicians but most other tasks had to be certified as completed by an LAE. The certified job cards served as a record that the work had been completed in accordance with approved data (ie the AMM and applicable company procedures). A correctly completed set of job cards formed an integral part of the chain of accountability that enabled the final declaration of airworthiness, the Certificate of Release to Service, to be issued with confidence on completion of the maintenance work.

The job cards for all scheduled tasks on a maintenance input were raised by the Production Planners at the maintenance organisation. The job of the Production Planners was to divide the tasks within the AMM into manageable jobs for the production staff. In the event that a non-scheduled task needed to be carried out, for example if a defect was found that needed repair, an LAE was authorised to raise a defect job card to carry out the repair task. Also, if a panel needed to be removed that had not been included in a scheduled or 'routine'

[6] In the context of this report the term 'production staff' refers to those people who perform the maintenance work on the aircraft.

[7] In the context of this report an LAE is a person who holds an EASA Part 66 Cat B1, B2 or C licence (or equivalent Joint Aviation Authorities licence) and holds a Part 145 maintenance organisation type authorisation.

job card, then an LAE could raise a defect card to have the panel removed and an additional defect card to have it refitted. Technicians and Mechanics were not authorised to raise defect cards. However, they were required to bring to the attention of their Technical Team Leader (TTL) anything that affected airworthiness or inspection requirements.

The time involved to raise defect cards for the purge door removal/installation was estimated by one LAE to be between 5 and 10 minutes. The cards were created on a computer and then printed. Each zone had a workstation with a computer and the workstation for the forward freight zone (1F) was located close to the CWT.

1.6.10.3 Maintenance Zones

To simplify the organisation of maintenance on a large aircraft, the airframe is divided into different zones. The maintenance organisation used zones similar to those specified by Boeing for the 777 airframe. The zones relevant to this investigation were: forward freight (1F), left engine (4A), right engine (4B), left wing (5), right wing (6), and landing gear bays (7). The forward freight zone encompassed the forward cargo areas and the CWT. Zones 4A and 1F were paired zones, meaning that the same maintenance team might work both zones depending on workload.

1.6.10.4 Maintenance Teams

A team was assigned to each work zone with each team led by a TTL who was an LAE. The TTL assigned job cards to the small group of Technicians and Mechanics that he or she managed. Some Technicians were also LAEs and were known as 'Authorised Technicians' whereas all the Mechanics were unlicensed. Each team was also assigned to a shift. There was a complex shift structure at the maintenance organisation but the primary shifts were the early, late and night shifts. To facilitate communication between shifts there was some time overlap between shifts and the TTL was required to complete a shift handover sheet.

1.6.10.5 Centre tank drain and purge procedure job card

The maintenance organisation had produced a job card entitled '*Drain and Purge Center Fuel Tanks'*. This job card listed the following three tasks, each of which needed to be stamped once completed[8]:

[8] Someone reading the three itemised tasks on this job card could interpret it to mean that there were three separate sections of the CWT that needed to be independently drained, but that is not the case. There are only two drain ports on the CWT, one on each side, and these ports drain the entire contents of the CWT.

1. Left center fuel tank drained and purged.
2. Right center fuel tank drained and purged.
3. Center tank drained and purged.

This job card referenced the AMM's fuel tank draining procedure as well as the '*Purging and Fuel Tank Entry*' procedure, but it did not reference the purge door removal procedure. In addition, separate job cards were raised to remove both CWT access doors (531AB and 631AB) on the inboard lower surface of the wing and the CWT access door on the belly (139AZ). No job card was raised for the removal of the purge door and no job cards were raised for removing any of the other under-wing CWT access doors, despite the AMM purge procedure calling for all seven CWT access doors to be removed. In addition, no job card was raised for installing the ventilation equipment which is a required part of the purging procedure.

1.6.10.6 Fuel leak-check procedure job cards

The maintenance organisation had also produced a job card entitled '*Leak check Center Fuel Tanks Access Panels*' to leak-check the CWT access doors once the tank had been closed up. This job card listed the following three tasks, each of which needed to be stamped once completed:

1. Carry out a fuel leak-check on access doors on the left center tank IAW MM TASK 28-11-00-790-801.

2. Carry out a fuel leak-check on access doors on the center tank IAW MM TASK 28-11-00-790-801.

3. Carry out a fuel leak-check on access doors on the right center tank IAW MM TASK 28-11-00-790-801.

Task 28-11-00-790-801 refers to the Fuel Leak Detection Procedures section of the AMM as described in section 1.6.9 of this report. Specific job cards were also raised to leak-check access doors 531AB and 631AB which are CWT access doors on the left and right inboard wing sections of the CWT. However, no job card was raised to leak-check the purge door because no card was raised to remove the purge door.

1.6.10.7 Maintenance activity timeline during the 2C check

The following timeline of the relevant maintenance activity was established from an examination of the job cards, handover sheets, and from interviews with maintenance personnel. All the times within this table are local times (UTC +1 hour).

Sun 2 May 2004 at 1250 hrs	G-YMME arrived at the maintenance organisation.
Tue 4 May Early Shift 0600 to 1435 hrs	CWT draining started by the team working the forward freight zone (1F). Handover note to the late shift with a request to open the tank and purge when ready.
Tue 4 May Late Shift 1410 to 2245 hrs	No record of CWT work performed in zone 1F. The team responsible for zone 1F worked paired zone 4B (right engine). No handover sheet from 1F zone.
Tue 4 May Night Shift 2035 to 0630 hrs	The team in zone 1F opened CWT access panel on belly (139AZ) and certified the CWT drain and purge job card as completed. This team normally worked the 747. They worked G-YMME just this one night shift. Note in handover sheet: "CWT opened for purging as requested".
Wed 5 May	Handover sheets made no mention of any CWT work. Refit of CWT left inboard wing access panel (531AB) certified.
Thu 6 May Early Shift 0600 to 1435 hrs	Rear spar inspection inside CWT carried out by TTL working zone 1F. Door 139AZ reinstalled. Refit of CWT right inboard wing access panel (631AB) certified. Note in handover sheet: "CWT closed – fuel going on at 14:00ish".
Thu 6 May Late Shift 1410 to 2245 hrs	Aircraft refuelled and all fuel tank leak-checks performed and certified by a TTL working the left wing zone (he was not aware of purge door location).
Fri 7 May	Refit of CWT door (139AZ) certified.
Mon 10 May	G-YMME departed maintenance organisation.

On 4 May 2004 the TTL working the landing gear zone certified the card for having completed an external surveillance inspection of the left main gear wheel well. He was working the night shift so the card could have been certified either early morning on 4 May or late at night on 4 May. In the past this TTL had removed the purge door to help purge the CWT of a 777, but on G-YMME he could not recall if the purge door was or was not in place at the time of his wheel well inspection.

1.6.10.8 Interview of maintenance personnel

The AAIB interviewed 10 maintenance personnel (7 TTLs and 3 Technicians) who had been involved with work in the vicinity of the CWT. During G-YMME's 2C check in May 2004, no one recalled having removed the purge door or was aware of anyone else having removed the purge door. Of the seven TTLs interviewed, four of them did not know that the Boeing 777 had a purge door and none of the Technicians interviewed were aware of a purge door on the 777 (prior to this incident). The Boeing 747 also has a purge door (see section 1.18.4 for more information) but most were aware of it on that aircraft.

The TTL who certified that the drain and purge of the CWT had been completed was working the night shift in G-YMME's forward freight zone on 4 May 2004. This TTL, who shall henceforth be referred to as TTL1, had worked at the maintenance organisation for nine years. Although he had worked primarily on the 747, he had undergone the 777 type rating training course about 18 months before the incident so he was authorised to work on both types. One month before the incident he was promoted from an Authorised Technician to a TTL. He only worked on G-YMME for the one night shift before going back to working a Boeing 747. That night his team consisted of two Technicians and one Mechanic, all of whom worked primarily on the 747.

TTL1 recalled that the centre tank drain sumps were connected when he arrived on shift at about 2030 hrs local on 4 May 2004. He assigned one of his Mechanics and one of his Technicians to work on a corrosion inspection of the cargo door sill. His other Technician, who shall henceforth be referred to as TechA, removed the CWT access door (139AZ) on the belly of the aircraft under his supervision. TTL1 readily admitted that he did not refer to the *'Purging and Fuel Tank Entry'* procedure in the AMM to determine how to purge the CWT. He said he used "natural purging", allowing the tank to vent itself, once door 139AZ had been removed. On this basis he certified the drain and purge of the CWT as completed. He did not recall removing or asking anyone else to remove any other CWT doors or panels during his shift. He stated that he did not know where the purge door was on a 777, although he was familiar with the purge door on the 747.

TechA, who was working for TTL1 during that night shift, had worked for the maintenance organisation for 11 years as a Technician. He estimated that 99% of the time he worked on the 747 and that he had not yet been on a 777 training course. During the year leading up to the incident he only worked on the 777 on two occasions. During his night shift on G-YMME he recalled removing the CWT access door 139AZ but stated that he did not remove the purge door and did not know where it was on the 777. He said he had removed the purge door on a 747 before.

The TTL who was working the early shift in G-YMME's forward freight zone on 4 and 6 May 2004 shall be referred to as TTL2. TTL2 had worked for the maintenance organisation for the past four years on both the Boeing 747 and the Boeing 777 but until January 2004, he had only worked in the aircraft's cabins. The G-YMME 2C maintenance check was TTL2's first experience of working the forward freight zone on a Boeing 777. He recalled attaching two fuel bowsers to drain the CWT during the early shift of 4 May. He stated that he did not open or supervise the opening of any doors or panels on the CWT and that he did not know where the purge door was on the 777. He was also not aware that there was a suction hose for purging the CWT and that, if he had been involved in purging the tank, he would have allowed it to vent naturally. While G-YMME was in maintenance he did not work on any other aircraft.

TTL2 was also tasked with carrying out the rear spar inspection (see section 1.6.10.11 for detail on the rear spar inspection). He recalled going inside the CWT to carry out the rear spar lower chord inspection. He used a "sniffer" (a fuel vapour level detector) to check that the fuel vapour levels were safe and then entered the tank. It was the first time he had entered the CWT of a Boeing 777. He carried out his inspection in accordance with a diagram (Figure 10, page 26) on a Boeing task card. This diagram contained multiple errors and could readily be misinterpreted such that it was the forward spar or forward spanwise beam that required inspection (see section 1.6.11.2). TTL2 inspected the forward spanwise beam in the forward section of the CWT and did not remove the baffle doors to gain access to the rear of the CWT where the rear spar was located. After completing his inspection he checked the area for foreign objects, exited the tank and then refitted the access door (139AZ) with the assistance of a Technician. Because he did not enter the rear of the tank, there was no opportunity for him to notice a missing purge door.

A TTL who was working the left wing zone on G-YMME said he knew about the purge door on the Boeing 777 and had seen it removed occasionally but was not aware of it having been removed on G-YMME.

A Technician working on G-YMME said that he had purged the CWT on the 777 before by opening the centre access door and one inboard wing access door. He was not aware of a purge door on the 777.

The TTL who carried out the fuel leak-checks on the wing tanks and CWT of G-YMME shall be referred to as TTL3. TTL3 had worked for the maintenance organisation for the past 11 years, primarily on the 747. He completed his 777 type rating course in October 1999, but during the year prior to the incident, he had spent only 10 days working on a 777. He was tasked with leak-checking all the fuel tanks on G-YMME but he did not know where the purge door was and he had never purged the CWT of a 777 before. He could not specifically recall the fuel amounts he used to leak-check the access doors but he thought he filled the left and right wing tanks to volumetric shutoff (ie full, approximately 29,322 kg per tank). Then he pumped fuel from the wing tanks to the CWT and believed he probably used 30,900 kg (the value given in the AMM for leak-checking all the CWT access doors apart from the purge door) or possibly more. Fuel records indicated that a total of 39,976 kg of fuel was loaded onto G-YMME. It was normal procedure at the maintenance organisation to rely on a visual check without talcum powder to detect leaks and all his checks of the access doors were done visually rather than using talcum powder (the method specified in the AMM). Although this did not follow the AMM procedure, since this incident the aircraft manufacturer has stated that using talcum powder was unnecessary following routine panel installations. Boeing also stated that the company will amend the AMM to reflect this change (see safety action taken para 5.2.1).

The reason that 39,976 kg of fuel was loaded onto the aircraft was that 40 tonnes of fuel was considered by some experienced 777 engineers as a 'catch-all' quantity because, according to the AMM, 32 tonnes was the highest listed fuel figure for all the leak checks including the purge door. Another reason 40 tonnes of fuel was used was because it provided sufficient ballast on the aircraft for carrying out high-power engine runs. It is possible that the entire 39,976 kg of fuel was pumped into the CWT on G-YMME but even that amount would not have been sufficient to reach the level of the purge door.

1.6.10.9 Re-installation of centre tank belly door (139AZ)

According to the handover sheets the CWT access door on the belly (139AZ) was re-installed during the early shift on 6 May. By the end of the late shift on 6 May (2245 hrs local) the aircraft had been refuelled, which confirms that the 139AZ access door was in place at that time. However, the job card that certified the refitting of door 139AZ was not stamped until the following day, 7 May, by a Technician working the early shift.

1.6.10.10 Previous events of purge door removal

Although the maintenance organisation had not raised a routine job card for the removal of the purge door, the incident on G-YMME was not the first time the purge door had been removed on a 777 aircraft undergoing maintenance at the maintenance organisation. A search of all the completed 777 job cards revealed three instances where defect job cards had been raised to refit the purge door. The three known occasions were on the following Boeing 777 aircraft at the maintenance organisation:

G-YMMC during 2C check between 22 February 2004 and 1 March 2004
G-VIIY during 2C check between 23 October 2003 and 4 November 2003
G-YMMA during 2C check between 2 February 2004 and 13 February 2004

On G-YMMC the defect card showed that the purge door had been stamped as removed and also stamped as refitted. The engineer who raised the defect card was a TTL who worked predominantly on the 747 (on the 747 the purge door is removed on a routine job card as part of the purge procedure, see section 1.18.4). The TTL could not recall specifically raising the defect card but he recognised it as being written in his style and it showed that he had stamped for having removed the purge door.

On G-VIIY a defect card had also been raised to remove the purge door, refit it and carry out a leak check on it. The leak-check fuel amount was stated on the card as 32,000 kg in accordance with the AMM, although this is now known to be an inadequate amount. The TTL who raised this defect card recalled that he came upon the purge door reference by chance while trying to increase the purging speed of the CWT. He had previous experience of removing the purge door on the Boeing 747 CWT, so he raised a defect card with a reference to the purge door removal procedure in the Boeing 777 AMM.

On G-YMMA a defect card was raised to refit the purge door but there was no job card recording that it had been removed. The defect card was raised by a TTL experienced on the Boeing 777 who noticed that the purge door was off while he was carrying out the rear spar inspection inside the CWT. He recalled that the purge door removal was unusual so he searched the job cards but could not find a card calling for its removal. He therefore raised a defect card to cover refitting the purge door. The card also covered refitting the baffle doors but it did not include a leak check of the purge door. It is not known who removed the purge door on G-YMMA. The engineer who certified having purged the CWT on G-YMMA said that he could not recall specifically doing this but he was sure that he did not remove the purge door because he did not know that a purge door existed on the Boeing 777 until after the G-YMME incident.

In the case of G-YMMA the purge door was removed and not recorded as removed, as was the case on G-YMME. However, in the case of G-YMMA, the missing door was noticed by an experienced engineer who rectified the problem but he did not raise an occurrence report to highlight the maintenance error that had occurred. He did, however, raise a written query (QEAN[9]) to highlight the problem with the rear spar inspection procedure contained in the AMM (for more detail see section 1.17.8.1).

1.6.10.11 Rear spar inspection

An internal structural inspection of the rear spar inside the CWT was required during G-YMME's 2C maintenance check. The job card for this inspection stated:

> *"Carry out a detailed internal inspection of the wing centre section rear spar lower chord horizontal and vertical legs only from left side of body to right side of body."*

The rear spar forms the aft wall of the centre section of the CWT. It can only be inspected by entering an access hole (139AZ) in the front section of the tank, removing the baffle doors and then passing aft through the exposed openings in the spanwise beams (see Figure 11, page 26). A pictorial description of the area to be inspected was provided on a Boeing task card. This task card (revision May 2003) incorrectly showed the front spar or forward spanwise beam (depending upon interpretation – see section 1.6.11.2) as the area to be inspected and did not detail the access requirements. The engineer who carried out the inspection on G-YMME followed the pictorial description and incorrectly inspected the forward spanwise beam instead of the rear spar. Consequently, the engineer did not remove the baffle doors or enter the rear section of the CWT where the purge door was located.

1.6.11 Aircraft maintenance manual (AMM) deficiencies

1.6.11.1 AMM revisions and task cards

The AMM is updated three times a year in January, May and September. Between these revision periods any important changes that might affect safety are published and distributed as Temporary Revisions. The maintenance organisation is required by regulation[10] to follow the procedures in the AMM

9 Query for Engineering Advice Note.
10 EASA Part 145.A.45 Regulation.

unless they can demonstrate that their revised procedures result in equivalent or improved maintenance standards and they inform the manufacturer of the change. The maintenance organisation is also required by regulation to establish procedures to ensure that any inaccurate, incomplete or ambiguous procedures in the AMM are notified to the author of the AMM.

The aircraft manufacturer also publishes maintenance task cards which contain the procedures and instructions from the AMM for a particular task. These task cards perform a similar function to the job cards produced by the maintenance organisation. At the maintenance organisation the job cards take precedence and the Boeing task cards are only used as reference material for assisting engineers in carrying out inspections, as the task cards illustrate the area to be inspected.

During this investigation several deficiencies and omissions were uncovered within procedures in the AMM and in the Boeing task cards. In addition to the incorrect purge door leak check quantity, and the missing purge door references in both the CWT purge procedure and the fuel tank leak-check procedures, deficiencies were found in the rear spar inspection diagram (see para 1.6.11.2). Also, the inspection procedures for the CWT did not contain any reference to the removable baffle doors and the baffle doors were not depicted in any diagram. (see para 1.6.11.3).

1.6.11.2 Rear spar inspection diagram deficiencies

The Boeing task card for the rear spar inspection (last revised on 5 May 2003) stated:

> *'Wing Center Section – REAR SPAR, lower chord horizontal and vertical legs only, from left side of body to right side of body LOWER PANEL, access hole 139AZ only.'*

The ensuing instructions simply stated '*Do the inspection*' and then the illustration depicted in Figure 10 followed. The AMM (also last revised 5 May 2003) contained the same instructions and the same diagram.

There are a number of errors in Figure 10 and these can best be visualised by comparing it to a corrected diagram in Figure 11. Both figures depict the forward section of the centre section of the CWT, but Figure 10 has the front spar incorrectly labelled as the rear spar, the STA (station) numbers are reversed and the FWD arrow in the lower diagram of Figure 10 points the wrong way. In Figure 10 the area shown to be inspected (A-A) is the lower section of the front spar but it could be interpreted to be the lower section of the forward spanwise beam due to the FWD arrow pointing the wrong way. A new diagram, Figure 12, clearly shows the aft section of the CWT and the area to be inspected on the rear spar.

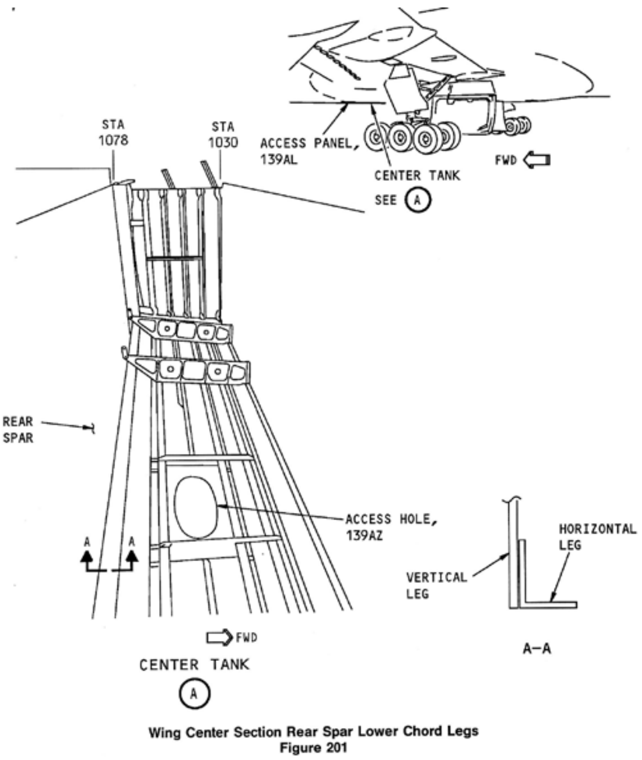


Figure 10

Rear spar inspection diagram with errors (Rev 5 May 2003)
(Copied with permission of The Boeing Company)

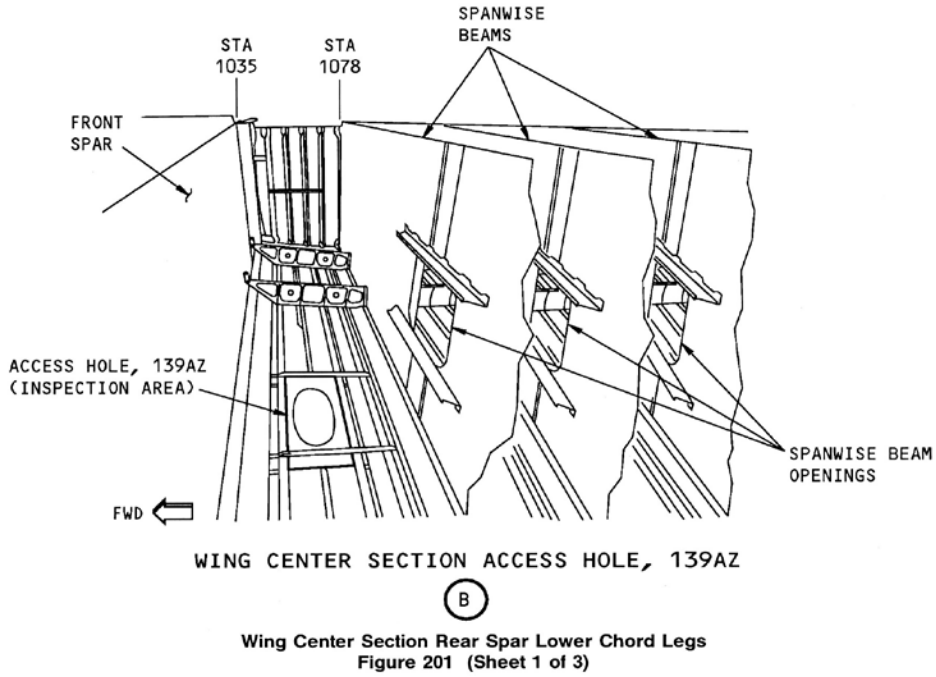


Figure 11

Revised diagram for rear spar inspection, part 1 (Rev 5 September 2004)
(Copied with permission of The Boeing Company)

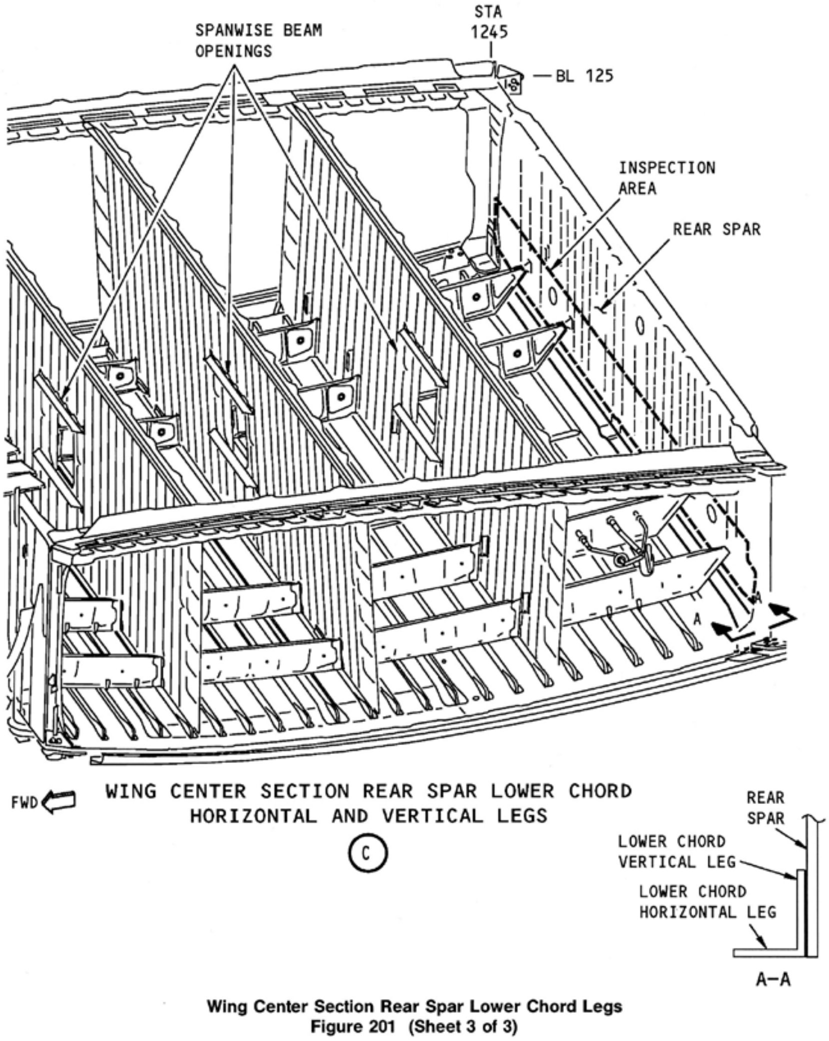


Figure 12

Revised diagram for rear spar inspection, part 2 (Rev 5 Jan 2005)
(Copied with permission of The Boeing Company)

The revised and corrected diagrams shown in Figure 11 and Figure 12 were published in a revised Boeing task card on 5 January 2005. Figure 11 was published in a revised AMM on 5 September 2004 and Figure 12 was published in a revised AMM on 5 January 2005 (interim diagrams were published prior to these - see section 5.2.1 on safety action for details).

1.6.11.3 Missing baffle doors in AMM

The centre section of the CWT is separated into four bays by spanwise beams (see Figure 6, page 10). Each spanwise beam has an opening to permit access between the bays. On 'wet' centre wing 777 aircraft such as G-YMME, these spanwise beam openings are closed with removable baffle doors (see Figure 7, page 11). The Boeing 777-200 variant with a 'dry' centre wing does not have these baffle doors. The AMM (Rev 5 May 2004) which applied to both 'dry' and 'wet' Boeing 777 centre wings did not contain any reference to the baffle doors in any CWT related procedure. Moreover, the baffle doors were not depicted in any diagram in the AMM. Removing the baffle doors was, however, necessary to carry out the rear spar inspection on G-YMME.

1.7 Meteorological information

When G-YMME departed Heathrow the surface wind was 240°/12 kt and the visibility was greater than 10 km. The main cloud base was at 25,000 feet with some isolated cloud at 4,200 feet. There was no significant change to the weather during the period of the flight.

1.8 Aids to navigation

Not applicable.

1.9 Communications

Communications between the various Air Traffic Control agencies and the aircraft were recorded. The controller working the London Heathrow Tower (Departures) frequency informed the flight crew about the vapour trail from the incident aircraft and updated them with visual reports from other aircraft. These observations were significant as nothing could be seen by those on board the incident aircraft. Once the aircraft commander had made his decision to jettison fuel and return to Heathrow, communication was transferred to discrete radio frequencies until the aircraft was established on final approach at Heathrow.

1.10 Aerodrome information

Runway 27L at London Heathrow Airport has a Landing Distance Available (LDA) of 3,658 metres. The performance section of the company's Quick Reference Handbook advises that in the prevailing conditions, with flaps 30 and autobrake 1 selected, a minimum landing distance of 2,527 metres would be required.

1.11 Flight recorders

The aircraft was fitted with a solid state Cockpit Voice Recorder (CVR) and a solid state Flight Data Recorder (FDR) that recorded a comprehensive range of parameters. The aircraft was also fitted with a Quick Access Recorder (QAR) which recorded the same parameters as those on the FDR. It was decided that the QAR data would provide sufficient information for analysis related to fuel leakage.

Fuel and aircraft weight parameters on the QAR included centre, left and right fuel tank contents; fuel used by each engine; left and right engine fuel flow; aircraft zero fuel weight and gross weight.

Using the above parameters, an estimate of the fuel leakage was derived by comparing the rate of reduction of the CWT contents with the fuel used by the engines. The calculation was done over the period covering the acceleration during takeoff until the aircraft was in level flight at FL60 and the fuel jettison process was initiated. During this period the left and right wing fuel tank contents remained constant at about 28,700 kg each. The elapsed time was from about FDR subframe 830 seconds to FDR subframe 1,970 seconds or about 19 minutes.

During this time the CWT fuel contents parameter decreased from 43,100 kg to 34,100 kg, giving a calculated reduction of 9,000 kg. However, according to the Boeing 777 data recording system document (ref D247w018-8) the accuracy of the CWT fuel contents parameter varies as a function of tank content level, and aircraft pitch and roll attitude. Because the CWT was less than half full and the aircraft was in the climb for part of the flight before fuel was jettisoned, the accuracy of the CWT contents measurements was inferred to be about ± 1,500 kg.

Because the fuel consumed by both engines in the same period was 7,280 kg, the calculated fuel leakage was thus:

$$(9{,}000 \pm 1{,}500 \text{ kg}) - 7{,}280 \text{ kg} = 1{,}720 \pm 1{,}500 \text{ kg}.$$

This value is close to the calculated accuracy of the CWT fuel contents, and so the amount of fuel lost to leakage could not be determined.

The fuel jettison process took place between FDR subframes 1,970 and 3,430 seconds (an elapsed time of 24 minutes 20 seconds), during which the total fuel contents decreased from 92,100 kg to about 35,150 kg. The fuel used by the engines in this period was about 6,000 kg, so the fuel jettisoned was about 50,950 kg, giving a calculated fuel jettison rate of about 2,100 kg/min. The published jettison rate was 2,500 kg/min with fuel in the CWT and 1,400 kg/min with an empty CWT.

1.12 Wreckage and impact information

Not applicable.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

There was no fire.

1.15 Survival aspects

Not applicable.

1.16 Tests and research

None.

1.17 Organisational and management information

1.17.1 Maintenance organisation structure

The maintenance organisation was a wholly owned subsidiary of the operator. It was established in 1993 and was approved under EASA Part 145[11]. It undertook all the heavy maintenance of the operator's fleet of Boeing 747 and Boeing 777 aircraft. In December 2004 the company had a total of 667 employees, consisting of 23 managers, 112 LAEs, 208 Technicians, 198 Mechanics and 126 support staff. The LAEs, Technicians and Mechanics made up 78% of the work force.

A top level organisation chart is shown in Figure 13. The General Manager, also known as the Accountable Manager for quality purposes, was in charge of the maintenance organisation and was a member of the organisation's board of directors. The Planning Manager was in charge of the group responsible for planning all maintenance work and for creating the job cards. The Technical Services Manager ran the Technical Services group which was responsible for answering technical queries from the shop floor (such as how to carry out a specific repair) and for providing company specific technical directions. The Quality/Health & Safety Manager was responsible for the quality of maintenance and for the health and safety of employees. There were three Production Bay Managers who were each responsible for one of the production bays at the maintenance organisation. The Aircraft (A/C) Controllers reported to a Bay Manager and they were responsible for a particular aircraft undergoing

[11] EASA Part 145 contains regulations concerning maintenance organisations. EASA Part 145 replaced Joint Aviation Regulation JAR 145 with effect from 29 November 2003.

maintenance. The LAEs, Technicians and Mechanics all reported to an Aircraft Controller. Although the Technicians and Mechanics worked for a Technical Team Leader (TTL), who was an LAE, the Technicians and Mechanics were line-managed by an Aircraft Controller.

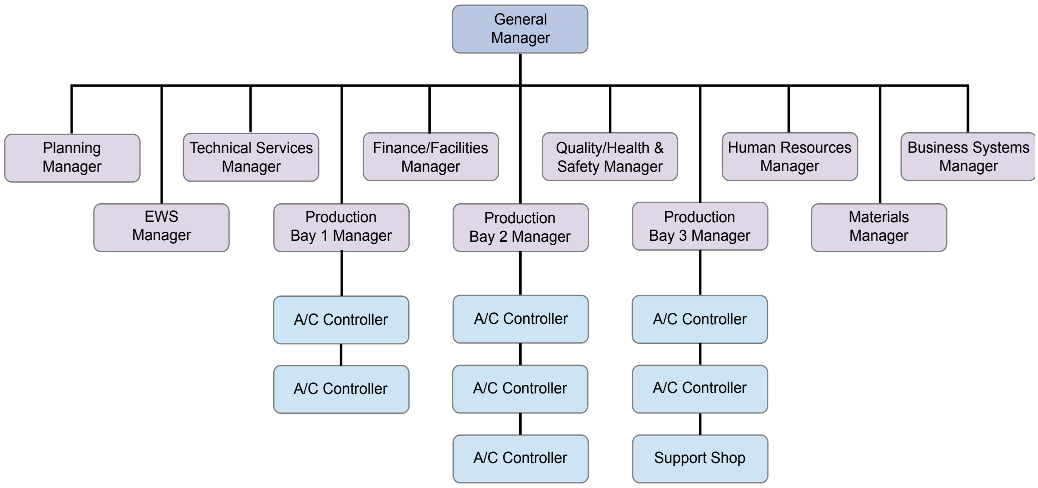


Figure 13

Top level organisational structure of maintenance organisation

1.17.2 Relationship between the operator and the maintenance organisation

The operator subcontracted all its Boeing 777 base maintenance to the maintenance organisation. The operator also owned the maintenance organisation and was, therefore, accountable for its operation. The maintenance organisation's board of directors was chaired by the operator's Director of Engineering. The other two board members were the operator's Finance Manager and the maintenance organisation's General Manager. Consequently, staff appointments at the maintenance organisation were ultimately controlled by the operator.

To comply with EASA Part 145 the operator and the maintenance organisation were required to have an Interface Agreement establishing the responsibilities of each organisation. The Interface Agreement in place at the time of the G-YMME incident was Revision G dated 12 March 2003. This Interface Agreement referred to the superseded JAR-145 regulations although these closely mirrored the EASA Part 145 regulations that replaced them[12]. The agreement described the responsibilities of the Quality Manager, Planning Manager, Technical Services Manager and Production Bay Managers at the maintenance organisation. It

[12] The Civil Aviation Authority allowed UK operators and maintenance organisations a grace period for updating their documentation to reflect the change from JAR 145 to EASA Part 145 regulations.

also described the responsibilities of the operator's Fleet Planning Manager, Materials Manager, Operations Quality Manager, NDT (non-destructive test techniques) Manager, Technical Information Services Manager and Fleet 2 Technical Manager. Some top-level procedures were also included in the agreement which referred to occurrence reporting and the tracking of spares and materials.

Among the responsibilities listed were the following: The operator's Operations Quality Manager '*establishes and maintains an audit schedule to monitor standards at BAMC*.' The operator's Technical Information Services manager '*provides relevant technical information*' and provides the maintenance organisation's Planning Department with all technical documentation and drawings – this is interpreted to include the AMM. The maintenance organisation's Technical Services Manager was to act as the operator's technical representative and had responsibility for issuing and approving design documents for Boeing 747 and 777 series aircraft, pertaining to all deviations from approved data.

The Interface Agreement also established that regular meetings would take place between the operator and the maintenance organisation, including but not limited to a monthly supply chain meeting, a monthly maintenance plan committal meeting, a quarterly maintenance task committal meeting and a quarterly ('*or as necessary*') quality/performance forum.

The Interface Agreement did not state who had responsibility for the content of the job cards. At the time of the G-YMME incident, the maintenance organisation was generating the job cards with no oversight from the operator yet the job cards had to be generated in accordance with the operator's Approved Maintenance Programme (AMP)[13].

As a result of misunderstandings between the maintenance organisation and the operator concerning responsibility for ensuring compliance with the requirements of the AMP, the Civil Aviation Authority (CAA) wrote to the operator on 13 July 2004 to clarify the situation. The letter stated that JAR Ops 1.890[14] '*simply and unequivocally*' placed the responsibility with the operator for ensuring that the requirements of the AMP were met. It stated that the maintenance organisation could be sub-contracted by the operator to prepare job cards but the maintenance organisation was not responsible for ensuring that they complied with the AMP. The maintenance organisation

[13] The Approved Maintenance Programme (AMP) contains all the maintenance tasks and states at what intervals (cycles or flight hours) the tasks will be carried out. The AMP is based on the manufacturer's Maintenance Planning Document (MPD).

[14] JAR Ops (operations) regulations (subpart M) remained in effect until 28 September 2005. They were then replaced by EASA Part M.

was only responsible for ensuring that the work required by the operator was accomplished correctly. The letter further stated that the operator could fulfil its responsibility by conducting a comprehensive audit of the job cards in use at the maintenance organisation (see safety action taken para 5.3).

1.17.3 Quality Regulations

As a Part 145 approved organisation, the maintenance organisation needed to comply with the quality regulations of EASA Part 145.A.65. These regulations state that:

> *'the organisation shall establish procedures agreed by the competent authority taking into account human factors and human performance to ensure good maintenance practices and compliance with this Part…'* (the competent authority refers to the CAA in this case).

The regulations continued with:

> *'the organisation shall establish procedures to minimise the risk of multiple errors and capture errors on critical systems…'*

The organisation also has to establish a quality system that includes:

> *'independent audits in order to monitor compliance with required aircraft/aircraft component standards and adequacy of the procedures to ensure that such procedures invoke good maintenance practices and airworthy aircraft/aircraft components.'*

The organisation also has to establish a '*quality feedback reporting system'* and take proper and timely corrective action in response to reports.

The quality regulations spell out the 'top level' requirements for a quality system but it is the responsibility of a maintenance organisation to develop the more detailed or specific procedures that are acceptable to the CAA.

1.17.4 Quality Group

The Quality Group at the maintenance organisation was managed by the Quality/Health & Safety Manager. According to the company's Maintenance Organisation Exposition (MOE):

'The Quality Manager is responsible for monitoring the company's compliance with [EASA] Part 145 [Regulations] and requesting remedial action as necessary by the General Manager or Departmental Heads.'

The Quality Manager managed a team of one Quality Team Leader, one Quality Engineer and one Quality Assurance Assessor.

1.17.5 Quality Assurance Procedures at the maintenance organisation

The maintenance organisation had established a number of procedures to ensure the quality of the maintenance work carried out and to ensure compliance with the regulations. The primary responsibilities carried out by the Quality Group were as follows:

1. Controlling and issuing stamps, authorisations and approvals to engineers and carrying out engineer oral examinations as part of the process.
2. Controlling, evaluating and approving suppliers to the maintenance organisation.
3. Carrying out audits to ensure airworthiness integrity and compliance with regulations.
4. Monitoring and controlling an occurrence reporting scheme.
5. Publishing, approving and producing company procedures.

The group carried out a number of internal audits on the organisation. These audits included aircraft, stores and materials, facilities, planning, production, technical services and technical publications, technical training, technical records and more. Each of the groups that were audited was also required to complete product sample reports and forward them to the Quality Group.

The '*Production Area Product Sample Report'* was carried out monthly by an aircraft controller and its purpose was to find any deficiencies of an airworthiness or quality nature. It included inspections of the Technical Log, working practices, mandatory read information log, hangar environment and the aircraft. As part of the aircraft inspection, three maintenance tasks were chosen at random and the standard of the maintenance work, including completion of aircraft documentation, was examined.

The Quality Group examined the Production Area Product Sample Reports for any deficiencies and ensured appropriate action was taken to address them. The Quality Group also independently carried out an annual quality audit of an aircraft each year (one of each type every year). During an aircraft audit they were to check for compliance of tasks to the operator's list of work requirements, acceptable completion of job cards, acceptable standards of inspection and workmanship, acceptable shift changeover procedures, usage of up-to-date technical information and AMM, and additional checks.

Together the Production Area Product Sample Reports and the annual aircraft audits could only serve to check a very small proportion (a 'snapshot') of the maintenance work being carried out. The company relied on the training, skills and professionalism of the Mechanics, Technicians and LAEs to produce good quality work with a quality check, where applicable, by the TTL. This system defined the concept of a quality assurance system as opposed to a quality control system.

1.17.6 Differences between Quality Assurance and Quality Control

Some years ago many maintenance organisations moved from a system of Quality Control to one of Quality Assurance. The maintenance organisation has always employed a Quality Assurance system. The two concepts are fundamentally different in their approach.

A traditional Quality Control system required specialist inspectors whose function was to physically check and certify that all steps of maintenance tasks had been correctly executed in accordance with approved instructions. When strictly applied, this meant that the work had to stop for an independent inspection to be performed prior to any activity that would preclude subsequent access for inspection of the work completed thus far, or when the next stage was critically dependent on the previous one being correct, until an inspector had certified it.

One of the key differences with the concept of Quality Assurance is the shift from independent checks of the work performed, to individuals having responsibility for the quality of their own work. As a result, the airline maintenance industry has generally adopted the process of self-certification for certain types of task which are deemed as non-critical to airworthiness. In this case, the person performing the task stamps a job card to signify that he/she has completed the task and then further stamps the card to certify that the work has been completed to the appropriate standards of airworthiness.

The foundations of a successful Quality Assurance system are comprehensive working procedures which are fully adopted by staff that are appropriately trained and qualified. It places greater responsibility on the individual for ensuring that tasks are performed to the required standard.

1.17.7 Quality oversight by the operator

JAR-Ops Regulation 1.900 required that the operator monitor sub-contracted maintenance organisations to ensure that all contracted maintenance was carried out in accordance with the contract (ie the Interface Document). The frequency of monitoring (or auditing) was to be agreed between the operator and the National Aviation Authority[15]. Initially, the operator in this case was carrying out annual audits of the maintenance organisation. The most recent audit (termed '*Compliance Audit*') prior to the G-YMME incident was carried out between 11 and 12 December 2002. During this audit five non-conformances were identified but none was considered high risk and so the audit report recommended that the period between audits be increased from 12 months to 18 months. This change was not discussed with the CAA. However, the CAA stated during this investigation that had they been consulted, they would not have objected to the change. Although 18 months was the new audit period, the subsequent audit was not performed until 22 months later; on 1 October 2004. This audit included checks of safety actions taken by the maintenance organisation following the G-YMME incident.

The operator did not rely solely on its compliance audits for oversight of the maintenance organisation. The operator used an electronic eBasis[16] reporting system to report in-service maintenance related problems to the maintenance organisation. To prevent recurrence, the maintenance organisation had to respond to the operator through eBasis with their investigation findings and safety action taken. The operator's Quality Group also had regular informal meetings with the maintenance organisation's Quality Group (approximately every 3 months) to discuss maintenance related quality issues.

1.17.8 QEAN and PQF process

Anyone at the maintenance organisation could obtain engineering advice by submitting a written electronic 'Request for Engineering Advice Form', also known as a QEAN (Query for Engineering Advice Note). A sample QEAN

[15] JAR OPS AMC (Acceptable Means of Compliance) 1.035 stated: '*All aspects of the operation should be reviewed within every period of 12 months in accordance with the programme… [An operator] should not decrease the frequency without the agreement of the Authority. It is considered unlikely that an interval between audits greater than 24 months would be acceptable for any audit topic.*'

[16] A computer based reporting system accessible from all company computer terminals. It is used to record all safety-related incidents including air safety and engineering quality lapses.

is shown in Appendix 2. The QEANs were received electronically by the Technical Services group who were responsible for providing a written response to them. QEANs would typically concern issues on how to perform a repair, how to carry out an inspection or how to interpret a service bulletin from an aircraft manufacturer. In many instances the query would be passed to the aircraft manufacturer for a response. At the time of the G-YMME incident, the maintenance organisation did not have a tracking process for QEANs to identify which ones were still unanswered ('open'). The system relied on individual engineers in the group remembering which ones they were dealing with and which ones were still unanswered or 'open'.

In general this did not cause any problems because the majority of QEANs would be answered within the time period of the affected aircraft arriving and departing the maintenance facility. However, one QEAN directly relating to the G-YMME incident was still unresolved after more than two years and its status forgotten (see section 1.17.8.2).

A separate but similar process called PQF (Planning Query Form) was used by engineers to raise queries involving planning issues such as problems with job cards. The PQF system was paper-based. Sometimes the generation of a PQF by a production engineer (ie a Mechanic, Technician, or LAE working the shop floor) to a planning engineer would result in a QEAN being raised by the planning engineer to the Technical Services group if the planning engineer did not have the information to answer the PQF.

On 17 December 2003, the PQF process was suspended at the maintenance organisation because the planning engineers were too heavily involved in implementing EWS (Engineering Wide System - see section 1.17.10 for more detail about EWS) to be able to respond to PQFs. The process was re-instated on 31 March 2004 (prior to the G-YMME incident) but the engineers were not informed of its resumption. After the G-YMME incident some engineers interviewed believed that the process was still under suspension.

1.17.8.1 Query relating to rear spar inspection diagram

Two months before the G-YMME maintenance input, on 4 March 2004, an experienced TTL raised a QEAN to highlight the errors in the rear spar inspection diagram in the Boeing task card. He requested clarification as to whether it was the front spar or the rear spar that needed inspecting. A technical services engineer responded to the QEAN the following day by stating that it was the rear spar that needed inspecting (in accordance with the AMP) and that he would contact the aircraft manufacturer to query the rear spar inspection diagram. No action was taken to withdraw the confusing diagram or to highlight its errors to other maintenance staff. Also, no action was taken to determine if rear spar inspections on previous aircraft had been carried out correctly.

On 16 March 2004, the technical services manager sent a fax to the aircraft manufacturer advising them of the errors in the rear spar inspection diagram. The fax also noted that to accomplish the rear spar inspection, the baffle doors needed to be removed but no such access requirements were listed in the inspection procedure. The actions requested of the aircraft manufacturer in the fax were to confirm the intent of the rear spar inspection and to confirm that the diagram was incorrect. No action regarding the baffle doors was requested of the manufacturer.

The aircraft manufacturer responded to the request by 'fax' on 23 March 2004 but this fax went missing and so, prompted by a follow-up query from the maintenance organisation, it was re-sent on 15 April 2004. The manufacturer confirmed that the rear spar was the area to be inspected and confirmed that the diagram was incorrect and would be corrected in time for the May 2004 AMM revision cycle. The baffle door issue was not mentioned.

A corrected version of the rear spar inspection diagram was published in the 5 May 2004 revision (Revision 41) of the AMM and of the Boeing task cards (see Appendix 3, it is an earlier version of Figures 11 and 12). This AMM revision was shipped to the operator on a CD (Compact Disc) on 22 April 2004 but, for unknown reasons, it was not received by the operator until 8 June 2004 (a month after the G-YMME maintenance). However, even without this delay the revised diagram would not have been sent to the maintenance organisation in time for G-YMME's maintenance because the operator and the maintenance organisation were under an AMM freeze period and were still using AMM revision 39, dated 5 September 2003 (see section 1.17.11 for the reason behind the freeze). This AMM freeze continued at the maintenance organisation until 24 January 2005. However, following the G-YMME incident, a copy of the revised diagram was sent to the maintenance organisation on a CD on 19 July 2004.

1.17.8.2 Query relating to baffle doors

To carry out the rear spar inspection three baffle doors inside the CWT must first be removed, but as previously mentioned in section 1.6.11.6, no job cards or AMM reference existed for the baffle doors. This problem may have first been identified in 2002. On 11 March 2002 a planning engineer raised a QEAN concerning the lack of a baffle door reference. This QEAN was raised in response to a PQF from a production engineer who requested that routine job cards to remove and refit the CWT baffle doors be raised (a copy or record of this PQF could not be found but it was referenced in the QEAN). The planning engineer who received this PQF could not find any reference to the baffle doors in the AMM so he raised the QEAN which requested that technical services provide panel numbers for the baffle doors. The planning engineer could then use the panel numbers to raise job cards for removing and refitting the baffle doors.

Two months later, on 9 May 2002, a technical services engineer responded to the QEAN by stating that part numbers for the baffle doors could be found in the Illustrated Parts Catalogue (IPC). However, the planning engineer had requested panel numbers (ie such as 139AZ for the belly door) and not part numbers. On 10 May 2002 the planning engineer raised another QEAN, referencing the previous QEAN, stating:

> *'we request some panel numbers not part numbers. Now that you have a part number for said panel could it not now be furnished with a panel number and added to the relevant part of the AMM.'*

On 23 May 2002 a technical services engineer responded to the QEAN stating that he had informed the aircraft manufacturer that the baffle doors were missing from its MPD (Maintenance Planning Document). On the same day he sent a fax to the aircraft manufacturer requesting panel identification numbers for the CWT baffle panels. The aircraft manufacturer responded the next day stating that:

> *'Boeing baffle ribs are located at Ribs 2,3,4,5,13, and 15 on the wing… each of these ribs have openings for access, but no panels. There are no access panels to these areas on the bottom of the wing.'*

For some reason the aircraft manufacturer mistook the request to relate to the ribs inside the wing rather than the spanwise beams inside the centre section of the CWT. Technical services appeared to overlook this discrepancy and no further action was taken.

A year later, on 23 June 2003, the planning engineer, who originated the first two QEANs, wrote another QEAN stating that he had not yet seen any evidence of the baffle panels appearing in the MPD or AMM. A technical services engineer responded to the QEAN stating that the lack of baffle panel references had been communicated to the aircraft manufacturer and that it was in their hands and that:

'these changes will come but at this present time they are slow and we, unfortunately, cannot pressurise Boeing to speed up.'

This response was incorrect because the aircraft manufacturer had closed the issue, having responded to the fax in May 2002. The open query had not been tracked and the technical services engineer who had faxed the aircraft manufacturer had in the meantime left the maintenance organisation. The Technical Services Manager was relying on his memory when he was asked what was happening about the baffle doors. Although the query was still open the QEAN had been closed because a response was issued. The response stating '*we will contact the manufacturer*' closed the QEAN but the query was still unanswered and this fact was not tracked.

At no time did the planning group consider issuing routine job cards to remove and refit the baffle doors using the IPC part numbers as a reference. Therefore, the system was relying on defect cards being raised on the shop floor each time the baffle doors were removed. However, there were few cases of this having been accomplished.

Following the G-YMME incident the AAIB asked the aircraft manufacturer why the CWT diagrams in the AMM did not show the baffle doors on the spanwise beams. The manufacturer's safety services group responded that there were no baffle doors installed in the openings. Eventually they discovered that baffle doors were fitted to the spanwise beams of 'wet tank' 777 aircraft and the AMM, MPD and Boeing task cards were revised accordingly. For some reason the addition of baffle doors when the 'dry tank' on the 777 was converted to a 'wet tank' was overlooked when the AMM for the 777ER was first created.

1.17.9 Job card engineering

Engineering the job cards involves careful consideration of what information is required to carry out the task, what access requirements might be required, the time involved and what equipment might be required. If an access requirement was required then an additional 'panel removal' card would be raised and linked to the original job card. The rear spar inspection job card was not 'fully engineered' because the access requirements were overlooked and the erroneous diagram in the manufacturer's task card was not noticed. Instead the rear spar inspection job card became a near copy/paste of the manufacturer's task card.

The purge and drain job card was also not fully engineered because consideration was not given to the fact that draining and purging were two separate tasks that can occur many hours apart. The person who wrote the job card also did not appreciate that there were only two drain ports on the CWT.

Most of the job cards concerning the CWT were created in 1999 before a 777 aircraft had arrived at the maintenance organisation. Therefore the planners were writing cards for tasks on an aircraft that they had not seen or worked on. Many of the planners writing the cards were non-certifying Technicians who had been seconded from production because this was normal staff rotation policy at the maintenance organisation. Their cards were then reviewed and authorised by a planning engineer. However, one of the planning engineers who authorised some of the job cards, including the purge and drain card, had been seconded from Planning Control. He was not as experienced at writing job cards as most planning engineers and he only had temporary authority to approve job cards.

The ability of the planning group to engineer job cards fully was also affected by the introduction of EWS.

1.17.10 Effects of EWS database introduction

In April 2002 preparations began at the maintenance organisation for the introduction of a new database system called EWS (Engineering Wide System) which was developed using SAP software (Systems, Applications and Products in Data Processing). The plan was that EWS would at some point replace many different legacy database systems in use by both the maintenance organisation and the operator. For example, EWS would replace both the maintenance organisation's 'Open Air' job card database and the operator's 'OMEGA' database which contained their own job cards for their base maintenance. EWS would also include the stores database for tracking parts and materials.

In October 2002 data migration to EWS was begun by eight engineers in the planning group. No extra resources were provided for the introduction of EWS and therefore other work normally done by the planning group had to be sacrificed. Eventually this included suspending the PQF process in December 2003. Revisions to job cards and all new job cards had to be created on both EWS and on the 'Open Air' system which was still 'live', effectively doubling the workload for these tasks. Before the introduction of EWS, the planning group would fully engineer tasks by breaking them down into component parts and also providing kitted materials for the task. Following the EWS introduction the planning group would often only have time to copy and paste the tasks from the aircraft manufacturer's MPD.

Another time saving measure introduced by the planning group as a result of EWS was the removal in September 2003 of Illustrated Task Cards (ITCs) which accompanied job cards. Job cards only contained text and therefore the ITCs helped the engineer to understand the task to be carried out and reduced time spent printing out diagrams from the electronic AMM. A benefit of EWS is that illustrations from the AMM will be included in the job card database system.

The introduction of EWS also resulted in a freeze of the AMM. This meant that job cards could not be updated in either system when a procedure in the AMM was revised except by Temporary Revision (TR) as described below.

1.17.11 Aircraft Maintenance Manual (AMM) freeze period

The operator and the maintenance organisation obtained permission from the CAA to freeze the Boeing 777 AMM until 1 October 2004 to facilitate the implementation of EWS. The AMM was frozen at Revision 39 (issued 5 September 2003). The plan was that all future revisions would be reviewed by the operator's fleet engineers and any changes deemed to affect aircraft safety or health & safety would be raised in a Temporary Revision and sent to the maintenance organisation. Due to problems with EWS the freeze period was extended and Revision 40 from January 2004 was not added to the database at the maintenance organisation until 24 January 2005. During this freeze period of more than one year, none of the AMM revisions (Revisions 40, 41 and 42) were sent to the maintenance organisation. Moreover, the operator did not raise any TRs as a result of its review of those revisions until after the G-YMME incident. Revision 41 included the change to the rear spar inspection diagram. This would not normally have been considered a change significant enough to warrant a TR, but once its relevance to the G-YMME incident was discovered, the operator issued a TR. All TRs originated by the aircraft manufacturer were, however, passed on to the maintenance organisation during the freeze period.

AMM Revision 41, with the corrected rear spar inspection diagram, was sent by the manufacturer on 22 April 2004 but for unknown reasons it was not received by the operator until 8 June 2004.

1.17.12 Panel storage procedures at the maintenance organisation

The company's procedure for storing removed components from an aircraft was included in their Material Control procedure. The procedure stated that:

> *'All serviceable components removed from the aircraft are to be clearly labelled with a PR0066 label, which identifies the*

component and the aircraft from which it was removed. The component should then be stored on the clearly marked serviceable racks adjacent to the work area.'

Completing the refit job cards should ensure that all panels were refitted, but verifying that the panel storage rack was empty at the end of a maintenance input provided an extra safety net for capturing missed panels. However, this safety net would not capture panels that were removed but left connected to the aircraft on a lanyard. The purge door was one such panel that could be removed but left secured to the aircraft with a lanyard. There were also other panels on the aircraft that fell into this category, such as the engine strut access doors. Before the G-YMME incident, the maintenance organisation did not have a procedure for dealing with such panels.

It should, however, be noted that the purge door removal procedure in the Boeing 777 AMM called for the purge door to be completely removed from the aircraft, but the procedure could be interpreted that complete removal was only necessary if the door was to be replaced rather than simply opened for purging. The purge door procedure on the Boeing 747 (see section 1.18.4) allowed the purge door to be left hanging on its lanyard when it was opened for purging.

1.17.13 Currency requirements of maintenance engineers

A number of the maintenance personnel working G-YMME during its 2C check had not recently worked on a 777 aircraft and were more experienced on the 747 aircraft. The EASA Part 145 regulations require that LAEs have at least six months of relevant aircraft experience in any consecutive two year period. The regulations do not require that LAEs have type specific experience in the two year period. Therefore, an LAE who has worked solely on 747 aircraft for the past two years is permitted by regulation to work on a 777 aircraft. There are no regulatory recency requirements for unlicensed Mechanics or Technicians. However, Part 145 requires that '*The organization shall establish and control the competence of personnel involved in any maintenance...*' The regulations also require that LAEs receive continuation training every two years. At the maintenance organisation continuation training was provided to all production staff every two years. The maintenance organisation had recency requirements for issue of type authorisations but once an LAE, Technician or Mechanic had been authorised on type, he or she no longer had to meet any type recency requirements to work on a specific type of aircraft. The maintenance organisation had a production procedure called '*Manpower Control*' but neither this procedure nor any other addressed recency when moving people between aircraft types. However, the company stated that the people who carried out the maintenance on G-YMME '*were competent and correctly trained and approved.*'

1.17.14 Occurrence reporting system at the maintenance organisation

There were three types of occurrence reports used at the maintenance organisation at the time of the incident. These were: Mandatory Occurrence Reports (MOR[17]s), Ground Occurrence Reports (GORs) and Quality Discrepancy Reports (QDRs). All three types of reports could be raised by any individual at the maintenance organisation by using the same QL0001 form. The three types were classified as follows:

1. MOR, Mandatory Occurrence Report: for notification of incident/malfunction relating to an aircraft or component which could endanger the aircraft or a person.
2. GOR, Ground Occurrence Report: for notification of defects found during aircraft or component maintenance which are worthy of special attention.
3. QDR, Quality Discrepancy Report: for notification of any item of an airworthiness nature relating to aircraft maintenance operations/procedures.

The reports were then classified according to risk category and, where necessary, an investigation into the report would be initiated. There was, however, particularly in relation to internally raised QDRs, no provision for providing feedback to the reporter. Most GORs were raised by the operator and the operator would receive a response on the action taken. All MORs, GORs and QDRs were logged on the maintenance organisation's Paradox computer database.

1.17.15 Reporting of maintenance errors at the maintenance organisation

The majority of reported occurrences at the maintenance organisation fell under the QDR category and it was in this category that one might expect to find internally generated reports of maintenance errors. However, a review of all the QDRs (approximately 150) for a six month period leading up to the G-YMME incident (1 December 2003 to 30 May 2004) did not reveal any internal maintenance error reports. The majority of QDRs concerned damaged or un-serviceable parts on the aircraft. Other QDRs concerned

[17] MORs are reports required by the Civil Aviation Authority in accordance with CAP 382.

damaged tools, out-of-date drawings, out-of-date parts, incorrect labelling, wrong parts supplied and a health and safety incident. There were reports of an incorrect assembly and a part not fitted correctly but these errors did not necessarily occur at the maintenance organisation.

Most reported maintenance errors were discovered and then reported by the operator once the aircraft had returned into service. The operator would file these reports under GORs or an MOR if it was very serious. A review of all the GORs between February 2003 and February 2005 revealed that 34 out of a total of 82 GORs were considered caused by 'task errors'. The next most common cause was 'significant spares issues' (23 out of 82). These GORs included both Boeing 777 and Boeing 747 aircraft maintained at the maintenance organisation.

One of the operator's GORs revealed a 'task error' similar in nature to the failure to refit the purge door on G-YMME. During a routine turn-around check at Heathrow, following base maintenance at the maintenance organisation, an engineer discovered that a panel inside the avionics bay of a Boeing 747 was lying on the floor with its bolts in a plastic bag tied to a panel. This maintenance error was investigated by the maintenance organisation but no records could be found regarding work in that area and an interview of personnel did not reveal any additional causal information.

No other reported 'task errors' were found that were similar in nature to the failure to refit the purge door on G-YMME. However, it is known that on at least one previous occasion the purge door was removed and not recorded as removed (G-YMMA see para 1.6.10.10) but because this error was caught prior to the aircraft departing the maintenance organisation, it was not reported.

An engineer at the maintenance organisation carried out an anonymous survey of 50 engineers within the organisation, as part of a personal project for a university degree. The survey asked the engineers to provide a narrative report of a maintenance error which they had been a party to in some way. Several anonymous reports were returned in which personal errors were admitted. One reported incident was considered serious but until that time it had not been reported.

1.17.16 Disciplinary policy at the maintenance organisation

The maintenance organisation's disciplinary policy was managed by the Human Resources group and it listed the procedures to be taken to deal with cases of misconduct. Examples of 'Misconduct' listed in the procedures were:

'failure to reach expected standard of performance or behaviour', 'absenteeism', and 'poor time keeping'.

These forms of misconduct would result in progressive disciplinary action being taken. However, in cases of 'Gross Misconduct', the employee would normally be dismissed without warning. Examples of 'Gross Misconduct' listed were:

'theft', 'conduct prejudicial to safety', 'incapacity on duty due to the effect of alcohol or drugs', 'disobedience of lawful and reasonable orders',

and others. In cases of misconduct the progressive stages of disciplinary action were: Stage 1 Verbal Warning, Stage 2 First Written Warning, Stage 3 Final Written Warning, and Stage 4 Final Stage (usually resulting in dismissal).

The policy did not specifically address maintenance errors and it was not evident from the policy what types of maintenance error would be considered 'Misconduct' and what errors would be considered 'Gross Misconduct'. The policy also did not address what disciplinary action might be taken if an engineer self-reported a maintenance error.

1.17.17 CAA recommended disciplinary policy

The CAA has published guidance material in CAP 716 for how maintenance organisations can deal with maintenance human factors issues. It discusses how to set up a Maintenance Error Management System (MEMS, see section 1.18.8) and it includes an example disciplinary policy. CAP 716 states:

'One of the prerequisites for a successful Maintenance Error Management System is that staff should feel that they can report occurrences and errors openly, without fear of punitive action. The reporting aspect may be accomplished by means of a confidential reporting scheme, but in order to investigate the occurrences, it is necessary to speak to the individuals involved. A blame-free approach is not the answer, since some actions are blatantly negligent and warrant punitive action. It is necessary to have clear policy stating that staff will not be punished for genuine errors.'

The document includes a decision tree chart to help organisations determine the degree of culpability following a maintenance error. This chart and the example disciplinary policy from CAP 716 are included in Appendix 4. Finally it discusses the 'substitution test' as follows:

'The "substitution test" is a good rule of thumb when illustrating where blame is inappropriate. If an incident occurs, ask yourself whether another similar individual (with the required skill, training and experience) in the same circumstances would have done anything different. If not, then blame is definitely inappropriate.'

1.17.18 Perception of disciplinary procedures at the maintenance organisation

No one at the maintenance organisation could recall a maintenance error resulting in serious disciplinary action in the preceding five years although some could remember incidents from approximately ten years before when the company was under different management. However, the perception of the culture and disciplinary procedures at the maintenance organisation varied among the engineers interviewed. One engineer was very positive about the safety culture and believed that the person who removed the purge door would come forward. Other engineers did not think the person would come forward due to the high profile nature of the investigation. Another engineer stated that there was "very much a blame culture" and believed that even if the person who removed the purge door was not disciplined, it would still affect their promotion prospects.

1.17.19 Incident investigation procedures at the maintenance organisation

The maintenance organisation had an Incident Investigation procedure and as a subset of this they also had a Maintenance Error Investigation procedure (MEI). An MEI investigation was considered mandatory for all Category A and Level 1 investigations and was recommended for Category B investigations (see Appendix 5 for definitions of categories). The G-YMME incident was classified as Category A. The investigation was to be conducted by a Quality Engineer or Quality Assessor and by an appointed independent Investigating Manager. For more details on the outcome of this internal investigation see paragraph 1.18.5.

1.18 Additional Information

1.18.1 Aircraft manufacturer's safety case on open purge door

Fuel leakage from an open purge door in flight results in the potential risk that the fuel could ignite in the wheel well – an environment where ignition sources can be present (ie chafed wires or hot brakes). The aircraft manufacturer was asked to comment on the probability of a fire resulting from an open purge door. The company stated that it does not carry out a probability analysis if a maintenance error is involved in the chain of events. Therefore, the manufacturer did not determine the probability of an open purge door leading to a fire but it accepted that the potential existed. The manufacturer's Safety Review Board convened to discuss the open purge door issue and they decided it was a "safety issue" for all applicable models (747, 757, and 777). The Safety Review Board issued the following statement:

'The board determined this issue to be an Airplane Safety Issue for 747, 757 and 777, based on the potential for a maintenance error to result in both the possibility of significant fuel leakage into the wheel well, resulting in the potential for a wheel well fire, and the un-covered purge door opening allowing the potential for ignition propagation into the center wing tank.'

This triggered a process to examine all the possible safety actions that could be taken to minimise the risk. The safety action taken by the manufacturer following the G-YMME incident is included in section 5.2.

1.18.2 Potential for fuel ignition

Hot surface ignition of Jet A fuel can result when a very high temperature surface comes into contact with fuel but is highly dependent upon many factors, including the geometric aspects of the hot surface and the environmental conditions affecting the fuel. Research[18] indicates that hot surface ignition of fuels similar to Jet A can occur at temperatures ranging between 480°C and 700°C. Fuel in vapour form can ignite at much lower temperatures.

The large duct which runs past the 777 purge door opening (see Figure 2) is the Auxiliary Power Unit (APU) pneumatic supply duct, which delivers APU bleed air to the air conditioning packs. The normal operating temperature of the duct is 193°C with a maximum temperature of 254°C, at which point the shut-off valve automatically closes. Running vertically below and slightly to the left of the purge door opening in Figure 3, are duct leak fire wires which are designed to detect any leaks from the pneumatic duct and will trigger a flight deck warning if the air temperature exceeds 154°C. There was no evidence of a leaking duct on G-YMME.

Chafed wires can result in electrical arcs. Electrical arcing can generate temperatures of several thousand degrees Celsius and is a function of the total voltage drop in the arc multiplied by the arc current.[19] The three white wire

[18] Kuchta, J. M. et. al. 1985. *Aircraft Mishap Fire Pattern Investigations*. Final Report APWAL-TR-85-2057.
[19] NTSB Aircraft Accident Report on TWA 800 Boeing 747-131 (N93119) on 17 July 1996 (PB2000-910403, NTSB/AAR-00/03, DCA96MA070).

looms beneath the purge door opening (see Figure 3) are power supply wires carrying 28 Volts DC and are rated at 5 Amps. An inspection of the wiring inside the left main gear wheel of G-YMME did not reveal any obvious damage.

The wheel brake temperatures are likely to be moderate following a normal taxi and takeoff. However, during landing and rejected takeoffs the wheel brakes can reach very high temperatures. During a maximum energy rejected takeoff (from takeoff decision speed, V_1, at maximum takeoff weight) the Boeing 777 brakes can reach temperatures as high as 1,330°C. In this incident, fuel had been deliberately jettisoned and the fuel leak ceased before the aircraft landed.

1.18.3 Missed rear spar inspection on other 777 aircraft

The rear spar inspection was not successfully carried out on G-YMME because the wrong area was inspected as a consequence of the aircraft manufacturer's incorrect diagram (see para 1.6.11.2). As a result of this discovery, an investigation was undertaken to determine if the rear spar inspection had been incorrectly carried out on any other aircraft.

It was determined that 19 Boeing 777 aircraft (including G-YMME) had undergone the rear spar inspection at the maintenance organisation prior to the G-YMME incident. The LAEs who had carried out these inspections were all interviewed by the organisation's Quality Manager and he determined that of the 19 aircraft, there were two other aircraft (apart from G-YMME) that had probably not had the rear spar inspection carried out correctly. The aircraft were G-VIIO and G-VIIS and they had been inspected by different people.

The aircraft manufacturer stated that the missed rear spar inspection on those aircraft did not pose an immediate safety concern because the aircraft were relatively young with low hours and low flight cycles. The manufacturer's structures department did not expect fatigue cracks would appear in the rear spar inspection area until at least 30,000 cycles had been flown and the highest cycle 777 in the world had completed 18,000 cycles. Another factor was accidental damage but this was considered of low probability in that area of the tank. Consequently, permission was obtained from the CAA and the aircraft manufacturer to defer the inspections on all three aircraft until their next C checks.

1.18.4 Purge door and purge procedure on Boeing 747 aircraft

The maintenance organisation also carries out maintenance on Boeing 747-400 aircraft which also have purge doors. The purge door on the 747 is located on the rear spar of the CWT and is accessible from the right main gear wheel well, unlike the 777 purge door which is accessible from the left main gear wheel well. The 747 purge door opening has a diameter of 5 inches (twice the diameter of the 777 purge door opening) and is shown in Figure 14. The first part of the CWT purge procedure in the 747-400 AMM (Rev 10 Jun 1997) stated: '*Remove the center wing tank purge door'* with a reference to the purge door removal/installation procedure in the AMM. This differed to the 777 CWT purge procedure in the AMM which did not reference the purge door. The 747 purge procedure then called for an air duct to be secured to the purge door opening to purge the tank. At the maintenance organisation staff had the required adaptor to secure a suction air hose to the 747 purge door opening and this task was routinely performed when purging the 747 CWT.

The 747-400 purge door removal/installation procedure was similar to the 777 purge door removal/installation procedure in that it called for a lanyard to be attached to the external face of the purge door before lowering it inside the tank. Unlike the 777 purge door removal procedure, the purge door on the 747 did not need to be fully removed from the aircraft but could be left hanging on its lanyard and then re-installed by using the lanyard to realign the door. When this difference in procedures was highlighted to the aircraft manufacturer, the manufacturer decided to change the 747 procedure to require complete removal of the purge door. The rationale for this was to facilitate the replacement of the O-ring seal around the purge door.

The fuel required in the CWT to leak-check the purge door on the 747 was stated as '*minimum of 70,000 pounds (31,800 kilograms) of fuel*'. This was similar to the incorrect purge door leak-check amount in the 777 AMM which was stated as '*minimum fuel quantity of 70,000 LB (32,000 KG)*'

1.18.5 Maintenance organisation's internal investigation of G-YMME incident

In line with the maintenance organisation's incident investigation procedures described in section 1.17.19, the company launched its own investigation into the G-YMME incident. A bay manager was assigned to be responsible for the investigation and an aircraft controller (who was not involved with the G-YMME maintenance input) was assigned to carry out the investigation and write a report. This investigation was initiated shortly after the incident and was completed with the issue of a final report on 26 July 2004. The conclusions and safety recommendations from this report are attached at Appendix 6. The safety recommendations related to:

Figure 14

Boeing 747-400 purge door (highlighted by red box) with hazard tape

> *'communication issues', 'centre wing tank task issues', 'Boeing documentation issues', 'engineering process issues', and 'production process issues'.*

1.18.6 Investigation of G-YMME incident by the operator

The operator initiated its own investigation of the G-YMME incident by tasking one of its full-time Air Safety Investigators from its Safety Services group. The operator completed its investigation and, on 28 July 2004, it issued a report containing its findings and safety recommendations. The conclusions and safety recommendations from this report are attached at Appendix 7. The safety recommendations related to:

> *'recording of work', 'centre tank technical instructions', 'technical query follow-up' and 'aircraft and zone familiarity'.*

1.18.7 Occurrence reporting schemes

The UK has a well established Mandatory Occurrence Reporting (MOR) scheme that exists in order that significant safety issues are brought to the notice of the CAA. Reporting is only mandatory if incidents or defects:

'hazard, or could hazard the safety of civil aircraft operations when they involve, in any way, UK operated public transport aircraft and private category turbine powered aircraft.'

However, the CAA encourages voluntary reports on incidents and hazards that do not fall in the aforementioned category. In order to try and secure free and uninhibited reporting the CAA gives an assurance that:

'it will not be its policy to institute proceedings in respect of unpremeditated or inadvertent breaches of the law which come to its attention only because they have been reported under the Scheme, except in cases involving dereliction of duty amounting to gross negligence.'[20]

And under similar terms the CAA expects employers to also refrain from disciplinary or punitive action which might inhibit their staff from duly reporting incidents of which they may have knowledge.

Another UK occurrence reporting scheme is the Confidential Human Factors Incident Reporting Programme (CHIRP) which provides an alternate reporting mechanism for individuals who want to report safety concerns and incidents confidentially.

However, the CAA believes that the MOR and CHIRP schemes are not intended to collect and monitor the normal flow of day-to-day defects and incidents which remain an industry responsibility and form an important part of the overall operational safety task. The CAA therefore encouraged maintenance organisations to adopt a form of Maintenance Error Management System to cover the reporting and investigation of more minor but potentially significant incidents.

1.18.8 Maintenance Error Management System (MEMS)

On 20 March 2000 the CAA published CAA Airworthiness Notice 71 (Issue 1) which explained the CAA's policy on MEMS and encouraged maintenance organisations to adopt a form of MEMS. However, it also stated that the CAA would not approve a MEMS and it would not be subject to auditing by the CAA. On 21 March 2005 the CAA published a revised Airworthiness Notice 71

[20] This assurance is upheld in European Union (EU) law. EU Directive on occurrence reporting in civil avation 2003/42/EC states under Article 8(3) that '*Without prejudice to the applicable rules of penal law, Member States shall refrain from instituting proceedings in respect of unpremeditated or inadvertent infringements of the law which come to their attention only because they have been reported under the national mandatory occurrence-reporting scheme, except in cases of gross negligence*.'

(Issue 2) (attached at Appendix 8) stating that they would audit a maintenance organisation's MEMS as part of the EASA Part 145.A.60(b) (see Appendix 9) requirement to establish an internal occurrence reporting system and correct adverse trends.

For full details on MEMS see Appendix 8, but the aim of a MEMS scheme is to identify the factors contributing to incidents and to make the system resistant to similar errors. An example of a maintenance error that would not require an MOR but might be captured by MEMS is the omission of an oil filler cap which, by chance, is noticed and corrected before the aircraft leaves base maintenance. The CAA believes that a MEMS should contain the following elements:

1. *Clearly identified aims and objectives*
2. *Demonstrable corporate commitment with responsibilities for the MEMS clearly defined*
3. *Corporate encouragement of uninhibited reporting and participation by individuals*
4. *Disciplinary policies and boundaries identified and published*
5. *An event investigation process*
6. *The events that will trigger error investigations identified and published*
7. *Investigators selected and trained*
8. *MEMS education for staff, and training where necessary*
9. *Appropriate action based on investigation findings*
10. *Feedback of results to workforce*
11. *Analysis of the collective data showing contributing factor trends and frequencies*

The CAA also encourages organisations to share their MEMS results (dis-identified if necessary) with other maintenance organisations in the hope that:

> *'by sharing such data the CAA and industry can jointly develop a better understanding of maintenance error causation and develop more focused human factors strategies.'*

1.18.9 Example of the benefits of a non-punitive incident reporting system

A paper published by the Head of incident investigation, Naviair, Denmark, describes the benefits obtained by the introduction by the Danish Parliament of a compulsory, non-punitive and confidential aviation incident reporting system.[21] The new law granted immunity unless gross negligence or substance abuse was present. The paper discusses the way this new law affected Air Traffic Controllers in Denmark. The reporting system started operating on 15 August 2001 and during the first 24 hours, Naviair received 20 reports from Air Traffic Controllers. One year after the reporting system was started, Naviair had received 980 reports, compared to the previous year's 15 reports. Part of the success was the compulsory nature of the system but the paper argues that the non-punitive nature of the system also had a large impact.

The paper includes the following advice for companies adopting such a non-punitive reporting system:

> *'It is important to mention that any company management that puts a system like this in place has to prepare for new and maybe unpopular knowledge. It may come as a surprise for the management of any company when more breaches of safety are being reported. It is very important that this new knowledge is not seen as a sign that safety is sliding. Rather it should be interpreted as an uncovering of things that have existed and gone unreported for years. The paradox remains, however, that the safest companies will initially be viewed as the unsafe companies due to their willingness to elicit a greater number of reports. For the time being it takes courage to be safe!'*

1.19 Useful or effective investigation techniques

Not applicable.

[21] *The Creation of an Aviation Safety Reporting Culture in Danish Air Traffic Control*, by Peter Majgard Norbjerg, Head of incident investigation, Naviair; Kastrup, Denmark.

2 Analysis

2.1 Handling of the incident by the flight crew

The flight crew were made aware of a vapour trail emanating from their aircraft at an early stage of the flight. Its diagnosis was not straightforward; there were no abnormalities displayed on the flight deck instrumentation and the fuel flow to the engines also appeared normal. The fuel synoptic page of the EICAS showed no imbalance between the wing tanks and this, combined with the lack of a visible leak from the engine pylons, led to the flight crew correctly diagnosing that the leak must be from the CWT. Continued visual reports of the leak from other aircraft indicated that the leak was not transitory so the crew rejected the option of continuing to their intended destination. A decision was then required between landing as soon as possible, with the aircraft still about 65 tonnes above its maximum landing weight, or remaining airborne and reducing the fuel load in order to land at maximum landing weight. The crew decided that the additional fire hazard associated with the increased brake temperatures generated during an overweight landing outweighed the hazards associated with remaining airborne and jettisoning fuel. Although they were not aware at the time, the nature of the fuel leak was such that this extra time airborne meant that fuel was no longer leaking when they landed, further reducing the risk of fire. Jettisoning fuel for 24 minutes also allowed for a considered and well-planned approach and landing with sufficient time to brief cabin crew, passengers, ATC and the operating company. In view of their limited knowledge of the nature of the fuel leak, landing with minimum braking from an automatic approach was well reasoned and well executed.

Information gathering to assist the commander with decision making was considerably helped by the presence of the third flight deck member. He was particularly useful in visually checking the exterior of the aircraft from the passenger cabin, liaising with the cabin crew, checking documentation for relevant information and communicating with the company's maintenance control. However, given the time available to the crew, these tasks could have been delivered in the same manner by the normal crew complement.

2.2 Cause of the fuel leak and its potential consequences

The fuel leak on G-YMME was caused by fuel escaping from the CWT through the open purge door. Prior to departure the CWT on G-YMME was more than half full with 43,400 kg of fuel, which would have reached a level in the tank just below the purge door opening. Therefore, despite the open purge door, no fuel would have leaked from the CWT during the refuelling period at the aircraft stand. During the acceleration of the takeoff roll the fuel in the CWT would have migrated towards the rear of the tank, potentially causing some fuel to spill out of the purge door opening into the wheel well. The fact that the crew of an aircraft waiting at the holding point reported smelling fuel vapour indicates that fuel probably did leak from the purge door opening during the takeoff roll. During the aircraft's takeoff rotation and climb-out the aircraft's positive pitch angle would have caused more fuel to move aft and spill out of the purge door opening. The fuel then entered the wheel well and probably exited the aircraft via drain holes in the lower landing gear door, close to the aircraft centreline. This fuel, streaking aft of the fuselage, became immediately apparent to ATC and to others as the aircraft climbed.

Following the incident, the aircraft manufacturer stated in its safety analysis that the fuel leakage could have led to a wheel well fire which might have propagated through the open purge door into the CWT. However, there were no ignition sources such as defects in the pneumatic ducting close to the purge door or chafed wiring in the landing gear bay.

The brakes in the wheel well, had they been hot, could also have provided a potential ignition source, although normally brake temperatures would be moderate after takeoff. However, had the crew decided to initiate an immediate turnback and landed above the maximum landing weight, the brakes, then possibly coated in fuel, could have become very hot. The crew correctly assessed the situation and decided to jettison fuel first. By the time the aircraft returned for landing, the fuel level in the CWT was sufficiently below the purge door for the leak to have stopped. Consequently, there was little risk of a fuel-fed fire in flight, or during and after the landing.

2.3 Determination of when and where the purge door was removed

Following the incident it was clear that the purge door had been deliberately removed because the door's retaining bolts were in a plastic bag tied to the purge door opening. This is an aircraft maintenance practice common during panel removals and the possibility of this resulting from malicious interference was considered remote.

No specific maintenance record could be found of the purge door having been removed but the last time maintenance was carried out requiring access inside the CWT was during a 2C check between 2 May and 10 May 2004. Between this maintenance and the incident flight the highest CWT fuel level was 26,800 kg which would not have been sufficient to slosh out of an open purge door on the ground or during normal flight. Also, between the 2C check and the incident flight, there was no record of the left main inboard gear door having been opened or of any record of maintenance work that would have required the left main inboard gear door to be opened. With the inboard gear door closed, it would not have been possible to see the open purge door and therefore it is very likely that the open purge door would have been hidden from view between 10 May 2004 and the incident flight on 10 June 2004.

It was possible that the purge door had been removed at some point before the 2C check and then gone un-noticed for a longer period of time. The aircraft's fuel records were examined to determine the last time the purge door was definitely installed. The last time the CWT was fuelled to more than 52,200 kg – an amount that would have revealed an obvious fuel leak on the ground with an open purge door – was on 10 February 2003. Therefore on this date the purge door must have been in place. A review of maintenance records between 10 February 2003 and the 2C check on 2 May 2004 did not reveal any work requiring entry to the CWT or any work that might warrant opening the purge door. Consequently, it was concluded that the purge door was removed during the CWT work carried out during the aircraft's 2C maintenance check at the maintenance organisation.

The purge door is unique among the fuel tank access doors on the aircraft for two reasons. Firstly, it is the only fuel tank access door that cannot be immediately removed from the aircraft once it has been opened – all the other fuel tank access doors can be removed from the exterior of the tank and there is no provision for allowing them to hang inside the tank on a lanyard. Secondly, because the purge door is mounted vertically and high up in the CWT, it is the fuel tank access door most likely to go un-noticed during partial refuelling. This is because the wing tanks are normally filled completely following heavy maintenance but the CWT is only partially filled.

2.4 Centre wing tank maintenance activity

Initially the investigation concentrated on trying to discover and understand the events surrounding the CWT maintenance at the maintenance organisation during the aircraft's 2C check.

2.4.1 Reasons for purge door removal

As there was no record of the purge door having been removed and no one came forward stating that they had removed the purge door, it was not possible to determine definitively why the purge door was removed. Although awareness of the existence of the purge door on the Boeing 777 was low amongst maintenance staff at the maintenance organisation, it is known from job card records that the purge door was removed from three other Boeing 777 aircraft on at least three previous occasions. (See para 1.6.10.10 for details.)

The most likely period during which the purge door was removed on G-YMME was between 0600 hrs local on 4 May 2004, when the CWT draining was initiated, and 0630 hrs local on 5 May when the team which completed the CWT 'opening and purging' finished its shift.

Reasons considered for removing the purge door were: to pass a light through the purge door opening to assist with the rear spar inspection, for carrying out the CWT special float switch check, or to expedite purging of the tank.

The purge door could have been opened to offer some additional natural lighting or to pass through a lead light to assist with the rear spar inspection. However, the TTL who carried out the rear spar inspection did not enter the rear of the tank but incorrectly carried out his inspection in the front of the tank, therefore the open purge door would have had no benefit for him. It is possible, however, that someone who did understand the rear spar inspection either removed or requested that the purge door be removed for that purpose.

The CWT special float switch check was carried out entirely within the left and right inboard wing regions of the CWT and therefore, an open purge door would not have assisted with those checks except to provide some minimal additional ventilation.

The most likely reason for removing the purge door was to expedite purging of the tank. In the case of G-VIIY (see para 1.6.10.10) it is known that the purge door was removed specifically to increase the purging speed of the CWT. The TTL who raised the defect card to have the purge door removed on G-VIIY stated that he had discovered the purge door reference in the AMM by chance. However, on G-YMME, the TTLs who worked zone 1F during the early shift on 4 May and the night shift on 4 May said they were not aware of the existence of the purge door on the Boeing 777 (both worked primarily on the Boeing 747). The TTL who certified that the draining and purging of the CWT had been completed stated that he did not refer to the purging procedure in the AMM (although had he done so he would not have found a reference to the purge door). He stated that he decided to purge the tank by simply opening the remaining access panel 139AZ on the belly of the CWT. It is a concern that despite being unfamiliar with the 777, he did not refer to the AMM. He was, however, familiar with the purge door on the 747 and had seen it open before and removing the purge door would have been a routine task for a Boeing 747.

In between the early and night shifts of 4 May, a late shift was responsible for zone 1F but that shift did no work within zone 1F; it only worked its paired zone, zone 4B (the right engine). The TTL of the late shift was aware of the purge door on the 777 and he was the person who detected the unrecorded opening of the purge door on G-YMMA (see para 1.6.10.10) while carrying out the rear spar inspection on that aircraft. However, he said that since he did not actually work on the CWT of G-YMME, he was not aware that the purge door had been opened and he was not responsible for closing up the tank. There was no zone 1F handover sheet from this TTL to the night shift TTL who was tasked to carry out the CWT purge but there would have been no reason to mention the purge procedure in it anyway.

The engineer investigating the incident at the maintenance organisation suggested that because of the purge door's unusual location and the awkward access required for its removal, someone who knew the task (ie had performed the task before) directed (or suggested) that the purge door should be removed; it may then have been removed by someone who had never removed it before. The investigating engineer also considered that this two-person scenario might explain why no individual has volunteered information.

The removal of the purge door in itself was not the cause of a problem. There was no routine job card calling for the removal of the purge door but that did not mean that the purge door could not be removed. It was perfectly acceptable to remove additional panels required for maintenance as long as a defect card was raised, recording its removal, and an additional card was raised, requiring its re-installation. The maintenance error that occurred in the case of G-YMME was not raising the appropriate paperwork. A defect card should have been raised and stamped to record that the purge door had been removed and an additional defect card should have been raised calling for its reinstallation and a leak-check.[22] Potential reasons considered as to why the paperwork was not raised were: the time involved doing it; it was forgotten; it was assumed that routine cards existed for the task; or, it was assumed that someone else would raise the defect card.

The time involved to raise the required defect cards was estimated by one LAE to be between 5 and 10 minutes. The cards are created on a computer and then

[22] An additional but less serious error was made in not completely removing the purge door from the aircraft (as per the AMM procedure) but this was understandable because the 747 AMM purge door removal procedure allowed the purge door to be left hanging on its lanyard.

printed. Each zone has a workstation with a computer and the zone 1F workstation was located close to the CWT. During the second and third days of the eight-day maintenance input, the time pressure on personnel would have been low compared to the end of a maintenance input. Therefore the few minutes of time involved in raising the defect cards was probably not a likely reason for omitting to raise the cards. It is possible that someone intended to raise the defect cards and then simply forgot to do so, perhaps because they were distracted by something or were called away. It is also possible that it was assumed that a routine card already existed for the purge door removal and that the card would get stamped at some later time. Had this been a Boeing 747 undergoing internal CWT maintenance, a routine card for the purge door removal would have existed. An engineer more familiar with the 747 might have expected this to be the case for the 777.

The person who removed the purge door should have looked for a card to stamp shortly after completing the task, but delays in card stamping were not uncommon. For example, the refit job card for the 139AZ panel was not stamped until the day after the panel was refitted (see section 1.6.10.9). This is a practice that can lead to panels being missed. It is also possible that it was assumed that someone else would raise the defect card. Yet only Authorised Technicians and TTLs had the authority to raise defect cards and there were very few teams working G-YMME that had Authorised Technicians working for a TTL. It is unlikely that a TTL would have expected a TTL from another zone or shift to raise his defect cards.

The true reason why the defect cards were not raised will not be known unless the person or persons involved with the purge door removal explain their actions. Nevertheless, regardless of the reason, and because, even with the best intentions, at some point someone could forget to raise a defect card, the CWT maintenance process needs a safety net for a safety critical panel such as the purge door.

2.4.2 Job cards used during the CWT maintenance

The quality of some of the job cards written for the CWT maintenance was poor and possibly contributed to some confusion over what needed to be done. The CWT drain and purge job card (see para 1.6.10.5) listed the following three tasks: '*1. Left center fuel tank drained and purged, 2. Right center fuel tank drained and purged, 3. Center tank drained and purged*'. A logical person would probably interpret this card as meaning that there were three separate sections of the tank that each needed to be drained and purged. However, the CWT only has two drain ports, one on each side of the centre section of the CWT and these drain the entire contents of the CWT. Purging the CWT and draining the CWT are separate tasks. The purging task could be done some time after the tank had been drained and so, these tasks should not have been combined. In addition, the job card does not explain how the CWT should be purged. The AMM lists more than one option depending upon the type of ventilation or blower equipment the organisation uses. The job card should have broken down the steps involved in purging and should have noted whether the purge door needed to be removed as part of the task.

The purge procedure in the AMM called for all six CWT underwing access doors and the 139AZ belly door to be removed. However, only routine job cards had been raised to remove one of the CWT underwing access doors on each wing and the 139AZ door. An engineer performing the purge task in accordance with the AMM would have had to raise defects cards for the other four underwing doors. The general practice at the maintenance organisation was to remove only the two underwing doors specified on the routine cards. The removal of two panels instead of six reduced the effectiveness of purging but this did not in itself create a safety issue because no tank should be entered until the fuel vapour levels are below acceptable maximums. This example does, however, show an undesirable inconsistency between following the routine job cards and following the AMM. Further complicating matters, the job cards for removing the underwing CWT access doors were the responsibility of the teams working the wing zones 5 and 6. So the team working in zone 1F carrying out the CWT purge task did not have oversight or control of all the CWT access doors.

The rear spar inspection job card was also inadequate because it simply reiterated the words from the Boeing task card without offering clear directions on the area to be inspected or noting the access requirements for the inspection. Additionally, the card did not include an AMM reference which an engineer would need to find the relevant diagram depicting the area of inspection. Ideally, the diagram of the inspection area would be included with the job card. The introduction of EWS (see safety action taken para 5.1) will allow illustrations to be appended to job cards.

There were no routine job cards for the removal of the baffle doors. Removal of these doors was a routine task because it was necessary to remove them to carry out the rear spar inspection. The planning group were aware of this but no action was taken to generate routine cards because they were awaiting panel numbers from the manufacturer (see para 2.8.1). This led to production staff needing to raise defect cards each time the baffle doors had to be removed. On several occasions the baffle doors were removed but their removal was not recorded on defect cards; this was an unacceptable practice that may have contributed to the unrecorded removal of the purge door.

2.4.3 Rear spar inspection

The rear spar inspection task was carried out by a TTL who had never carried out the inspection before, nor had he been inside a Boeing 777 CWT before, but he had been inside a 747 CWT. Until January 2004 he had been working primarily in the 777 cabin. Because he was unfamiliar with the task he referred to the rear spar inspection procedure in the AMM which still had the incorrect version of the diagram (Figure 10, page 26). He inspected the area labelled 'rear spar' in the diagram using the access hole 139AZ and the FWD arrow as positional references. This resulted in him inspecting the forward spanwise beam instead of the rear spar. This error remained undetected until the TTL was interviewed by the AAIB as part of the investigation into the purge door removal incident.

The fact that the rear spar had not been inspected did not create an immediate safety issue because the aircraft had relatively low hours and had completed a low number of cycles (1,907 flight cycles). The aircraft manufacturer did not expect cracks to develop in this area until at least 30,000 flight cycles had been completed. However, if on subsequent inspections the wrong area had been repeatedly inspected, the aircraft's structural integrity might eventually have been compromised.

The incorrect rear spar inspection did not have a direct bearing on the cause of the fuel leak incident but had the fuel leak incident not occurred, the incorrect rear spar inspection may not have been discovered. However, if the rear spar inspection had been carried out correctly, the TTL would have removed all the baffle doors and entered the aft section of the CWT where the purge door is located. Had he gone there, he might have noticed light entering through an open purge door and he might have ensured that the purge door was re-installed before the tank was closed, as happened in the case of G-YMMA.

2.4.4 Fuel tank leak checks performed

The CWT was closed by the TTL who had carried out the rear spar inspection with help from one of his Technicians. Neither of them was aware of the purge door on the Boeing 777 and because there were not any job cards relating to the purge door, they did not know that it might be open. The purge door is also in a remote corner of the left main gear bay so could easily go unnoticed. However, fuel tank leak checks could have revealed the open purge door before the aircraft was released for service.

It was normal practice at the maintenance organisation for the fuel tank leak-checks to be performed by staff working the left wing zone (zone 5) because this is the zone from which refuelling of all tanks takes place. The TTL from zone 5 who carried out the leak checks on G-YMME worked primarily on the 747 and he did not know where the purge door was on the 777. Although he could not remember the specific amounts of fuel he used, he probably used the 40,000 kg 'catch-all' amount that was standard practice at the maintenance organisation. Unfortunately 40,000 kg of fuel in the CWT was not sufficient to cause fuel to leak from an open purge door. The 40,000 kg figure was considered a 'catch-all' fuel amount based on the AMM purge door leak check figure of 32,000 kg that was incorrect (it should have been stated as 52,163 kg). Had at least 52,200 kg of fuel been added to the CWT, the open purge door would have been readily apparent.

The job card that called for a fuel leak-check on the CWT access doors did not have an AMM reference to the purge door leak-check procedure. Furthermore, the AMM leak-check procedure that was referred to did not itself refer to the purge door (see para 1.6.9). Had either the job card or the AMM made the TTL carrying out the leak-checks aware of the purge door, he might have carried out a visual check of the purge door. He would have still used an insufficient fuel amount to leak-check the purge door but by doing a visual check for leaks he would have discovered the open door. Therefore the lack of references to the purge door in both the job cards and the AMM were contributory factors to the open purge door being missed.

2.4.5 Post maintenance inspection – why the open purge door was not detected

Several routine procedures should have revealed the open purge door but they all failed. Firstly, the paperwork failed because no defect card was raised indicating that the purge door had been opened. Secondly, tank inspection before its closure failed because the rear spar inspection was carried out in the wrong location and because the engineers closing the tank did not know the purge door existed. Thirdly, the 'safety net' leak-checks failed because the job cards and the AMM CWT leak check procedure did not refer to the purge door. Moreover, the purge door leak check fuel quantity was incorrect and the engineer carrying out the leak-checks did not know about the purge door.

The final 'safety net' procedure, the post maintenance checks, also failed to discover the purge door for several reasons. The post maintenance checks involve checking that all tooling is accounted for and checking that there are no leftover panels on the panel rack. All fuel tank access doors, except for the purge door, have to be placed somewhere once removed and this would normally be on the panel rack. A check of the panel rack at the end of a maintenance input serves as a 'safety net' that all panels have been re-installed. However, because the purge door is secured to a lanyard when it is removed, there is a risk that it will be left hanging instead of being placed on the panel rack. Although the AMM procedure calls for the purge door to be completely removed from the aircraft, the door can only be removed by someone inside the tank. Consequently, the door has to remain hanging on its lanyard while the tank is purged. During this purging period the door could be forgotten or, as in the case of G-YMME, it could have been opened with no intent to completely remove it from the aircraft.

The final maintenance checks also include a walk-around inspection of the aircraft's exterior but the left inboard landing gear door, when closed, conceals the purge door from view. The walk-around inspection could be conducted before the landing gear doors have been closed but normally they would already be closed by the time of the walk-around. Therefore the last person to see inside the left gear bay was probably the engineer who closed the left inboard gear door. Because the purge door opening is small (2.5 inches in diameter) and in a distant dark corner, it is unlikely to be noticed by a person visually scanning the interior of the gear bay. If, on the other hand, a highly visible streamer had been secured to the purge door when it was first removed, then this streamer would probably have been noticed by a person closing the inboard gear door. Since this incident the AMM has been revised to require that a '*Remove Before Flight*' streamer be secured to the purge door when opening it (see safety action taken para 5.2.1).

Once the aircraft departed the maintenance organisation with the inboard main gear doors closed, the open purge door would have been undetectable until either the left inboard main gear door was opened for maintenance reasons or sufficient fuel was added to the CWT to cause a leak. During G-YMME's ensuing 53 flights there was no reason to open the left inboard main gear door and so the problem was not revealed until the in-flight fuel leak on 10 June 2004.

2.5 Aircraft Maintenance Manual issues

2.5.1 Aircraft Maintenance Manual deficiencies

During this investigation several errors and omissions in the Boeing 777 AMM and Boeing task cards were discovered. These were:

a. The rear spar inspection diagram incorrectly depicted the area to be inspected.

b. The fuel quantity required to leak-check the purge door was incorrect.

c. The fuel tank purging procedure did not refer to the purge door.

d. The fuel tank leak detection procedure did not refer to the purge door leak check procedure.

e. The CWT baffle doors were not mentioned or depicted in any procedure.

If the rear spar inspection diagram had been correct, the engineer would probably have inspected the correct area in the rear of the tank and noticed the open purge door. If the purge door leak-check fuel quantity had been correct there might have been awareness that the 40,000 kg ‘catch-all’ leak-check amount did not cover the purge door. Had the fuel tank purging procedure and leak detection procedures referenced the purge door, then again the awareness of the door would have been raised among both engineers and the planners writing the job cards. Had the baffle doors ‘existed’ in the AMM there would probably have been job cards for their removal, as part of the rear spar inspection, which would have been a clue to the engineers that it was the rear of the tank that needed inspecting. Consequently, these errors and omissions all contributed to the chain of events that resulted in G-YMME departing with its purge door removed.

The aircraft manufacturer provided assistance to the AAIB during this investigation and they took action to address all the problems raised above (see safety action taken para 5.2). However, the manufacturer’s safety investigators were unable to identify the source or cause of the errors.

The probable chain of causal factors for these errors is as follows. The AMM was first issued for the original A-market 777 which did not have a wet centre fuel tank. Although the purge door existed on the A-market aircraft, it served no purpose because the centre wing area was never exposed to fuel. For that reason the purge door was probably not included in the original fuel tank purging and fuel leak detection procedures. The separate purge door removal/installation procedure was probably added to the AMM at a later date when the B-market 777 with the wet centre fuel tank was introduced. At this point a cross-reference to the new procedure within the original purge and fuel leak-check procedures should have been added but it was omitted. The change from the dry centre wing 777 to the wet centre wing 777 also explains in part why the baffle doors were omitted. The A-market 777 does not have baffle doors and therefore the original 777 AMM did not include them. During the subsequent AMM review for the B-market 777, the fact that baffle doors had been added to the aircraft was overlooked.

The error involving the incorrect fuel quantity to leak-check the purge door was puzzling. Again, the manufacturer could not establish how this error arose. However, it is probably not a coincidence that the fuel leak check quantity listed for the 777 purge door (70,000 lb in imperial units) was the same as the fuel leak-check amount listed for the 747 purge door (also 70,000 lb).[23] But how this confusion arose could not be determined.

To ensure that there were no other errors or omissions, the aircraft manufacturer carried out a review of the 777 Aircraft Maintenance Manual in late 2005 to identify any other differences between the 'dry tank' A-market aircraft and the 'wet tank' B-market aircraft that had not been correctly captured (see safety action taken para 5.2).

2.5.2 Aircraft Maintenance Manual freeze period

During the freeze period which lasted until 24 January 2005, AMM revisions (40, 41 and 42) were reviewed by the operator's fleet engineers (see para 1.17.11). However, they did not raise any TRs as a result of reviewing those revisions until after the G-YMME incident. The corrected rear spar inspection diagram had been published in Revision 41 but it arrived too late to prevent the incorrect rear spar inspection on G-YMME, even if a TR had been raised. However, had the G-YMME incident not occurred, it is unlikely that the corrected diagram would have been considered a change affecting aircraft safety and therefore would not have caused a TR to be raised.

The extended AMM freeze period meant that other seemingly minor changes to procedures may not have been passed on to the maintenance organisation because they were not deemed to directly affect the aircraft's safety. The AMM freeze ended in January 2005 but operators and airworthiness authorities should be mindful of the impact an AMM freeze can have, if changes (which are deemed of sufficient importance by the manufacturer to warrant a change) are not carefully reviewed and/or passed on to the operator's subcontracted maintenance organisation.

2.6 Job card engineering

Job card engineering (see para 1.17.9) involves careful consideration of what information is required to carry out a task, what access requirements might be required, the time involved and what equipment might be required.

[23] The respective fuel amounts listed in metric units were slightly different (32,000 kg and 31,800 kg) but this was probably due to the method of 'rounding-up' the figure following its conversion from pounds.

The rear spar inspection job card was not fully engineered because the planner who raised the card did not appreciate the access requirements (baffle door removal) and did not notice the erroneous rear spar inspection diagram. Overlooking the baffle doors was understandable because they were not mentioned in the AMM and the planner did not have access to a 777 aircraft. However, the error in the diagram could have been identified at this point.

The purge and drain job card was also not fully engineered because the planner did not appreciate that draining and purging were two separate tasks that can occur hours apart, and did not realise that there were only two drain ports on the CWT. Additional problems with some job cards were listed in section 2.4.2. The causes of these problems could not be definitively determined.

During the period leading up to and shortly after the incident, it was apparent that fully engineering new job cards was not a priority. Instead, due to a shortage of planning resources, priority was being given to the development of the new EWS database. Moreover, due to the implementation of EWS, the PQF process which formed a vital part of ensuring the quality of job cards, was also a low priority activity (see section 2.8.2).

In October 2004, partly in response to the G-YMME incident, the operator carried out an audit of all the maintenance organisation's job cards for a D-check on a Boeing 777 (a D-check is the most comprehensive check and it encompasses all work performed during a 2C check and more). The purpose of the audit was to ensure that the job cards fully met the intent of the jobs as written in the operator's Approved Maintenance Programme (AMP). A total of 2,200 cards were checked and recommendations were made where deficiencies were found. This was an important audit but it would not have gone into the detail of checking if each card was also correctly broken down into easily understood and manageable tasks. Such a detailed check cannot realistically be carried out during an audit. Therefore, it falls to the production engineers who are carrying out the individual tasks to recognise deficiencies and report them through the PQF process. Consequently it was recommended that:

> British Airways Maintenance Cardiff should actively encourage staff to raise problems with procedures in job cards and in the Aircraft Maintenance Manuals, take prompt action to remedy the problems and provide subsequent feedback. (Safety Recommendation 2006-097)

2.7 Panel removal procedures

At the time of the G-YMME incident the procedure at the maintenance organisation for removing and storing aircraft panels was part of their general 'Material Control' procedure which included all aircraft parts. Both aircraft components and access panels were labelled with the same PR0066 label and then stored on racks in the work area. The procedure did not cover how to handle panels such as the purge door which can be left tethered to the aircraft. These panels were not labelled or tracked in any way except through the job cards. Since the G-YMME incident the maintenance organisation has introduced a new procedure entitled '*Identification and Storage of Temporarily Removed Parts*' which includes how to handle parts that can be left tethered to the aircraft (see safety action para 5.1). It states that if it is impracticable or undesirable to remove a tethered panel then a six foot (minimum) length section of hazard tape must be secured to the panel. If the panel is not visible from the ground then additional hazard tape should be placed to draw attention to the panel from the ground. Carrying out this new process should attract attention to tethered panels and should help to ensure that they are refitted.

2.8 Internal reporting system issues

2.8.1 Issues with the QEAN system

The QEAN system (see para 1.17.8) at the maintenance organisation is an important system that allows production staff and planning staff to raise technical queries with the Technical Services group.

Flaws in the QEAN system directly contributed to the missed rear spar inspection and indirectly contributed to G-YMME departing with its purge door removed. Two months prior to the G-YMME maintenance input the error in the rear spar inspection diagram had been highlighted by an experienced TTL via a QEAN. Action was taken by the Technical Services group to inform the manufacturer of the error but no action was taken to inform the production engineers of the error. Consequently, the TTL who was tasked with performing the rear spar inspection on G-YMME was not aware of the error. The QEAN system only provided feedback to the originator of the query and not to staff in general. The second flaw was that long-term issues were not tracked formally; instead their resolution relied upon the memory of those pursuing the issues. The issue with the missing baffle door cards was first raised in a QEAN more than two years before the G-YMME maintenance input. Various attempts were made to ask the manufacturer to create panel numbers for the baffle doors but no attempts were made to solve the problem in-house in the interim. Eventually the technical services engineer tracking the issue left the company, but there was no tracking system noting that the issue needed resolution. The Technical Services manager believed that an answer was still pending from the manufacturer, when in fact the manufacturer had closed the issue after incorrectly answering the question.

As a result of these system flaws the production engineers continued for more than two years to remove the baffle doors when required without appropriate routine job cards. In some cases defect cards were raised for this task but not in all cases. This could have led to those engineers who were aware that the issue had been raised (initially via a PQF), to lose confidence in the QEAN system.

Since the G-YMME incident, the maintenance organisation has taken action to address the problems with the QEAN system (see safety action para 5.1). The system now includes an electronic database which tracks long-term issues to ensure that issues are not closed or forgotten before they have been satisfactorily addressed. A long-term issue is defined as one which has not been resolved by the time the aircraft being worked has departed. The Technical Services group has also introduced a Technical Information Circular for communicating technical issues to the production staff, including those raised by QEANs. All LAEs are required to read the circular and sign that they have done so. It is their responsibility to disseminate the information to the Technicians and Mechanics.

2.8.2 Issues with the PQF system

The PQF system (see para 1.17.8) at the maintenance organisation was designed for engineers to raise queries involving planning issues such as problems with job cards. Like the QEAN system, the PQF system was an important process for ensuring the quality of the job cards.

Some job cards are created by people who have never worked on the aircraft type. Consequently, job cards can be unclear, misleading, or incomplete and these deficiencies are most likely to be caught by an experienced engineer trying to perform the task. The PQF allows the engineers to report these deficiencies to the Planning group. Prompt rectification of the deficiencies can then prevent other potentially less experienced engineers from making mistakes (eg performing the rear spar inspection in the wrong location).

The problem with the rear spar inspection diagram was first raised by a production engineer via a PQF. This particular PQF (which is a paper form) could not be found by the maintenance organisation but it was referenced in a QEAN from a planner.

On 17 December 2003 (five months prior to G-YMME's 2C check) the PQF process was suspended because the planning engineers were too busy implementing EWS. The process was re-instated on 31 March 2004 but production staff were not informed and after the G-YMME incident some engineers still believed that the process was under suspension. The suspension of the PQF process left the organisation vulnerable to mistakes arising through poor job cards or inadequate planning support. Furthermore there was a perception among some engineers that PQFs were not being answered (even before their suspension) and so they had stopped raising them. Quality assurance relies heavily on engineers raising problems found on the shop floor. Resolving their difficulties and providing them with feedback shows that their queries are being promptly acted upon and encourages them to report deficiencies rather than work around them. Without such a system some of the problems that led to the G-YMME incident could be repeated in similar scenarios.

In light of these findings, the maintenance organisation took action to improve the PQF process (see safety action para 5.1). The PQF was changed to an electronic form and subsequent PQFs were tracked in a database; feedback was also provided to the originator. The Quality group acquired oversight of PQFs and could examine trends of 'number of PQFs raised', 'number of PQFs cleared', and 'number of PQFs open'.

In November 2005 the AAIB examined a sample of 18 PQFs that had been raised on the 777 during the period 22 July 2005 to 20 October 2005. Many of the raised PQFs were related to problems with job cards and corrective action had already been taken. This indicated that confidence in the system was being restored.

2.8.3 Lack of internal maintenance error reporting

The maintenance organisation had a system in place, called QDR, which lent itself to maintenance error reporting but maintenance errors identified before the aircraft left the facility were not routinely being reported.

A review of QDRs for a six month period (see para 1.17.15) did not reveal a single report of an internal maintenance error. However, it is known that maintenance errors were occurring because they were being reported by the operator once aircraft had returned to service. The extent of the lack of internal maintenance error reporting could not be determined but it was discovered that on at least one previous occasion the purge door had been removed but not recorded as removed. This event was not reported at the time but was revealed during the investigation. Had it been reported and thoroughly investigated, the lessons learned could have prevented the G-YMME incident.

The anonymous survey carried out by an engineer from the maintenance organisation (see para 1.17.15) was an example of how people can be encouraged to report incidents when the reporter believes they will not face disciplinary action as a consequence.

The QDR was not an anonymous reporting system. Lack of anonymity might inhibit self-reporting, but anonymous reporting systems present difficulties in investigation because follow-up questions cannot be asked. It is better to have identified reports, such as the QDR, which enable full investigations to take place.

There were several potential reasons why maintenance errors were not always reported under the QDR system. Amongst these reasons was the anticipated reaction of the maintenance organisation's management. A reporter might fear being blamed or a colleague being blamed, or the reporter might believe that no effective action would be taken to prevent a recurrence. Therefore, to encourage reporting it is essential that the reporter feels he can trust the company to be fair and has confidence that appropriate action will be taken. The investigation of reported errors enables preventative action to be taken before a maintenance error leads to an aircraft accident or incident.

2.9 Disciplinary policy at the organisation

For some staff at the maintenance organisation it was not clear where the blame boundary lay and the perception among them varied from the company having a good safety culture to the company having "very much a blame culture".

The disciplinary policy at the maintenance organisation referred to examples of misconduct that are non-industry specific, ie '*absenteeism*', '*poor time keeping*', '*disobedience of reasonable orders*', etc. (see para 1.17.16). The policy did not specifically address maintenance and it did not address what disciplinary action might be taken if an engineer self-reported a maintenance error. Therefore, it was not clear to staff where the blame boundary lay and this factor would have discouraged maintenance error reports.

The company should demonstrate to its staff that people who make maintenance errors will be treated fairly with the priority placed on improving safety rather than attributing blame. The changes to the Danish aviation incident reporting system (see para 1.18.9) demonstrated with dramatic effect the sudden increased level of error reporting once the threat of punishment was removed (except in cases of gross negligence or substance abuse).

Since the G-YMME incident the maintenance organisation has added a Culpability Evaluation Flowchart to the appendix of its Incident Investigation Procedure (see para 5.1) which helps clarify when a maintenance error will result in disciplinary proceedings. However, it is a stand-alone chart that is not referenced in the organisation's disciplinary policy or in its Maintenance Error Investigation guide.

The CAA has published guidance material in CAP 716 on how to set up a clear and fair disciplinary policy that will encourage staff to feel that they can report maintenance errors openly, without fear of punitive action (except in cases of gross negligence). Maintenance staff need to have confidence that they will not be punished for genuine errors, particularly in cases where another individual in similar circumstances would have likely made the same error (the 'substitution test'). Consequently it was recommended that:

> British Airways Maintenance Cardiff should identify and publish clear disciplinary policies and boundaries relating to maintenance errors to encourage uninhibited internal reporting of maintenance errors. (Safety Recommendation 2006-098)

2.10 Maintenance error management at the organisation

The EASA regulations require that maintenance organisations

> *'establish procedures to minimise the risk of multiple errors and capture errors on critical systems…'* (Part 145.A.65).

How the maintenance organisation accomplishes this has to be agreed between the organisation and the national aviation authority. In the UK, the CAA has published guidance material on how to set up a Maintenance Error Management System (MEMS) to fulfil the EASA requirements. The important 11 elements of MEMS are included in section 1.18.8 and full details of MEMS are included in Appendix 8.

The Quality group at the maintenance organisation had not set up a formal MEMS procedure. Instead the group relied on individual procedures such as '*Incident Investigation*' and '*Quality Deficiency Reporting* (QDR)' to fulfil the requirement. The '*Incident Investigation*' procedure contained a reference to the company's Maintenance Error Investigation (MEI) guide. This was a clear and useful guide (similar to Boeing's Maintenance Error Decision Aid, MEDA) that was employed during the internal G-YMME investigation. However, there were important elements of the CAA's recommended MEMS that were not fully implemented. The following 5 of the 11 elements were considered to be inadequately implemented at the time of the G-YMME incident:

1. *Corporate encouragement of uninhibited reporting and participation by individuals.*
2. *Disciplinary policies and boundaries identified and published.*
3. *Investigators selected and trained.*
4. *Feedback of results to workforce.*
5. *Analysis of the collective data showing contributing factor trends and frequencies.*

The company's disciplinary policy did not set clear boundaries and it did not encourage uninhibited reporting. The company did not have investigators who had been pre-identified (they were selected at the time of an incident) and the investigators, including the investigator of G-YMME, did not receive any formal maintenance error investigation training. There was no formal feedback process following an incident investigation and in cases where disciplinary action was taken, very limited information was made available. At the time of the G-YMME incident the Quality group was not analysing collective data to try and identify trends.

Since the incident the Quality group started analysing maintenance error data held in their eBasis system. They are trying to use this data to be more pro-active and prevent future errors.

Following the G-YMME incident the company also provided feedback on its findings to the workforce. Progress has been made but the company still does not meet in full the CAA's requirements. Therefore it was recommended that:

> British Airways Maintenance Cardiff should ensure that its Maintenance Error Management System fulfils all the elements recommended in the Civil Aviation Authority's Airworthiness Notice 71. (Safety Recommendation 2006-099)

2.11 Communication issues

Several communication issues were identified although none could be considered directly causal to the incident. The error in the rear spar inspection diagram was first reported two months prior to the G-YMME maintenance input but no action was taken to communicate this fact to maintenance staff. Because the inspection could only be carried out by an LAE, there should have been a process to inform all LAEs. There was also a communication error between the maintenance organisation and the aircraft manufacturer concerning the baffle door query and a communication breakdown within the Technical Services group concerning the status of the query. The Technical Services group communication issues appear to have been addressed by the introduction of a tracking system for long-term queries and the introduction of the Technical Information Circular (see safety action para 5.1). In addition, the maintenance organisation has re-instated Team Leader Meetings which were meetings between the Aircraft Controller and TTLs; they were supposed to be held monthly but the practice had become irregular. The new Team Leader Meetings are held every two months and Authorised Technicians are now invited (ie all LAEs take part). The agenda for the meetings is set by the Quality Group and agendas usually include discussions of QDRs, health & safety issues and other maintenance issues (see safety action taken para 5.1).

This new system enables an important improvement in communication between the Quality group, Aircraft Controllers and LAEs. However, the communication of these issues from TTLs to the Technicians and Mechanics (who are not included in the meeting) is not formalised. The company relies on TTLs being conscientious and communicating relevant information to the Mechanics and Technicians in their team. Moreover, the constitution of a TTL's team is not permanent and people could easily miss information through moving between teams or changing shift patterns. Consequently, it was recommended that:

> British Airways Maintenance Cardiff should ensure that its Technical Team Leaders are adequately disseminating information from Technical Team Leader meetings to the Technicians and Mechanics in their team. (Safety Recommendation 2006-100)

2.12 Manpower transfer between aircraft types

Some maintenance personnel working on G-YMME during its 2C check had not recently worked on a Boeing 777 aircraft; they were more experienced on the 747 aircraft. The EASA Part 145 regulations require that LAEs have at least six months of actual relevant aircraft experience in any consecutive two year period but the regulations do not require that they have type specific experience in that two year period. Therefore, an LAE who has worked solely on 747 aircraft for the past two years is permitted by regulation to work on a 777 aircraft.

The maintenance organisation had its own recency requirements for the issue of type authorisations but once an LAE, Technician or Mechanic had been trained and authorised on type, they no longer had to meet any type recency requirements to work on a specific type of aircraft. Also, there was no written policy or procedure for transferring people between aircraft types.

Following the G-YMME incident the operator recommended to the maintenance organisation that they:

> *'Ensure the risks highlighted by this incident in the lack of familiarity with aircraft types and zones are incorporated into procedures for the transfer and rotation of staff to maintain organisational flexibility whilst minimising risk.'*

The maintenance organisation did not take any direct action in response to the operator's recommendation; it informed the operator that everyone working on G-YMME was '*competent and correctly trained and approved*'.

It could also be argued that despite being unfamiliar with an aircraft type, an LAE should have the necessary skills to understand and carry out a maintenance procedure on that aircraft type, and the wisdom to seek assistance if difficulties are encountered. Additionally, Technicians and Mechanics should always be under the close supervision of an LAE. However, the maintenance organisation still has a responsibility for the upkeep of its maintenance staff's currency, because a lack of task familiarity can contribute to maintenance errors. This is an issue that requires careful management.

2.13 Quality oversight by the operator

The operator's oversight of its maintenance organisation was implemented through a combination of: compliance audits, regular meetings between the two company's Quality Groups, and maintenance related incident reports via the eBasis reporting system (see para 1.17.7). Before the G-YMME incident, the interval between compliance audits was increased from 12 months to 18 months and the subsequent audit was further delayed; it was not performed until 22 months had elapsed. The CAA's agreement to this change in audit interval should have been sought but the Authority has since stated that it would not have objected to the change. However, since the G-YMME incident, the operator has reverted to the 12 month audit interval. (See safety action taken para 5.3.)

In addition, it is ultimately the operator's responsibility to ensure that job cards comply with the AMP (see para 1.17.2). The operator carried out a physical audit of all the maintenance organisation's job cards for a D-check performed on a Boeing 777 to ensure that the job cards fully met the intent of the job as written in the AMP (see safety action taken para 5.3). Once EWS is fully implemented, the operator will acquire electronic access to the maintenance organisation's job cards to facilitate monitoring.

2.14 Risk of recurrence

2.14.1 Risk of recurrence at the maintenance organisation

In the short-term, the risk of a Boeing 777 leaving the maintenance organisation with its purge door removed was considered to be very low because awareness of the purge door amongst engineers was raised by this event. The errors in the maintenance manual have been corrected (see safety action taken para 5.2.1) and so the risk of recurrence in the longer term is dependent upon the procedural changes taken by the maintenance organisation to prevent recurrence. The company introduced a new procedure that required hazard tape to be secured to panels that are removed but left secured to the aircraft. The AMM was also revised to require that a '*Remove Before Flight*' Streamer is secured to the opening when the purge door is removed. Additionally, the routine job cards at the maintenance organisation were revised as follows to reduce the risk of an unrecorded purge door removal (see safety action taken para 5.1):

1. The CWT purge job card includes the note '*Do not remove the centre wing tank purge door (rear spar) for the purpose of additional ventilation.*'
2. A routine baffle door removal job card has been created that includes the optional task of removing the purge door and raising a defect card for its removal. There is space on the routine job card for noting the defect card number and there is also a note requiring that a defect card be raised for leak-checking the purge door.
3. A routine baffle door refitment job card has been created which notes the possibility that a defect card may have been raised for purge door removal.
4. The job card for leak-checking the centre wing fuel tank access doors was revised to include a note referring to the table in the AMM which contains the fuel levels necessary to cover the fuel tank access doors. (This table in the AMM has been revised by the manufacturer to include a leak check quantity for checking the purge door.)

The cards make it clear that removing the purge door is unnecessary for CWT purging. However, if the purge door is removed for some other reason then the baffle door cards help to highlight the fact that a defect card will be needed. These first three job card changes will help to reduce the risk of an unrecorded purge door removal. To some extent, change number 4 above will increase the probability that a leak check will identify an unrecorded purge door removal. The company considered routinely requiring that 53 tonnes of fuel be uplifted to the CWT to detect an open purge door, but this idea was rejected because the extra weight would have overloaded the tail jack (see safety action taken para 5.1). If a leak check fails to detect an open door, then the requirement to add hazard tape and a '*Remove Before Flight*' streamer to an open purge door should increase the probability of an open purge door being detected before the inboard landing gear door is closed. However, if procedures are ignored and the purge door is removed without tagging it or recording its removal, the same incident could recur. Consequently, the safety of the aircraft is still dependent upon maintenance staff following the procedures. Therefore it is important that staff are regularly reminded of the importance of following procedures and recording their work; the G-YMME incident serves as a good example to illustrate the serious consequences of not doing so.

2.14.2 Risk of recurrence in the global fleet of Boeing 777 aircraft

Consideration must also be given to the global fleet of Boeing 777 aircraft with 'wet' centre tanks. There are probably other maintenance organisations that have not yet addressed the risk of an aircraft departing its maintenance facility with an open purge door. The only direct information alerting them to this risk was a Boeing All Operator Message sent on 10 August 2004 to all 747, 757 and 777 operators (see safety action taken para 5.2). If other maintenance organisations have not taken careful notice of this message or the subsequent related AMM changes, then there is a risk that the same maintenance error could be repeated elsewhere.

One potential preventative action would have been to require all operators to permanently blank off the purge door such that it could not be readily removed, particularly since the purge door is not necessary for purging the CWT of a 777. The aircraft manufacturer considered this option and carried out a survey of operators by asking them if blanking-off the purge door on the 777, 747 and 757 aircraft would adversely affect them (see safety action taken para 5.2). Most operators responded that they used the purge door at least once a year but they did not specify on which aircraft type. It is possible that these operators were referring to the purge door on the 747 which is larger and more accessible than the purge door on the 777. There is also provision for an adaptor to secure an air hose to the purge door on the 747. The possibility remains, therefore, that blanking off the purge door on the 777 (and possibly even the 757) would be a viable option but, given the safety actions already taken, this is not a priority.

2.15 Follow-up action by the operator

Whilst both the maintenance organisation and the operator carried out numerous early safety actions, this report makes four safety recommendations to the maintenance organisation. These recommendations will require 'change management' with a view, in part, to promoting better working practices and improving staff perceptions of the organisation's safety management system. The success of this 'change management' process can perhaps best be judged by an external body. The operator already carries out routine audits of the maintenance organisation; it also has its own safety management staff and a strong interest in the effective implementation of the safety recommendations. Therefore, it was recommended that:

> When British Airways Maintenance Cardiff has addressed safety recommendations 2006-097 to 2006-100, British Airways should carry out a safety audit at British Airways Maintenance Cardiff. (Safety Recommendation 2006-125)

3. Conclusions

(a) Findings

1. The fuel leak was caused by fuel escaping from the centre wing tank through the open purge door.
2. The flight crew correctly diagnosed and handled the fuel leak incident.
3. The aircraft manufacturer determined that the fuel leakage resulted in the potential for a wheel well fire.
4. In this incident there was little risk of an in-flight fire because there were no ignition sources in the vicinity of the fuel leak.
5. By jettisoning fuel to land at maximum landing weight, the flight crew were able to reduce the brake energy required and thus reduce the risk of fire immediately after landing.
6. The purge door was removed from G-YMME during base maintenance, between 2 May and 10 May 2004, and not re-installed prior to departure.
7. The open purge door was not detected between the aircraft's return to service and the incident flight on 10 June 2004 because the open door was not visible from the ground with the left inboard main gear door closed and the aircraft's fuel loads had been insufficient to create a leak.
8. Contrary to the maintenance organisation's procedures, the removal of the purge door was not recorded on a defect job card.
9. No person came forward stating that they were involved with the purge door removal.
10. A potential opportunity to detect the open purge door was lost when the rear spar inspection was carried out in the wrong location because of an error in a diagram in the Aircraft Maintenance Manual (AMM).
11. The maintenance organisation was aware of the error in the AMM diagram and had notified the aircraft manufacturer, but no action was taken to communicate this fact to production staff.
12. The Licensed Aircraft Engineer (LAE) and Technician who closed the centre wing tank access panels did not check that the purge door was in place because they were not aware that the purge door existed and because there was no paperwork recording its removal.
13. The absence of cross references in the AMM between the fuel tank purging procedure and the purge door removal procedure, and between the fuel

tank leak detection procedure and the purge door leak check procedure, contributed to the lack of awareness of the purge door's existence.

14. The fuel quantity stated in the AMM as being required to leak-check the purge door was incorrect and insufficient to detect a leak from the purge door.

15. The centre wing fuel tank leak check did not reveal the open purge door because the specified fuel quantity used was incorrect and no visual check of the purge door was made.

16. No routine job card calling for a specific purge door leak check had been generated because there was no routine card for the purge door to be removed. A defect card calling for a purge door leak check should have been raised when the purge door was removed.

17. The aircraft maintenance manual did not mention or depict the centre wing tank baffle doors in any procedure.

18. The maintenance organisation had been aware of the missing baffle door reference for two years before the G-YMME incident but no action had been taken to create routine baffle door removal cards.

19. During the period leading up to and shortly after the incident, a shortage of planning resources had led to priority being given to the development of the EWS database, at the expense of job card engineering and responding to PQF queries.

20. There was a perception among some engineers that PQFs were not being answered and so these engineers had stopped raising them.

21. The maintenance organisation's Technical Services group did not formally track long-term unresolved QEANs which resulted in the 'missing baffle door' query being unresolved more than two years after it was reported.

22. The maintenance organisation did not have a procedure in place for handling removable panels, such as the purge door, which can be left tethered to the aircraft.

23. In February 2004 another Boeing 777 undergoing a 2C check at the maintenance organisation had its purge door removed without the removal being recorded. In that case an experienced engineer noticed the open purge door before the aircraft left the facility and raised a job card to have the panel refitted but he did not raise an occurrence or discrepancy report.

24. Maintenance errors identified before an aircraft left the maintenance organisation's facility were not being routinely reported.

25. For some staff at the maintenance organisation it was not clear where the blame boundary lay and the perception among them varied from the company having a good safety culture to the company having "very much a blame culture".

26. The maintenance organisation's disciplinary policy did not address what disciplinary action might be taken if an engineer self-reported a maintenance error and this may have discouraged maintenance error reporting.

27. The maintenance organisation had a Maintenance Error Management System (MEMS) in place but it did not adequately meet all the elements of the MEMS guidance contained in CAA Airworthiness Notice 71 (Issue 2).

28. The maintenance organisation had no process in place for ensuring that Technical Team Leaders were adequately disseminating information from Technical Team Leader meetings to the Technicians and Mechanics in their team.

29. Some of the production staff working on the G-YMME centre wing tank were more experienced on the Boeing 747 aircraft and had not recently worked on a Boeing 777 aircraft.

30. The purge door was routinely removed on the Boeing 747 aircraft to assist with purging, and was left hanging on its lanyard in accordance with the 747 AMM.

31. The routine removal of the Boeing 747 purge door could have contributed to an experienced 747 engineer removing the purge door on the 777 without realising that its removal was not required on the 777.

(b) Causal Factors

The investigation identified the following causal factors:

1. The centre wing tank was closed without ensuring that the purge door was in place.

2. When the purge door was removed, defect job cards should have been raised for removal and refitting of the door, but no such cards were raised.

3. The centre wing tank leak check did not reveal the open purge door because:

a. The purge door was not mentioned within the AMM procedures for purging and leak-checking the centre wing fuel tank.

b. With no record of the purge door removal, the visual inspection for leaks did not include the purge door.

c. The fuel quantity required to leak check the purge door was incorrectly stated in the AMM.

4. Awareness of the existence of a purge door on the Boeing 777 was low among the production staff working on G-YMME, due in part to an absence of cross references within the AMM.

4. Safety Recommendations

The following safety recommendations were made as a result of this investigation:

4.1 **Safety Recommendation 2006-097**: British Airways Maintenance Cardiff should actively encourage staff to raise problems with procedures in job cards and in the Aircraft Maintenance Manuals, take prompt action to remedy the problems and provide subsequent feedback.

4.2 **Safety Recommendation 2006-098**: British Airways Maintenance Cardiff should identify and publish clear disciplinary policies and boundaries relating to maintenance errors to encourage uninhibited internal reporting of maintenance errors.

4.3 **Safety Recommendation 2006-099**: British Airways Maintenance Cardiff should ensure that its Maintenance Error Management System fulfils all the elements recommended in the Civil Aviation Authority's Airworthiness Notice 71.

4.4 **Safety Recommendation 2006-100**: British Airways Maintenance Cardiff should ensure that its Technical Team Leaders are adequately disseminating information from Technical Team Leader meetings to the Technicians and Mechanics in their team.

4.5 **Safety Recommendation 2006-125:** When British Airways Maintenance Cardiff has addressed safety recommendations 2006-097 to 2006-100, British Airways should carry out a safety audit at British Airways Maintenance Cardiff.

5. Safety Action Taken

5.1 Safety action taken by BAMC, the maintenance organisation

BAMC initiated its own internal investigation of the G-YMME incident shortly after it occurred. The assigned investigator reported on his findings and recommendations on 26 July 2004 (see Appendix 6).

Following the incident a presentation on the dangers of unrecorded work and its consequences was given by the General Manager to all BAMC's managers and TTLs. The focus was not only on the G-YMME incident but also on other similar occurrences. The Aircraft Controllers then delivered the same presentation to the Technicians and Mechanics.

The Production Area Product Sample Report, which was carried out monthly by the Aircraft Controllers, was amended on 28 June 2004 to include the following new task:

> *'Visit three separate work areas and examine a task in progress in each area. Ensure that any work being accomplished has the requisite paperwork (Job Card & Supporting documentation) raised and that all persons allocated to task are booked on job card. Reference should be made to panels, component changes/ removals etc.'*

On 26 August 2004 the organisation introduced a new procedure entitled '*Identification and Storage of Temporarily Removed Parts*' which included how to handle parts that can be left tethered to the aircraft. It stated:

> *'when complete removal of a tethered panel is impracticable or not desired then a six foot (min) length of hazard tape must be securely attached to the panel such as to highlight the area where the panel is located.'*

If the panel was not visible from the ground then additional hazard tape had to be placed to draw attention to the panel from the ground. Staff seeking qualification as a Mechanic or Technician were tested on this new procedure as part of their oral assessment.

The routine job cards that were used to carry out the CWT work on G-YMME were reviewed by BAMC and underwent many revisions during the period between January 2005 and December 2005. Initially, the organisation created routine job cards for the purge door removal, refit and leak check, to help ensure that the purge door was not missed during any CWT work. However, the need to upload 52,163 kg of fuel to leak check the purge door created some difficulties. The additional fuel weight caused the aircraft's weight to exceed the load limit for the tail jack. Delaying the leak checks until the aircraft was off the jacks was considered undesirable. Therefore, the organisation decided that the purge door should not be removed and that the engineers should routinely cross out the purge door job cards and write 'N/A' (not applicable) on them. The AAIB suggested to BAMC that if the intent was to raise awareness of the purge door without requiring it to be removed then the job cards should make that clear. Eventually the routine purge door removal, refit and leak check job cards were deleted and replaced by the following job card changes which were designed to increase awareness of the purge door without requiring it to be removed for purging:

> A note was added to the CWT purge job card stating: '*Do not remove the centre wing tank purge door (rear spar) for the purpose of additional ventilation.*'
>
> A routine card for the removal of the baffle doors was created which included an optional task stating *'If removal of CWT purge door is required raise a defect card to cover removal / refit requirements'*. The baffle door card then included space for noting whether or not defect cards were raised and what the defect card numbers were. The baffle door card also included a reminder that a defect card to leak check the purge door would also be required.
>
> A routine card for the refitment of the baffle doors was also created and the first task stated: '*Ensure CWT purge door (Rear Spar) is fitted.*' The card also included a note stating that a defect card may have been raised for the removal of the purge door.
>
> The job card for leak-checking the centre wing fuel tank access doors was revised to include a reference to the table in the AMM which contains the fuel levels necessary to leak check the fuel tank access doors. (This table in the AMM was revised by the manufacturer to include a leak check quantity for checking the purge door.)

Additional changes to some of the CWT job cards were as follows:

> The purge and drain CWT job card was separated into two separate cards, one for purging and one for draining. A reference to the '*associated equipment*' required for purging was added to the purge

card. The '*drain centre fuel tanks*' task was corrected to indicate that there were only two sump drains rather than three.

Routine job cards were created for the removal of the additional four CWT underwing access doors that were required for purging the CWT in accordance with the AMM.

The rear spar inspection job card was revised to include details on the access requirements and a reference number for the inspection procedure in the AMM was added.

The introduction of EWS should, once fully implemented, permit illustrations (such as diagrams of inspection areas) to be appended to job cards which should reduce the workload of engineers.

The QEAN system was revised to include an electronic database for tracking long-term issues, to ensure that issues were not closed or forgotten before they had been satisfactorily addressed. The Technical Services group also introduced a Technical Information Circular for communicating technical issues to the production staff, including those raised by QEANs. All LAEs were required to read the circular and sign that they had done so.

Team Leader Meetings between the Aircraft Controller and TTLs were reinstated on a regular basis. Before the G-YMME incident these meetings were supposed to be held monthly but the practice had become irregular. The new Team Leader Meetings were held every two months and Authorised Technicians were now invited (ie all LAEs involved). The agenda for the meetings was set by the Quality Group and the agenda usually included discussions of QDRs, health & safety issues and other maintenance issues.

The PQF was changed from a paper form to an electronic form to enable PQFs to be tracked in an electronic database. It was also decided that the Planning group should provide feedback to the originator of a PQF. The Quality group acquired oversight of PQFs and began to examine trends of '*number of PQFs raised*', '*number of PQFs cleared*', and '*number of PQFs open*' to ensure that the process was operating effectively.

In May 2005, BAMC added a Culpability Evaluation Flowchart to the appendix of its Incident Investigation Procedure. This flowchart is similar to the one recommended by the CAA in CAP 716 (see chart in Appendix 4). The chart is intended to clarify when a maintenance error would result in disciplinary proceedings taking place.

5.2 Safety action taken by Boeing, the aircraft manufacturer

Following correspondence between the AAIB and Boeing and a teleconference on 13 July 2004, Boeing decided to issue a Fleet Team Digest (FTD) highlighting the safety issue concerning the purge door.

On 20 July 2004 Boeing published 777-FTD-28-04004 entitled '*Reinstallation of Center Purge Door After Center Fuel Tank Maintenance'* on the Internet web site *myboeingfleet.com*. The FTD could only be accessed from the Internet by the operator or maintenance organisation and its issue was not announced by e-mail or other means. In addition, not every operator had access to the *myboeingfleet.com* web page. The AAIB and NTSB therefore encouraged Boeing to send a fax or telex to all operators highlighting the safety issue with the purge door.

On 10 August 2004 Boeing issued an All Operator Message (ID 1-36875416) entitled '*Reinstallation of Center Purge Door After Center Fuel Tank Maintenance*'. The message was sent via e-mail or fax to all 757, 777 and 747 operators as all three aircraft types had centre tank purge doors.

On 11 August 2004 Boeing published 777-FTD-57-04003 entitled '*Wing Center Section Rear Spar Inspection Discrepancy'* on *myboeingfleet.com*. This FTD highlighted the incorrect rear spar inspection diagram and the AMM revision of 5 May 2004 which corrected it.

On 16 September 2004 the Boeing Safety Review Board convened and released the following statement regarding the open purge door issue:

> *'The board determined this issue to be an Airplane Safety Issue for 747, 757 and 777, based on the potential for a maintenance error to result in both the possibility of significant fuel leakage into the wheel well, resulting in the potential for a wheel well fire, and the un-covered purge door opening allowing the potential for ignition propagation into the center wing tank.'*

Boeing decided in January 2003 that all new maintenance procedures, including post C-check procedures, would be validated, except for structural inspections. However, it was decided not to retrospectively validate all 777 post C-check maintenance procedures unless in-service problems with the procedures were reported.

Boeing considered the possibility of permanently sealing off the purge door. Therefore, in October 2004 the company carried out a survey of 777, 757 and

747 operators asking them how frequently they removed the purge door and if they would incorporate a Service Bulletin calling for the purge door to be 'blanked off'. Ten airlines responded and all but one stated that they used the purge door at least once a year as a means of purging and communication. The survey did not distinguish between aircraft types, but based on the survey results Boeing decided to retain the use of the purge door on all three aircraft.

5.2.1 Aircraft Maintenance Manual revisions by Boeing

777 AMM Revision 5 September 2004 (Rev 42):

> Center Purge Door – Removal/Installation procedure (28-11-04-000-801): leak-check fuel quantity changed from 70,000 lb (32,000 kg) to 115,000 lb (52,163 kg).
>
> Purging and Fuel Tank Entry procedure (28-11-00-010-801): reference to purge door added to the section on using blower type ventilation equipment: '*For additional ventilation, you can open the center tank purge door…*' However, no reference to the purge door was added to the section on using venturi type ventilation equipment (as used by some maintenance organisations).
>
> Wings – Structural Inspections – Maintenance Practices procedure (57-05-03-211-801), subtask Internal – Detailed: Wing Center Section: reference added to the three baffle doors (133AZ, 133BZ and 133 CZ) and a diagram added (Figure 201, sheet 2 of 3) showing the baffle doors installed and removed. Dotted line added encompassing the entire rear spar to highlight the inspection area, although inspection area was limited to the lower part.

777 Task Card Revision 5 September 2004:

> Rear spar inspection task card (57-501-00-01) revised to include a diagram showing the baffle doors and a procedure for removing the baffle doors.

777 AMM Temporary Revisions (TR) 15 October 2004:

> TR 28-1003 concerning Purging and Fuel Tank Entry procedure (28-11-00-010-801): reference to purge door added to the section on using venturi type ventilation equipment: *'For additional ventilation, you can open the center tank purge door…'*.

TR 28-1004 concerning Fuel Leak Detection Procedures (28-11-00-790-801): Center Purge door and its fuel leak-check amount added to Table 601 *'Fuel Necessary to Cover the Access Doors'*.

TR 28-1006 concerning Center Purge Door – Removal/Installation procedure (28-11-04-000-801): Task added to attach a REMOVE BEFORE FLIGHT streamer when opening the purge door.

TR 28-1007 concerning Center Tank Access Door – Removal/ Installation procedure (28-11-02-000-801): diagram added showing location of baffle doors.

777 AMM Revisions 5 January 2005 (Rev 43):

Wings – Structural Inspections – Maintenance Practices procedure (57-05-03-211-801), subtask Internal – Detailed: Wing Center Section: rear spar inspection diagram corrected using dotted line to highlight the lower section of the rear spar. Labelling of rear spar cross section corrected with vertical leg arrow pointing to the vertical leg instead of the rear spar as before.

TRs 28-1003, 28-1004, 28-1006 and 28-1007 incorporated into Revision 43.

777 Task Card Revision 5 May 2005:

Rear spar inspection task card (57-501-00-01) revised to include an access note stating '*Access panels 133AZ, 133BZ, and 133CZ are only applicable to airplane models "200ER, 200LR, 300, and 300ER" which utilize the center wing tank for fuel. Before tank entry drain/purge fuel tank for airplanes which utilize the center wing tank for fuel.*' Rear spar inspection diagram corrected using dotted line to highlight the lower section of the rear spar. Labelling of rear spar cross section corrected with vertical leg arrow pointing to the vertical leg instead of the rear spar as before.

777 AMM Temporary Revision (TR) 6 January 2006:

Purging and Fuel Tank Entry procedure (28-11-00-010-801): Figure 203 (sheet 3 of 5) was corrected to show all three inboard wing access doors open on the left wing during purging (previously only one door shown open contrary to the procedure which required all inboard access doors to be opened).

777 AMM Revision planned for 5 May 2006 (Rev 47):

Fuel Leak Detection Procedures (28-11-00-790-801) will be revised to clarify that the talcum powder procedure is not required and that a visual inspection is sufficient to check for leaks following re-installation of an access door that was removed for maintenance. The talcum powder procedure will still be required for known leaks.

In late 2005 Boeing carried out a technical review of the 777 AMM and identified several additional changes that would enhance the clarity of procedures with regards to the differences between the 777 A-market configuration and the B-market configuration. These additional changes were incorporated in the 5 January 2006 revision of the AMM.

In addition, the 757 AMM was revised on 28 September 2004 to reference the purge door removal/installation procedure in the fuel tank access and close-up procedures.

The 757 AMM was also revised on 28 September 2004 to include the use of a REMOVE BEFORE FLIGHT STREAMER when the purge door was removed (task 28-11-08-004-015).

The 747 AMM was revised on 25 October 2004 to include the use of a REMOVE BEFORE FLIGHT STREAMER when the purge door was removed (task-28-11-06-004-001).

5.3 Safety action taken by British Airways, the operator

On 10 June 2004 British Airways (BA) assigned a safety investigator to carry out an internal safety investigation into the incident.

On 11 June 2004, following reinstallation of the purge door, BA raised an Acceptable Deferred Defect (ADD) stating that G-YMME was not to be operated on routes requiring CWT fuel until a leak-check of the purge door had been carried out using a CWT fuel figure of 80,000 kg (full fuel).

On 12 June 2004 BA carried out a leak-check of the purge door with full fuel in the CWT. No leaks were found.

On 23 June 2004 BA issued a Temporary Revision to the 777 AMM correcting the fuel leak-check amount for the purge door.

On 28 July 2004 BA issued an internal Incident Investigation Report with safety recommendations for BAMC (see Appendix 7).

On 29 July 2004 BA defuelled the CWT on G-YMME and removed access panel 139AZ and the purge door to confirm that the forward and aft baffle doors were in place.

In August 2004 BA agreed a plan in conjunction with BAMC, Boeing and the CAA to postpone the rear spar inspection on those aircraft where it was not correctly completed until the aircraft's next C-check.

In October 2004 BA carried out a job card audit on BAMC's job cards for a D-check on a 777. The certified cards were reviewed to establish if they fully met the intent of the job as written in the AMP. A total of 2,200 cards were checked and 61 Category 1 (highest risk) deficiencies, 192 Category 2 deficiencies and 317 Category 3 deficiencies were found (see Appendix 5 for category definitions). These were all addressed by BAMC.

BA has also changed its compliance audit frequency of BAMC from once every 18 months back to once every 12 months.

5.4 Safety action taken by the AAIB

On 28 July 2004 the AAIB published a Special Bulletin S2/2004 describing the circumstances of the incident which highlighted the purge door safety issue and some of the errors in the AMM. The bulletin was published in paper form and on the AAIB's website *www.aaib.gov.uk*.

Throughout the investigation the AAIB has made informal safety recommendations and suggestions to British Airways, BAMC and Boeing. The formal safety recommendations made as a result of this investigation are listed in Section 4.

J J Barnett
Inspector of Air Accidents
Air Accidents Investigation Branch
Department for Transport
February 2007

DRAIN AND PURGE CENTER FUEL TANKS | Card Serial 000151

BAMC Card No 2811002AC01-001	A/C Reg G-YMME	Work Area 1F
Planned Duration : 2:00 Engineer : 0:30 Mechanic : 7:30	Forward lower fuselage/frei Airframe Engine drain	Card Completed BAMC [redacted] 04 MAY 2004
CERTIFICATION CARD	NEP	

	COM	Comp By	Cat Cert By
1. Left center fuel tank drained and purged IAW MM 28-11-00-010-801 & MM 12-11-02-650-801.		04 MAY 2004 BAMC [redacted]	04 MAY 2004 N BAMC [redacted]
2. Right center fuel tank drained and purged. IAW MM 28-11-00-010-801 & MM 12-11-02-650-801.		04 MAY 2004 BAMC [redacted]	04 MAY 2004 N BAMC [redacted]
3. Center tank drained and purged. IAW MM 28-11-00-010-801 & MM 12-11-02-650-801.		04 MAY 2004 BAMC [redacted]	04 MAY 2004 N BAMC [redacted]

No Materials for card

Defect Cards Raised

BAMC [redacted]

Cust Ref no | Cert.IAW BAMC Dept. Proc. DQL-8

A/C Reg G-YMME | W/O 001601 | Customer British Airways

Prepared By [redacted] | Print No 001 | Sht 1 of 1

Last Amd By | Version No 001 | Issue 003

Sample job card (certification stamp numbers ‘blacked out’)

Appendix 2

BAMC TECHNICAL SUPPORT
REQUEST FOR ENGINEERING ADVICE FORM

A/C Type: 777-200	Reg: all	Source Doc:	ATA:	Date: 10/05/2002	Query No: QEAN 41696
Raised By: [redacted]		Grade: Planning Engineer		Shift:	Tele No: 2189

Part A. Please insert your query here

Query:

TANK PANELS.
With referance to QEAN 41171 we requested some panel No.s not part No.s.
Now that you have a part no. for said panel could it not now be furnished with a panel No. and added to the relevent part of the MM.

Thanks

Response required by .... in order to make a/c serviceable within scheduled downtime

Part B. Information contained below is advisory. All work carried out must be recorded and certified on the appropriate hanger documentation

Answer / Action:

Adrian,

Further to Q41171, I have informed The Boeing Company of the noted ommision from the 777 MPD and requested they amend the MPD at its next revision.

Thanks for info.

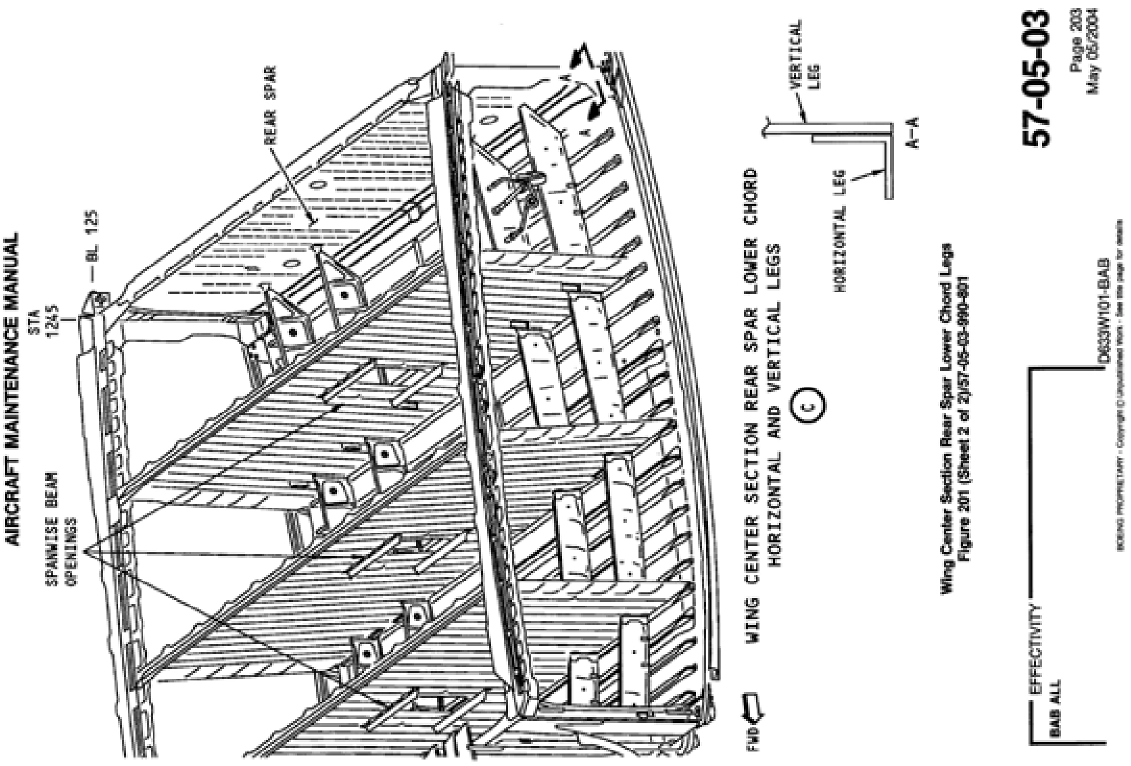
Response required by .... in order to make a/c serviceable within scheduled downtime

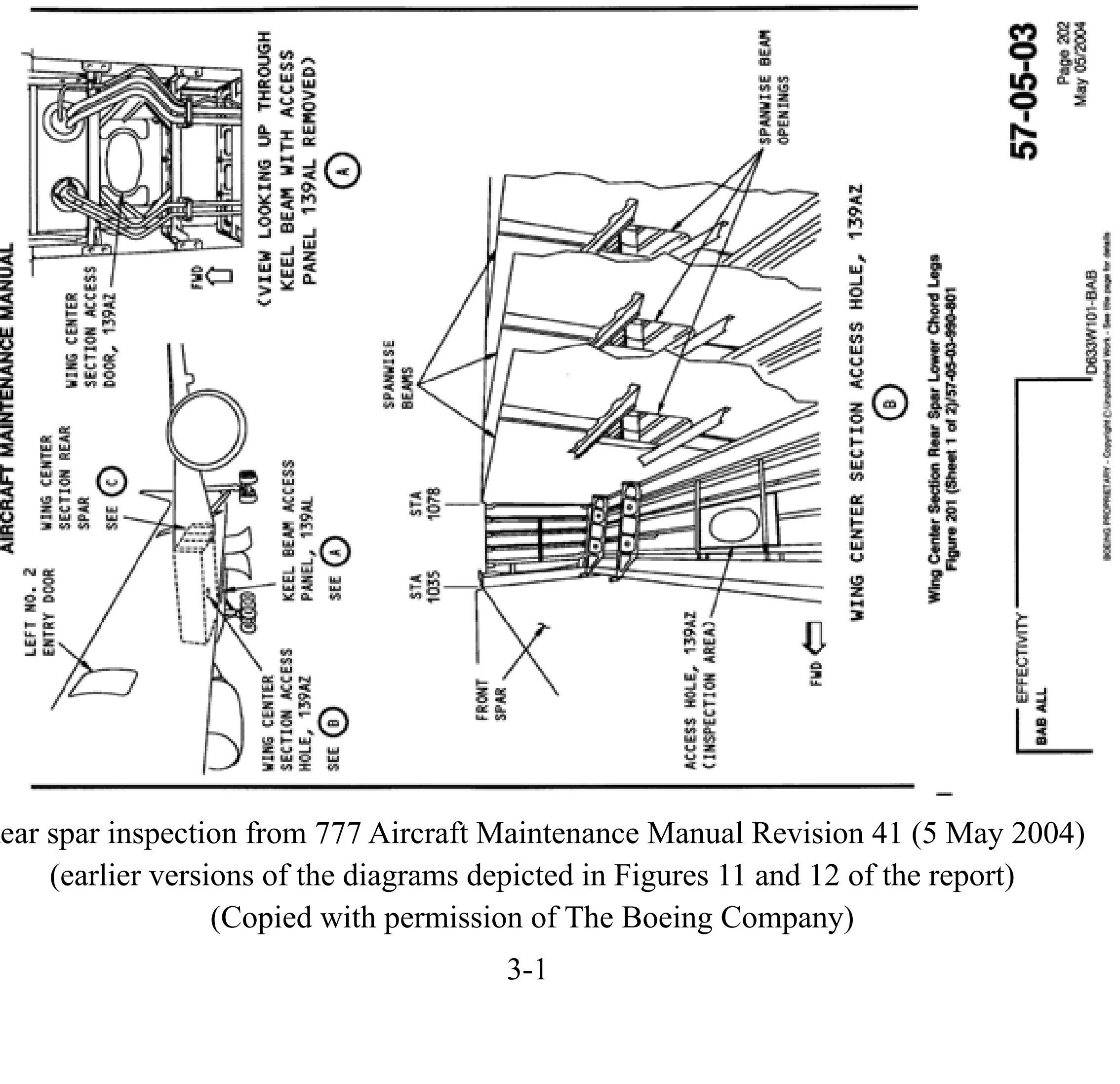
Responding Engineer: [redacted]	(Technical Support Eng.)	Date: 23/05/2002	Tele No: 2343

FORM : TS007 Rev.1

Sample QEAN (Query for Engineering Advice Note, (names 'blacked out')

Appendix 3





Rear spar inspection from 777 Aircraft Maintenance Manual Revision 41 (5 May 2004)
(earlier versions of the diagrams depicted in Figures 11 and 12 of the report)
(Copied with permission of The Boeing Company)

Appendix I Example Disciplinary Policy

One of the prerequisites for a successful Maintenance Error Management System is that staff should feel that they can report occurrences and errors openly, without fear of punitive action. The reporting aspect may be accomplished by means of a confidential reporting scheme, but in order to investigate the occurrences, it is necessary to speak to the individuals involved. A blame-free approach is not the answer, since some actions are blatantly negligent and warrant punitive action. It is necessary to have clear policy stating that staff will not be punished for genuine errors. Each company will need to decide what its policy is concerning the 'grey' areas between error and negligence, where violations may have been committed but where punitive action may not be appropriate.

Some example wording and further guidance are given below:

> Staff are encouraged to report safety concerns and errors, and to cooperate with investigation of incidents, the primary aim being to establish why the problem occurred and to fix it, and not to identify and punish the individual(s) concerned.
>
> It is the company's policy that an unpremeditated or inadvertent lapse should not incur any punitive action, but a breach of professionalism may do so.
>
> It may be necessary to stand down (suspend) an individual pending investigation. This should not be interpreted as punitive action but, rather, as a precautionary safety measure.
>
> As a guideline, individuals should not attract punitive action unless:
>
> (a) The act was intended to cause deliberate harm or damage.
>
> (b) The person concerned does not have a constructive attitude towards complying with safe operating procedures.
>
> (c) The person concerned knowingly violated procedures that were readily available, workable, intelligible and correct.
>
> (d) The person concerned has been involved previously in similar lapses.
>
> (e) The person concerned has attempted to hide their lapse or part in a mishap.
>
> (f) The act was the result of a substantial disregard for safety.
>
> This does not mean to say that individuals *will* incur puntive action if they meet one of the above conditions; each case will be considered on its merits.
>
> "Substantial disregard", in item (f), means:
>
> - In the case of a certification authorisation holder (e.g. licensed engineer or Certifying Staff) the act or failure to act was a substantial deviation from the degree of care, judgement and responsibility reasonably expected of such a person.
> - In the case of a person holding no maintenance certification responsibility, the act or failure to act was a substantial deviation for the degree of care and diligence expected of a reasonable person in those circumstances.

The degree of culpability may vary depending on any mitigating circumstances that are identified as a result of an investigation.

Example disciplinary policy from CAP 716, page 1

If it is deemed appropriate to take action concerning an individual, this need not necessarily be punitive, nor should be considered as such. The action should always be whatever is appropriate to try to prevent a re-occurrence of the problem. Action may take the form of additional training, monitoring by a supervisor, an interview with a manager to ensure that the individual is fully aware of the implications of their actions, etc. Only in the worst case would dismissal be considered as appropriate action.

Note: an organisation may wish to use Figure 1 as a guide when drawing up a disciplinary policy, whilst remembering what they are trying to achieve by ascertaining the degree of culpability - ie, to prevent a re-occurrence of that incident, not to establish blame or to mete out punishment for its own sake.

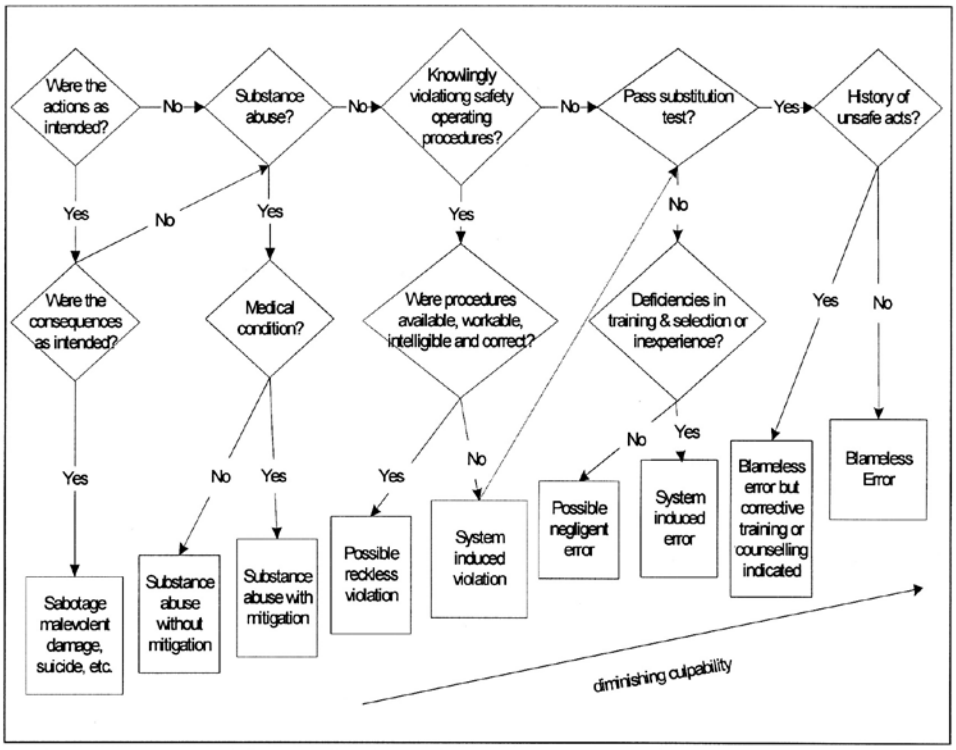


Figure 1 A decision tree for determining the culpability of unsafe acts. Reason, 1997.

The "substitution test" is good rule of thumb when illustrating where blame is inappropriate. If an incident occurs, ask yourself whether another similar individual (with the required skill, training and experience) in the same circumstances would have done anything different. If not, then blame is definitely inappropriate. Further information on this concept can be found in the article: *"Do blame and punishment have a role in organisational risk management?". Johnston, N. Flight Deck. Spring 1995, pp 33-6.*

Example disciplinary policy from CAP 716, page 2

Appendix 5

<u>Risk classification categories at BAMC</u>

Occurrence report classifications

A. *Significant lapse in Maintenance Standards and/or Control, which jeopardized airworthiness. This classification must be agreed with the Quality Manager prior to allocation.*

B. *Significant lapse in Maintenance Standards and/or Control, which has or may impact upon airworthiness or is estimated to have cost implications in excess of £5000.*

C. *A lapse in standards of Maintenance and/or Control, which may have an effect upon airworthiness.*

D. *A lapse in standards of Maintenance and/or Control in an engineering area, which has no direct bearing upon airworthiness.*

E. *A lapse in standards of maintenance and/or control in a non-engineering area, which has no direct bearing upon airworthiness.*

Audit discrepancy classifications

Level 1 *An Airworthiness or Regulatory non-compliance with, PART 145 or NAA requirements, which pose an immediate and significant threat to the aircraft's airworthiness, aircraft's operation or loss of regulatory approval to BAMC.*

Level 2 *Any non-compliance with PART 145 or NAA requirements.*

Level 3 *Any non-compliance with Company processes or procedures.*

Job card audit category classifications

Category 1 *'The task card does not comply with the AMP requirement. Task card re-write required within given timescales. Possible aircraft re-check required.'*

Category 2 *'The task card complies with the AMP requirement but there are errors associated with the card, for example MM* *subtask numbers incorrect, access requirements different to that specified in the AMP/MPD. Task card re-write required within given timescales. No aircraft re-check required.'*

Category 3 *'The task card complies with the AMP requirement but there are editorial errors associated with the card, for example typos, pre-MPD customer references and NEPs, no customer references or NEPs, etc. Task card re-write on attrition. No aircraft re-check required.'*

Appendix 6

Extract from BAMC report on the G-YMME incident, dated 26 July 2004

Conclusions

The primary cause of this incident is unrecorded work. Sadly, no person offered information so the specific details could not be gathered but supposition indicates a number of related contributory factors. The problem of unrecorded work is not a major factor at BAMC, but an overall increase in awareness of its consequences at all levels would be essentially.

A number of related contributory causes were identified. Poor AMM instructions in a number of instances led to the incorrect inspection and added confusion to the CWT purge process. The incorrect leak check level would have prevented detection of the missing panel, although as no card was raised, the leak check may not have been performed in any event.

Overall there was concern highlighted at the lack of task engineering at BAMC. Throughout the report, it was stressed that such lack of engineering did not directly contribute to the incident, but will have added additional stress to an already complex series of tasks. The task engineering is a valuable asset to BAMC and sets it apart from competitors and strenuous efforts should be made to re-establish fully engineered tasks.

Protracted or missing feedback periods from engineering to production staff, may have added to confusion over tasks, and certainly adds additional complexity to the TTL role which could be avoided. The introduction of the SAP computer system has placed great demand on resources and has perhaps compromised slightly the engineering process at BAMC. Although not of primary impact on G-YMME, these gaps will need closure to prevent another incident from occurring.

The production department has an inherent complexity, driven primarily from the need to match load with capacity for efficient maintenance management. This process although vital to the business success might have contributed to the incident on G-YMME, so a review of these process' is strenuously recommended. Also the inconsistency of typewritten handovers, although not a matter, should be addressed at some stage.

Safety Recommendations

1. Provide feedback of this investigation to ideally all, but in any event 90% of the company population, specifically highlighting the dangers of unrecorded work, and the advantages of recording work. *Such feedback need not be direct dissemination, but must highlight the relevant points of this investigation. Ideally this could be carried out as an extension to the TTL briefing process, which has already begun.*

2. Instigate an engineer's open forum, supported but not driven by management. Provide central co-ordination and valuable chair to direct and facilitate such meetings. *Content must include quality lapse feedback (from all BA areas and across the industry) and technical feedback (such as QEAN responses, in-service activity etc). The forum could also extend to working groups, working practises, possibly investigative processes. It will provide a free culture to air views and raise quality issues.*

3. Revise the Engineering to production feedback process to provide clear, accurate and up to date information. *Items for discussion should include providing a more global communicative process where information is promulgated more readily to all engineering (support and production) personnel. Perhaps an adaptive but distinctive form of the QIC process, and possibly relational feedback through the engineer's forum being established.*

4. A routine card must be established for the removal, refit and leak check of the purge door. This card should be linked to the purge CWT task card that is already called every 2C check. Additionally a card must be raised for the baffle door removal, which could be linked to the inspection card.

5. Change the work area of the 777 CWT, to be more coherent and worked from only one zone. *A review clearly should be performed but the view of this investigation team is that given the current ownership of the leak checks, WA5 would seem the most logical choice.*

6. Details of all the failures of the AMM must be returned to Boeing for rapid inclusion at the next revision. These specific details being:
    - Increase the leak check figure for the purge door in both the 28-11-04 and 28-11-00 sections to the correct value.
    - The purge fuel tank procedure of 28-11-00 has several mistakes and the whole procedure should be reviewed.
    - Introduction of identification numbers on the three span wise panels and the purge door.

7. Review the QEAN process to ensure that actions are not prematurely closed with requests for information and provide more inclusive feedback of the final solutions. *Discussion might include introducing a verification process to ensure positive follow up, particularly where third parties are involved. Additionally consideration must be given to introducing greater dissemination of QEAN replies*

8. Develop a cohesive attitude and strategy to fully engineering tasks. Included within this strategy must be the target of having all tasks fully engineered before they move to the production floor. *BAMC requires fully engineered tasks to be provided for all tasks. This review should not be limited to future tasks, but should consider reviewing some of the tasks that have gone through in the last two years.*

9. Reinitiate and invigorate the planning query form process. Clear communication should be given to the value and importance BAMC places on such support activities. *An engineering feedback process is vital for continued airworthiness. The system at BAMC is robust in its nature, but its application needs review.*

10. Review the current BAMC panel handling processes to establish methods of control of all panels and equipment removed from the aircraft. *Such review should consider changing the identification tag, and looking at methods of controlling fixed or hinged panels. Ensuring that panel racks are identified as such and that discipline of removed components, including certification is maintained.*

Appendix 7

Extract from British Airways Corporate Safety report on the G-YMME incident, dated 28 July 2004

Conclusions

The aircraft lost fuel on take off and climb due to the centre tank purge door not being fitted. The actions of the flight crew and ATC ensured a safe outcome to the flight. The most likely point that the purge door was removed was during G-YMME's maintenance input at BAMC from the 2nd to the 10th May. The reason that no fuel loss was evident between the 10th May and the incident was due to the limited use of the centre tank and the low fuel levels in it. The 101,000 kgs of fuel for the Harare service was the first exposure to potential fuel leakage that the aircraft had experienced since that input.

The exact process that led to the purge door being removed and left off could not be determined as it was not recorded and no member of staff came forward with direct information about it. It was however most probable that it was either removed by one shift in anticipation of a rear spar inspection, as it had been on previous aircraft, and not recorded or that it was removed as part of the purge process by staff familiar with the purge process on the 747-400. The staff on another shift that carried out the rear spar inspection and tank closure were not familiar with the area and therefore without a work card for it to be refitted were unaware of its removal.

The staff involved in the purge door removal either failed to follow the maintenance manual purge process or failed to record the removal of the door on a defect card. The distribution of the work across different shifts and unclear work instructions to people unfamiliar with the task, likely contributed to the removal of the door or the failure to record it. The AMM tasks, work cards and working practices at BAMC all helped to create a degree of confusion over the centre tank work and failed to ensure effective control over the tasks required.

The rear spar inspection on this aircraft was not performed correctly due to an incorrect diagram in the AMM and the LAE's unfamiliarity with the task. This incorrect AMM drawing had however been known about by BAMC for several months and there appeared to be no internal activity to ensure that the correct inspection was done without the need for prior knowledge of the task and the raising of defect cards.

The lack of effective technical instructions regarding the centre fuel tank and the rear spar inspection highlighted the potential risks associated with staff unfamiliar with a particular aircraft type or aircraft zone.

No analysis was done on the general reporting culture at BAMC as part of this investigation, it was however disappointing that no one felt able to come forward with knowledge of the purge door removal on this aircraft. This lack of information creates a potential barrier to effectively learning from incidents. In the interests of air safety it is vital that staff are encouraged to report all errors and omissions, and, assuming there was no willful intent behind the error or omission, can do so without fear of being disadvantaged.

Safety Recommendations addressed to British Airways Maintenance Cardiff

Recording of work
Reinforce to staff the importance of recording work performed on aircraft at the time it is performed. As part of this activity ensure that effective measures are in place to minimize the repetitive raising of defect cards for what are in effect routine tasks.
Discussion: The purge door was most likely removed for routine access and not recorded. The need for this access had been identified some months previously but still required individual defect cards to be raised.

Centre tank working
Carry out a thorough review of the AMM technical instructions, work cards and BAMC processes regarding centre tank working with the objective of minimizing confusion and ensuring effective task control.
Discussion: The AMM tasks, work cards and working practices at BAMC all helped to create a degree of confusion over the centre tank work and failed to ensure effective control over the tasks required.

Technical query follow-up
Implement effective process to ensure that queries raised over work documentation are dealt with internally in addition to activities undertaken by the aircraft manufacturer.
Discussion: The incorrect AMM drawing for the rear spar inspection had been known about for several months but there appeared to be no internal activity to ensure that the correct inspection was done without the need for prior knowledge of the task and the raising of defect cards.

Aircraft and zone familiarity
Ensure the risks highlighted by this incident in the lack of familiarity with aircraft types and zones are incorporated into procedures for the transfer and rotation of staff to maintain organisational flexibility whilst minimising risk.
Discussion: The lack of effective technical instructions regarding the centre fuel tank and the rear spar inspection highlighted the potential risks associated with staff unfamiliar with a particular aircraft type or aircraft zone.

UK Civil Aviation Authority

AIRWORTHINESS NOTICE

Civil Aviation Authority

No. 71
Issue 2
21 March 2005

Maintenance Error Management Systems

1 INTRODUCTION

1.1 In January 2003, JAR 145 amendment 5 (subsequently incorporated into EASA Part 145) introduced paragraph 145.A.60 - Occurrence Reporting, to require organisations to "establish an internal occurrence reporting system...to enable the collection and evaluation of such reports, [which have resulted, or may result, in an unsafe condition]. This procedure shall identify adverse trends, corrective actions taken or to be taken by the organisation to address deficiencies and include evaluation of all known relevant information relating to such occurrences and a method to circulate the information as necessary." CAA seeks to provide an environment in which such errors may be openly investigated in order that the contributing factors and root causes of maintenance errors can be addressed using a system that would complement, not supplant, the two current systems for reporting maintenance errors (MORS and CHIRP).

NOTE: Square brackets [ ] denote CAA insertion.

1.2 Mandatory Occurrence Reporting (MOR) scheme exists in order that significant safety issues are brought to the notice of the CAA. However, the MORs scheme is not intended to collect and monitor the normal flow of day-to-day defects/incidents etc. which, in remaining an industry responsibility (CAP 382 Mandatory Occurrence Reporting System, paragraph 5.4.5), forms an important part of the overall operational safety task. This Notice concerns, primarily, those events which fall below the MOR criteria but which, nevertheless, are important for an organisation to understand and control. However, the principles described in this Notice may also be applied by an organisation to their own internal investigation of incidents meeting the MOR criteria

NOTE: Organisations will still be required to report MORs to the CAA.

1.3 The Confidential Human Factors Incident Reporting Programme (CHIRP) scheme provides an alternate reporting mechanism for individuals who want to report safety concerns and incidents confidentially. However CHIRP should not be considered as an alternative to implementing a Maintenance Error Management System (MEMS) scheme. MEMS and CHIRP perform different functions albeit acting towards the same ultimate aim, i.e. improved flight safety.

1.4 Maintenance errors with serious consequences such as accidents or incidents are routinely investigated by organisations, Air Accident Investigation Branch or CAA. Other operationally significant events (e.g. technical delays, cancellations, etc.) may not be legally required to be reported externally but are frequently investigated by organisations albeit too often only to apportion responsibility for the event, rather than to determine cause. Below these levels are events without operational significance which may rarely be investigated (e.g. the omission of an oil filler cap which, by chance, is noticed and corrected before flight). In order to gain a better understanding of the problems and factors which contribute to errors it is necessary to investigate these and operationally significant events before they possibly contribute to or cause an incident or accident in the future.

1.5 It is important to examine not just *what* happened, but *why* it happened, in order to determine the root causes and problems.

CAA Airworthiness Notice, page 1

2 MAINTENANCE ERROR MANAGEMENT SYSTEM

2.1 AN 71 Issue 1 (2000) set out CAA policy on MEMS and, prior to the requirements introduced by JAR 145.60 and Part 145.A.60, encouraged maintenance organisations, in particular those maintaining large commercial air transport aircraft, to adopt MEMS concepts. Subsequently, the JAA Maintenance Human Factors Working Group incorporated very similar guidance into their report published in May 2001 (reproduced in CAP 716 issue 2, 18/12/2003), with the key elements being incorporated into EASA Part 145.A.60(b) and AMC 145.A.60(b). Both key, and more detailed, elements are described below, in particular the importance of a 'just culture' for the successful functioning of a MEMS.

2.2 Prevailing industry best practice has shown that a MEMS should contain the following elements:

- Clearly identified aims and objectives
- Demonstrable corporate commitment with responsibilities for the MEMS clearly defined
- Corporate encouragement of uninhibited reporting and participation by individuals
- Disciplinary policies and boundaries identified and published
- An event investigation process
- The events that will trigger error investigations identified and published
- Investigators selected and trained
- MEMS education for staff, and training where necessary
- Appropriate action based on investigation findings
- Feedback of results to workforce
- Analysis of the collective data showing contributing factor trends and frequencies

2.3 The aim of the scheme is to identify the factors contributing to incidents, and to make the system resistant to similar errors. Whilst not essential to the success of a MEMS, it is recommended that for large organisations a computerised database be used for storage and analysis of MEMS data. This would enable the full potential of such a system to be utilised in managing errors.

2.4 For the purpose of this Airworthiness Notice a maintenance error is considered to have occurred when the maintenance system, including the human element, fails to perform in the manner expected in order to achieve its safety objectives. The human element includes technicians, engineers, planners, managers, store-keepers – in fact any person contributing to the maintenance process. The foregoing definition differs from that of a human error as it demands consideration of the system failings (e.g. inadequate staffing, organisational factors, tooling availability, ambiguous manuals etc.) as well as the error committed by a person.

3 CAA ASSURANCES

3.1 It is recognised that the success of a MEMS programme is dependent on full and free investigation without fear of action by the CAA. Accordingly, the CAA gives the following assurances:

3.1.1 The CAA will be checking, as part of its approval audit process, that the organisation's internal occurrence reporting and investigation process is functioning as described in the procedures approved by the CAA and in line with the objectives of the programme as explained in CAP 716 Issue 2. The CAA audit may involve the review of disidentified MEMS investigations such that the foregoing can be satisfied. However, the CAA makes the following assurances that it will:

(a) subject to (b) not disclose the name of the person submitting the MEMS report, nor of a person to whom it relates, nor pass on a MEMS report to a third party, unless required to do so by law or unless the person(s) concerned authorises such disclosure.

(b) take all reasonable steps possible to avoid disclosing the identity of the reporter or of those individuals involved in the occurrence, should any follow-up action arising from a MEMS report be taken.

(c) not, as its policy, institute criminal proceedings in respect of unpremeditated or inadvertent breaches of the law or requirements which come to its attention only because they have been reported under the MEMS scheme, except in cases involving dereliction of duty amounting to gross negligence or recklessness. Such an assurance is similar to that provided under the MOR scheme.

3.2 As examples of what the CAA might require, as evidence that an organisation has a working MEMS programme in accordance with Part 145.A.60(b), a surveyor may ask to see the following documents and evidence, and in order to satisfy himself, he may wish to speak to individual members of staff at any level within the organisation:

(a) A copy of the company's safety and disciplinary policy and determine that staff are aware of this policy, and believe that it will be, and has been, applied fairly.

(b) The procedure describing the company's process for reporting and investigating incidents and errors, and the types of occurrences that would normally be investigated.

(c) Evidence that occurrences meeting the criteria detailed above, have been reported, and to assure himself that occurrences are not frequently going unreported

(d) Evidence that occurrences meeting the criteria detailed above, have been investigated, and to assure himself that occurrences are being, and have been, fairly investigated. It is hoped that an organisation would cooperate with a surveyor in putting him in touch with individuals who have been party to investigations, but only with the agreement of the individuals concerned.

(e) Within a large company, evidence that MEMS investigators had received appropriate training.

(f) Evidence that the organisation had acted, or was acting, upon results of MEMS investigations, based on risk assessment. This may mean that no action had been taken if a risk assessment has deemed that the causes were unlikely, in isolation or in combination, to result in a hazardous event in the future. A surveyor would expect to see evidence of action(s) to prevent root causes, and/or to mitigate the effects of error where appropriate.

(g) Evidence of feedback to the workforce, on both occurrences and their investigation, and remedial action taken, would also be expected.

3.3 For a small organisation, the surveyor would expect evidence as described above, but on a less structured basis.

3.4 If an organisation has no evidence to offer in the form of reported and investigated occurrences, the surveyor may wish to talk to staff to assure himself that there have been no such occurrences, as opposed to occurrences going unreported and uninvestigated. The surveyor would respect staff confidences in seeking such evidence.

4 MEMS CODE OF PRACTICE

4.1 The CAA encourages organisations to adopt the following code of practice regarding a MEMS:

4.1.1 Where an occurrence reported via MEMS indicates an unpremeditated or inadvertent lapse by an employee, as described below, the CAA would expect the employer to act reasonably, agreeing that free and full reporting is the primary aim in order to establish *why* the event happened by studying the contributory factors that led to the incident, and that every effort should be made to avoid action that may inhibit reporting.

4.1.2 In the context of error management it is considered that an unpremeditated or inadvertent lapse should not incur any punitive action, but a breach of professionalism may do so. As a guideline, individuals should not attract punitive action unless:

(a) the act was intended to cause deliberate harm or damage.

(b) the person concerned does not have a constructive attitude towards complying with safe operating procedures.

(c) the person concerned knowingly violated procedures that were readily available, workable, intelligible and correct.

(d) the person concerned has been involved previously in similar lapses.

(e) the person concerned has attempted to hide their lapse or part in a mishap.

(f) the act was the result of a substantial disregard for safety.

"Substantial disregard", for this purpose, means:-

- In the case of a certification authorisation holder (e.g. licensed engineer or Certifying Staff) the act or failure to act was a substantial deviation from the degree of care, judgement and responsibility reasonably expected of such a person.
- In the case of a person holding no maintenance certification responsibility, the act or failure to act was a substantial deviation from the degree of care and diligence expected of a reasonable person in those circumstances.

The degree of culpability would vary depending on any mitigating circumstances that are identified as a result of the MEMS investigation. It follows that any action taken by the organisation would also be on a sliding scale varying from corrective measures such as retraining through to dismissal of the individual.

4.1.3 In the case of incidents investigated via a MEMS, irrespective of whether or not such incidents were brought to the knowledge of the CAA, the CAA expects an organisation to address the problems which contributed to these incidents. The organisation should, where possible, implement appropriate measures to prevent the problem from re-occurring, or alternatively monitor future occurrences, according to the degree of risk and likelihood of re-occurrence. A supporting database is useful in these circumstances in helping to assess the frequency of occurrence and any associated trends.

4.1.4 The CAA would expect that identified safety issues would be acted upon. If the CAA becomes aware, by whatever means, that a significant safety problem existed and was not being addressed, it reserves the right to take appropriate action.

NOTE: The statement by an organisation that an incident is undergoing, or has undergone, a MEMS investigation, without any additional information provided to explain why the incident occurred, would not normally be an adequate basis for an MOR closure.

4.1.5 Organisations are encouraged to share their MEMS results with the CAA and with other maintenance organisations. It is hoped that by sharing such data the CAA and industry can jointly develop a better understanding of maintenance error causation and develop more focused human factors strategies. However, it is appreciated that some information in a MEMS may be considered sensitive to the organisation affected, and may need to be dis-identified before being shared with other organisations.

5 FURTHER INFORMATION

5.1 More detailed guidance information, including where to obtain free MEMS software, is included in CAP 716 Issue 2.

5.2 Maintenance Organisations requiring further information or advice on how to establish a Maintenance Error Management System should contact their CAA Aircraft Maintenance Standards Department (AMSD) local Regional Office;

or:

Maintenance Requirements and Policy Section,
Aircraft Maintenance Standards Department,
CAA
Aviation House
Gatwick Airport South
West Sussex
RH6 0YR
Tel: 01293 573366
Fax: 01293 573987

6 CANCELLATION

This Notice cancels Airworthiness Notice No. 71, Issue 1, dated 20 March 2000, which should be destroyed.

CAA Airworthiness Notice, page 4

L 315/56 EN Official Journal of the European Union 28.11.2003

145.A.60 Occurrence reporting

(a) The organisation shall report to the competent authority, the state of registry and the organisation responsible for the design of the aircraft or component any condition of the aircraft or component identified by the organisation that has resulted or may result in an unsafe condition that hazards seriously the flight safety.

(b) The organisation shall establish an internal occurrence reporting system as detailed in the exposition to enable the collection and evaluation of such reports, including the assessment and extraction of those occurrences to be reported under paragraph (a). This procedure shall identify adverse trends, corrective actions taken or to be taken by the organisation to address deficiencies and include evaluation of all known relevant information relating to such occurrences and a method to circulate the information as necessary.

(c) The organisation shall make such reports in a form and manner established by the Agency and ensure that they contain all pertinent information about the condition and evaluation results known to the organisation.

(d) Where the organisation is contracted by a commercial operator to carry out maintenance, the organisation shall also report to the operator any such condition affecting the operator's aircraft or component.

(e) The organisation shall produce and submit such reports as soon as practicable but in any case within 72 hours of the organisation identifying the condition to which the report relates.

EASA Part 145.A.60 Regulation on occurrence reporting