

AIRCRAFT ACCIDENT REPORT 1/92

Air Accidents Investigation Branch

Department of Transport

**Report on the accident to
BAC One-Eleven, G-BJRT
over Didcot, Oxfordshire
on 10 June 1990**

**This investigation was carried out in accordance with
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First published 1992.

ISBN 0 11 551099 0

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3/91	Lockheed L1011-500, C-GAGI 1 nm south-east of Manchester, Cheshire on 11 December 1990	December 1991
1/92	BAC One-Eleven, G-BJRT over Didcot, Oxfordshire on 10 June 1990	April 1992

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**Department of Transport
Air Accidents Investigation Branch
Royal Aerospace Establishment
Farnborough
Hants GU14 6TD**

February 1992

*The Right Honourable Malcolm Rifkind
Secretary of State for Transport*

Sir,

I have the honour to submit the report by Mr D F King, an Inspector of Air Accidents, on the circumstances of the accident to British Airways BAC One-Eleven, G-BJRT, that occurred over Didcot, Oxfordshire on 10 June 1990.

I have the honour to be
Sir
Your obedient servant

K P R Smart
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	-	Air Accidents Investigation Branch
AGS	-	Aircraft General Spares
ASR	-	Air Safety Report
ATC	-	Air Traffic Control
ATSSD	-	Air Traffic Services Standards Department
BAC	-	British Aircraft Corporation
BCAR	-	British Civil Airworthiness Requirements
°C	-	Degrees Celsius
CAA	-	Civil Aviation Authority
CATC	-	College of Air Traffic Control
CSC	-	Chief Sector Controller
CVR	-	Cockpit Voice Recorder
DME	-	Distance Measuring Equipment
DV	-	Direct Vision
FL	-	Flight Level
FOI	-	Flight Operations Inspectorate
HF	-	High Frequency
hrs	-	Hours
IAS	-	Indicated Air Speed
IPC	-	Illustrated Parts Catalogue
kg	-	Kilogram(s)
kt	-	Knot(s)
LATCC	-	London Air Traffic Control Centre
lbf in	-	Pound force inch(es)
LWTR	-	Licence Without Type Rating
°M	-	Degrees Magnetic
MATS	-	Manual of Air Traffic Services
MCP	-	Maintenance Control Programme
MHz	-	megahertz
NATS	-	National Air Traffic Services
psi	-	pounds per square inch
QMDR	-	Quality Monitoring Deficiency Report
QMP	-	Quality Monitoring Procedures
QNH	-	Corrected Mean Sea Level Pressure
QRH	-	Quick Reference Handbook
RAF	-	Royal Air Force
RAE	-	Royal Aerospace Establishment
TIME	-	Total Inventory Management for Engineers
UFDR	-	Universal Flight Data Recorder
UNC	-	Unified Coarse
UNF	-	Unified Fine
UTC	-	Coordinated Universal Time
VHF	-	Very High Frequency
VOR	-	VHF Omnidirectional Radio Range

Air Accidents Investigation Branch

Aircraft Accident Report No. 1/92

(EW/C1165)

Registered Owner and Operator: British Airways Plc
Aircraft Type: BAC One-Eleven
Aircraft Model: Series 528FL
Nationality: British
Registration: G-BJRT
Place of accident: Over Didcot, Oxfordshire
Latitude: 54° 34' North
Longitude: 001° 10' West
Date and Time: 10 June 1990 at 0733 hrs

This should read:
51° 34' North

All times in this report are UTC

Synopsis

The accident was notified by Southampton Airport Air Traffic Control to the Department of Transport on Sunday 10 June 1990 and the Air Accidents Investigation Branch (AAIB) began an investigation the same day. The following participated in the investigation:

Mr D F King, Principal Inspector of Air Accidents (Engineering) - Investigator in Charge
Mr R St J Whidborne, Senior Inspector of Air Accidents (Operations) - Operations
Mr S R Culling, Senior Inspector of Air Accidents (Engineering) - Engineering
Mr R J Vance, Senior Inspector of Air Accidents (Engineering) - Flight Recorders

The investigation was assisted by:

Mr I J Weston, Air Traffic Control (ATC) Investigations, - ATC
Safety Regulation Group,
Civil Aviation Authority (CAA)
Dr A J F MacMillan) Royal Air Force (RAF) Institute of - Rapid Decompression
Mr R Green) Aviation Medicine - Human Factors

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

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

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

The Shift Maintenance Manager's potential to achieve quality in the windscreen fitting process was eroded by his inadequate care, poor trade practices, failure to adhere to company standards and use of unsuitable equipment, which were judged symptomatic of a longer term failure by him to observe the promulgated procedures.

The British Airways local management, Product Samples and Quality Audits had not detected the existence of inadequate standards employed by the Shift Maintenance Manager because they did not monitor directly the working practices of Shift Maintenance Managers.

Eight Safety Recommendations were made during the course of the investigation.

1 Factual Information

1.1 History of the flight

The accident occurred during a scheduled flight (BA 5390) from Birmingham to Malaga, Spain. With 81 passengers, four cabin crew and two flight crew the aircraft took off from Birmingham International Airport at 0720 hrs and, having been transferred by ATC to the Daventry and then the Bristol Sector Controller of London Air Traffic Control Centre (LATCC), was cleared to Flight Level (FL) 140. A number of radar headings were ordered until the flight was instructed to maintain a radar heading of 195°M and cleared for a further climb to FL 230. The co-pilot had been the handling pilot during the take-off and, once established in the climb, the commander was handling the aircraft in accordance with the operator's normal operating procedures. At this stage both pilots had released their shoulder harness, using the release bar on the buckle, and the commander had loosened his lap-strap.

At 0733 hrs as the cabin staff prepared to serve a meal and drinks, and, as the aircraft was climbing through about 17,300 feet pressure altitude, there was a loud bang and the fuselage filled with condensation mist. It was at once apparent to the cabin crew that an explosive decompression had occurred. The commander had been partially sucked out of his windscreen aperture and the flight deck door had been blown onto the flight deck where it lay across the radio and navigation console. The No 3 steward, who had been working on the cabin side of the door, rushed onto the flight deck and grasped the commander round his waist to hold onto him. The purser meanwhile removed the debris of the door and stowed it in the forward toilet. The other two cabin staff instructed the passengers to fasten their seat belts, reassured them and took up their emergency positions.

The co-pilot immediately attempted to control the aircraft and, once he had regained control, initiated a rapid descent to FL110. He re-engaged the autopilot which had become disconnected by displacement of the control column during the commander's partial egress and made a distress call on the frequency in use but he was unable to hear its acknowledgment due to the noise of rushing air on the flight deck. There was some delay in establishing two-way communications and consequently the Bristol Sector Controller was not immediately aware of the nature of the emergency. This led indirectly to the LATCC Watch Supervisor not advising the aircraft operator of the incident, as required by the Manual of Air Traffic Services (MATS) part 1. Consequently the initiation of the British Airways Emergency Procedure Information Centre plan was delayed. Meanwhile the purser re-entered the flight deck and, having hooked his arm through the seat belts of the fourth crew member jump seat which was located behind the left-hand pilot's seat, was able to assist the No 3 steward in the restraint of the commander.

The two men tried to pull the commander back within the aircraft and, although they could see his head and torso through the left Direct Vision (DV) window, the effect of the slipstream frustrated their efforts. The No 2 steward entered the flight deck and he was able to relieve the No 3 steward whose arms were losing their strength as they suffered from frostbite and bruising from the windscreen frame. The No 2 steward grasped the commander's right leg, which was stuck between the cockpit coaming and the control column whilst his left leg was wedged against his seat cushion. The steward then strapped himself into the left jump seat and was able to grasp both of the commander's legs but not before he had moved a further 6 to 8 inches out of the window frame. He held him by the ankles until after the aircraft had landed.

Meanwhile, the aircraft had descended to FL100 and slowed to about 150 knots(kt). The co-pilot had requested radar vectors to the nearest airport and had been turned towards Southampton Airport and eventually transferred to their approach frequency. Having verified that there was sufficient runway length available for a landing, the co-pilot manoeuvred the aircraft onto a visual final approach to runway 02 and completed a successful landing and stop on the runway at 0755 hrs. The engines were shut down but the Auxiliary Power Unit, which the co-pilot had started up during the descent, was left running to provide electrical power to certain aircraft systems. As soon as the aircraft came to a halt, passengers were disembarked from the front and rear airstairs while the airport and local fire services recovered the commander back into the aircraft from his position half out of the windscreen frame, where he had remained throughout the descent and landing. He was taken to Southampton General Hospital suffering from bone fractures in his right arm and wrist, a broken left thumb, bruising, frostbite and shock. The other crew members and passengers were medically examined but apart from one steward who had cuts and bruising to his arm there were no other injuries.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	1	-	-
Minor/none	1	-	-

1.3 Damage to aircraft

The pilot's windscreen was missing and one securing bolt was found in the window frame, this had retained a portion of the rubber seal and a metal bush from the windscreen. The bolt was not new and its countersunk head had pulled

through the windscreen. The aircraft window frame was checked for distortion and found to be satisfactory.

Other damage to the aircraft consisted of:-

The High Frequency (HF) aerial, stretching from a forward position on the top of the fuselage to a fitting close to the tailplane bullet, was missing and the fittings damaged. There was a dent on the top left side of the fuselage approximately 3 inches long about 3 feet above the overwing emergency exit and a scratch on the top left side of the fuselage. Minor damage to several items on the flight deck.

1.4 Other damage

There was no other damage.

1.5 Personnel information

- 1.5.1 Commander:* Male, aged 42 years
Licence: Airline Transport Pilot's Licence
valid until 13 November 1999
Instrument rating: valid until 16 January 1991
Route check: valid until 30 September 1990
Safety procedures: last check 23 October 1989
Medical: last examination 14 March 1990 Class One,
no limitations
Height : 1.67 metres. Weight: 70 kg
- Flying experience:*
Total: 11,050 hours
On type: 1,075 hours
Last 28 days: 19 hours
Last 90 days: 96 hours
- 1.5.2 Co-pilot:* Male, aged 39 years
Licence: Airline Transport Pilot's Licence
valid to 24 June 1991
Instrument rating: valid until 19 November 1990
Route check: valid until 8 July 1990
Safety procedures: last check 9 October 1989
Medical: last examination 20 December 1989, Class One,
no limitations
- Flying experience:*
Total: 7,500 hours
On type: 1,100 hours

Last 28 days: 58 hours
Last 90 days: 169 hours

1.5.3 *Cabin crew:*

Purser:	Male, aged 37 years
No 2:	Male, aged 29 years
No 3:	Male, aged 36 years
No 4:	Female, aged 33 years

All Safety and Emergency procedure checks had been completed in the current year.

1.6 Aircraft information

1.6.1 *General information*

Manufacturer:	British Aircraft Corporation (BAC) Limited
Type:	BAC One-Eleven Series 528FL
Registration:	G-BJRT
Serial number:	BAC 234
Date of manufacture:	1977
Registered owner:	British Airways Plc
Total airframe hours:	37,724.07 hours
Certificate of Airworthiness:	Transport Category (Passenger) expires 16 March 1992
Hours to next check:	41 hours

1.6.2 *Aircraft weight and centre of gravity*

Maximum Take-off Weight Authorised:	44,000 kg
Dry Operating Weight :	25,818 kg
Zero Fuel Weight:	32,925 kg
Payload:	7,107 kg
Take-off fuel:	9,980 kg
Actual Take-off weight:	42,905 kg
Maximum landing weight:	39,460 kg
Actual landing weight (1):	40,725 kg

Note: 1 Fuel state on landing at Southampton was 7,800 kg, therefore fuel used during the flight was 2,180 kg.

1.6.3 *General description*

The BAC One-Eleven 500 series is a twin-engined, passenger aircraft powered by Rolls Royce Spey turbofans. The fuselage is pressurised and air-conditioned; 8,000 feet conditions being obtainable at 35,000 feet, under which conditions the pressure differential is 7.5 psi.

The pilots' windscreens are of five-ply glass/polyvinyl-butyl construction, the innermost (glass) laminate being low-tempered to form a splinter shield in the event of a bird strike. Windscreen heating is applied, primarily to improve the impact resistance of the windscreen at low outside air temperatures. The windscreen is not designed on the 'plug' principal, where cabin pressure effectively contributes to holding it in place, but is fitted from the outside of the aircraft and is secured by means of 90 countersunk bolts, also fitted from the outside. The large number of bolts are required to prevent leakage of pressurised air through the window seal but the force of internal air pressure could be satisfactorily resisted by far fewer bolts.

1.7 **Meteorological information**

1.7.1 *Synoptic situation*

High pressure existed to the west of Ireland with a light northerly flow over the Didcot area. There was a possibility of broken Stratus with a base at 600 feet and scattered Altocumulus with base at 12,000 feet and tops at 15,000 feet with a thin layer of Cirrus above 25,000 feet. Visibility was about 10 kilometres. At 18,000 feet the wind was 360° at 17 kt and the air temperature was minus 17 °C. The freezing level was at 9,000 feet.

1.7.2 *Actual conditions at Southampton*

The 0720 hrs observation at Southampton Airport included the following:-
Wind: 350°/12 kt. Visibility:- 8,000 metres in haze. Temperature:- plus 15 °C.

1.8 **Aids to navigation**

Not relevant.

1.9 **Communications**

1.9.1 *ATC assistance*

At the time of the accident the flight was receiving an Air Traffic Area Radar Control Service from the Bristol sector of LATCC on a frequency of 132.80 MHz. The flight came under the control of Southampton Zone on

frequency 131.00 MHz at 0744 hrs. A transcript of ATC recorded transmissions from the onset of the emergency is reproduced at Appendix A.

The co-pilot made a 'Mayday' call and declared that the aircraft had suffered an emergency depressurisation and was descending to FL100 on a heading of 195°M. The controller acknowledged receipt of the 'Mayday' call from BA 5390 but did not attempt to establish if the aircraft could still receive his communications and, although he alerted his Chief Sector Controller (CSC), took no further action since he was waiting for further information about the emergency. He continued to operate the sector as if no emergency existed, accepting further aircraft onto the frequency with no attempt to off-load traffic or minimise radiotelephony activity. However, fortunately there was no conflicting traffic and the CSC had advised the neighbouring sectors of the emergency descent and told the LATCC watch supervisor and the RAF Distress and Diversion Cell about the emergency call. Just prior to the handover to Southampton, BA 5390 was descended to an altitude of 4,000 feet in error rather than FL40 as had been co-ordinated, despite the Bristol Sector Controller not being aware of the airfield's QNH. This difficulty was resolved when the flight was transferred to the Southampton Zone Controller who had been alerted to the possibility of the aircraft landing there and had taken alerting action following a telephone call from LATCC.

The co-pilot did not select the special purpose Secondary Surveillance Radar transponder code (7700) to indicate an emergency condition but retained the code that had been already allocated to the flight. This accorded with the United Kingdom Aeronautical Information Publication RAC 7-4 which states : '....if the aircraft is already transmitting a code and receiving an air traffic service that code will normally be retained.'

1.9.2 ATC handling of emergencies

Guidance to controllers on the handling of emergency traffic is contained in the MATS Part 1 paragraph 5.1.7 which states:-

'Emergency aircraft - Selection of controlling agency

On receipt of information which indicates that an aircraft is in an emergency, the controller must decide whether or not to transfer the aircraft to another agency. The choice of agency will depend upon the circumstances and no hard and fast rules apply. The following guidance material will help controllers to make this decision:

Retaining Control

If the controller can offer immediate assistance the aircraft should normally be retained on the frequency. If necessary impose a radio silence on other aircraft or transfer them to another frequency.

Alternatively it may be more expedient to transfer the emergency aircraft to a discrete frequency, particularly if a radio silence would endanger other traffic.

The aircraft will have to be retained on the original frequency if it is unreasonable to ask the pilot, or if he is not prepared, to change frequency. The controller may be able to relay instructions and information from other units to the pilot.

Transferring Control

If a controller considers that another unit may be able to give more assistance than he can himself, and in the circumstances it is reasonable to ask the pilot to change frequency, he shall either;

- (a) Consult the Air Traffic Control Centre Supervisor and transfer the aircraft according to his instructions, or
- (b) Alert the nearest suitable unit and transfer the aircraft to a common frequency, giving assistance to that unit as required.

Before transferring aircraft, controllers should obtain sufficient information from the pilot to be convinced that the aircraft will receive more assistance from another unit. If a change of frequency is desirable the pilot must be instructed to revert immediately if there is no reply on the new frequency. Controllers should then listen out on the original frequency until the aircraft is known to be in two way communication.'

1.9.3 *ATC training*

An ATC service in the United Kingdom may be provided only by a person who holds an Air Traffic Controller's licence with the appropriate rating made valid at the ATC unit at which the service is to be provided. The Air Navigation Order authorises the grant of licences to persons who demonstrate their knowledge, experience, competence, skill and physical and mental fitness to the satisfaction of the CAA. The CAA publication CAP 160 details the evidence which must be

furnished, the examinations which must be passed and other requirements which must be met before licences, ratings, validations and endorsements are issued.

An applicant for a licence is required to demonstrate his or her knowledge and skill by passing examinations at two levels:-

- a. Rating. The ability to provide a particular type of ATC service (eg aerodrome control, area control or area radar control).
- b. Validity of a Rating. The ability to provide an ATC service at a particular place. This includes the ability to operate equipment (eg radar) when it is used to provide the service.

The Bristol Sector Controller had completed an approved course and examination for the issue of an Area Procedural and Area Radar rating at the National Air Traffic Services (NATS) College of Air Traffic Control (CATC) in May 1985 and was then posted to LATCC for validity training. This was successfully completed and led to the rating being validated on the Bristol Sector position.

Prior to the mid 1980's the Area Radar rating examination had included an emergency exercise. Both the CATC and the ATC Licencing Branch informally agreed that the inclusion of an aircraft emergency during the examination placed undue emphasis on the emergency and worked against assessing the examinee's ability to handle routine traffic situations. In order to overcome this problem, an agreement was reached between the College and ATC Licensing Branch that the emergency would be removed from the examination but that appropriate training for such events would continue to be given. The Bristol Sector Controller on duty at the time of the emergency had undertaken his course in 1985 but the precise content of his course could not be established as the records of courses conducted at that time were not available.

This situation is believed to have continued until 1988 when the ATC Licensing Branch was removed from NATS and placed within the CAA Safety Regulation Group, eventually becoming part of the Air Traffic Services Standards Department (ATSSD). Due in part to that change, the CATC, which remained within NATS, was required to submit to annual inspections by the ATSSD so that approved courses might continue. In contrast to other ATC courses which have a published syllabus (CAP 390 - ATC Training Manual) no such publication is made for Area Procedural/Area Radar Courses. As the CATC was the only establishment to provide such courses, individual syllabuses were agreed between ATSSD and the College. No mention of practical emergency training is given in this syllabus for area radar nor in the course approval which was given after the ATSSD inspection in 1989. The syllabus did require certain parts of MATS

Part 1 relating to emergency training to be covered, but instructors took a wider view and also tended to discuss the handling of emergency situations during theoretical lessons. The instructors, however, found it more difficult to incorporate emergency situations into routine practical exercises as they found it was likely to disrupt the learning process. Such training tended to be injected at a relatively early stage of the course with little opportunity for later consolidation. Therefore, the course manager was allowed to omit certain emergency situations. As a consequence, training in practical emergencies could be reduced to such an extent that it was non-effective. As the syllabus did not require practical emergency instruction, the CATC management did not inform ATSSD where such training was not given. ATSSD was not aware that such decisions had been taken and believed the situation remained as per the agreement following the removal of emergencies from the examination. Once a student leaves the College there appears to be no requirement to undergo any emergency training or periodic appraisal on emergency procedures in order to maintain an Area/Area Radar validated rating.

1.10 Aerodrome information

The single concrete runway, 02/20, at Southampton Airport is 1,723 metres long. The landing distance available on runway 02 is 1,650 metres. A VOR/DME (SAM 113.35 MHz) is located on the airfield which is at an elevation of 44 feet above mean sea level.

1.11 Flight recorders

1.11.1 *Cockpit Voice Recorder (CVR)*

A Fairchild Model A100 four channel CVR was fitted and a satisfactory replay of the 30 minute audio record was obtained. Channel allocation was :-

Channel 1	Cabin Address
Channel 2	Co-pilot's hot microphone
Channel 3	Pilot's hot microphone
Channel 4	Cockpit area microphone

The rapid decompression caused no discernible change to the signal on the area microphone channel but it was clearly audible on both crew hot microphone channels.

The bolts engage with 10 UNF Kaylock floating anchor nuts mounted on the inside of the windscreen frame. The replacement windscreen had been installed with 84 bolts (A211-8C) whose diameters were approximately 0.026 of an inch below the diameters of the specified bolts but of the same thread pitch, and six bolts (A211-7D) which were of the correct diameter, but 0.1 of an inch too short.

The left windscreen had been changed during the night shift of the 8/9th June 1990 and the accident flight was the first since that installation. Eighty of the bolts which had attached the old windscreen were recovered from the work area during the investigation, and 78 of these were identified as A211-7D, the remaining two being A211-8D. The old windscreen, which had been fitted four years earlier, before the aircraft had been acquired by British Airways, had therefore been primarily attached by bolts which were 0.1 of an inch shorter than those specified.

1.13 Medical and pathological information

Not relevant.

1.14 Fire

There was no fire.

1.15 Survival aspects

Following the loss of the left windscreen and subsequent decompression of the fuselage, the commander found himself half way out of the aircraft through his windscreen aperture. He recalls the impression of lying on his back against the upper surface of the flight deck exterior and, realising that he was still able to breathe, he concentrated on this until he assumes he lost consciousness. He regained consciousness after the aircraft had landed and when he was being recovered by fire and ambulance staff inside the flight deck prior to being placed on a stretcher and taken to hospital.

The co-pilot and the crew members who were holding on to the commander had individually reached the conclusion that his survival was highly improbable in the extreme conditions to which he was exposed. They were considerably reassured when, at a late stage in the descent at about 3,000 feet, the commander started to kick his legs.

The aircraft was not fitted with an automatic presentation oxygen system in the cabin and this was not required to be fitted under the original requirements for the

issue of the aircraft's Certificate of Airworthiness. Therapeutic oxygen was available in the cabin and consisted of 18 sets of facemasks and four portable oxygen cylinders. The oxygen system supplied gaseous oxygen to the crew and passengers if decompression occurred and for therapeutic purposes. Oxygen cylinders were mounted underfloor in the forward fuselage in the electrics bay. From the cylinders the oxygen was piped through in-line filters to the control panel in the flight deck right hand console. For therapeutic supply, an outlet from the double pressure regulator connected to an isolation valve (normally closed) and thence to a ring main which served twinflow sockets in selected passenger service panels. With the crew shut off valve and passenger isolation valve open, oxygen was obtained by connecting a therapeutic mask to an outlet point. Therapeutic masks were stowed in the aft stowage compartment. Immediately following the loss of pressurisation, the No 2 steward went and sat in seat 20D whilst donning the mask of a portable set that was stowed nearby. Oxygen masks were available to the flight deck crew but the co-pilot elected not to don his mask since he realised that the aircraft would soon reach FL100 (see paragraph 1.17.7 below). He also did not want to impede his ability to communicate with the other crew members who were holding on to the commander.

1.16 Tests and research

1.16.1 *Trials of 8 UNC and 10 UNF countersunk head bolts with 10 UNF anchor nuts*

During the course of the investigation British Airways carried out a simulation of the window fitting procedure to determine the torque that could be applied to 8 UNC countersunk head bolts fitting into 10 UNF Kaylock type anchor nuts. A 24 anchor nut test piece was used as follows:

To determine the torque at thread slip of twenty 8 UNC bolts in 10 UNF Kaylock nuts. This was found to be in the range of 1 to 7 lbf in.

To determine the torque required to engage the bolt in the locking mechanism of the nut, four 10 UNF bolts were fitted in 10 UNF Kaylock nuts. This torque was found to be in the range of 10 to 11 lbf in.

A further, more representative test was carried out in the presence of AAIB using a BAC One-Eleven in which 32 bolts (A211-8C) were used to fasten a window and seal in an aircraft. In this test torque figures ranging between 0 and 12 lbf in were achieved before the threads slipped.

A third test was carried out using some of the anchor nuts removed from G-BJRT to ensure that no unforeseen effect could have made the G-BJRT window

unrepresentative; ten 8 UNC bolts were fitted and these slipped at torques ranging from 0 to 6 lbf in.

The combined results using 8 UNC bolts in 10 UNF Kaylock nuts showed a maximum torque of 12 lbf in and an average of 4.7 lbf in at thread slip.

It was noted that the thread range 4 UNC to ½ inch UNF, commonly used on aircraft bolts, contains three adjacent pairs of sizes with similar thread pitches which allow the smaller bolt to engage in the larger Kaylock nut.

1.16.2 Examination of the torque limiting screwdriver used to fit the windscreen

Tests on a similar torque limiting screwdriver to that used to fit the windscreen showed that at a low setting (5 lbf in) the feel of the screwdriver clutch slipping was indistinguishable from the feel of an 8 UNC thread slipping in a 10 UNF anchor nut. At a higher setting (15 lbf in) a more pronounced click was felt as the screwdriver clutch released.

The actual torque limiting screwdriver used had a high level of residual friction (typically 7 lbf in at a setting of 20 lbf in) after the set value had been achieved and was therefore taken to the manufacturer for examination in the presence of AAIB and British Airways. The torque limiting screwdriver employed a cam plate with three lobes to retain three ball bearings which were displaced against the action of a spring to release at the set torque. Once released, the drive shaft carrying the ball bearings rotated through a third of a revolution until the balls re-indexed against the cam. Thus, in use, the torque should build up to the set value, slip and reduce to a residual value whilst the balls move across the constant radius section of the cam to the next indexing position.

The residual torque was confirmed as being high at a value of approximately 30 per cent of the torque set, rather than the usual value of between 5 and 10 per cent. Subsequent discussions with the manufacturer disclosed that the specification for the grease, used in the assembly of the torque limiting screwdriver, had been changed approximately five years ago because of problems of the grease breaking down with age. At this time retrospective action for those torque drivers already sold was considered impractical because of the large numbers involved and the lack of information about their location. The screwdriver under test was at least five years old and strip examination revealed that the excessive friction was caused by deterioration of the old specification grease. No significant wear was evident on the cam or the ball bearings, and when rebuilt with the correct grease the torque limiting screwdriver performed satisfactorily.

The high residual torque occurred after the set value had been achieved (*ie* 20 lbf in) and did not affect the torque at which the screwdriver operated. The residual torque would not have been felt before the set torque was reached.

1.16.3 Special checks called for on windscreen bolts after the accident

Before the diameter of the replacement bolts had been established British Airways issued an instruction to be carried out on all its BAC One-Elevens before the next flight, to remove every fourth bolt from the No 1 left-hand and No 1 right-hand windscreens to check for correct length.

Throughout the British Airways fleet of BAC One-Elevens two aircraft failed the check, having a total of 41 short bolts (A211-7Ds).

A similar check was carried out on the four BAC One-Elevens belonging to another airline and two aircraft failed the check, having a total of 107 short bolts.

When the smaller diameter bolts were identified in the detached window British Airways called for a 100 per cent visual inspection of bolt head diameter; this check utilised the fact that the smaller bolt head had 27 per cent less area than the head of the correct bolt. All the aircraft passed the check.

1.17 Additional information

1.17.1 Certification of Airworthiness of Aircraft

1.17.1.1 Type Certification of the BAC One-Eleven

The BAC One-Eleven Model 500 was type certificated to British Civil Airworthiness Requirements (BCAR) Section D in 1970 which calls up duplicate inspections after certain safety critical maintenance operations. However the glazing elements of windscreens are not identified as principal structural elements, nor does the application of this duplicate inspection philosophy attempt to cover possible safety critical situations caused by servicing errors.

There are no airworthiness requirements for aircraft windows to be fitted from the inside (plug type).

The BAC One-Eleven windscreen was designed to be secured with countersunk head bolts to British Standard A211-8D. This British Standard specifies that the British Standard number and the bolt part number shall not be applied on the bolts, but shall be clearly marked on the labels of parcels of bolts.

1.17.1.2 Aircraft Maintenance Requirements

a. Duplicate Inspections

BCARs require a duplicate inspection of all control systems in an aircraft to be made after initial assembly and before the first flight after overhaul, repair, replacement, modification or adjustment. In September 1985 BCARs introduced a requirement for duplicate inspections of 'Vital Points', which are defined as any point on an aircraft at which a single mal-assembly could lead to catastrophe, *i.e.* result in loss of the aircraft and/or fatalities. The CAA state that the term 'Vital Point' is not intended to refer to multiple fastened parts of the structure, but only applies to a single point, usually in a control system.

The regulations contain a waiver making the definition of 'Vital Points' non-mandatory for aircraft with a Maximum Take-off Weight Authorised of over 5,700 kg which were manufactured in accordance with a Type Certificate issued prior to 1st January 1986. This waiver includes the BAC One-Eleven. However, even had it not, British Aerospace would not expect the pilots' windscreens to appear in a 'Vital Point' analysis of the BAC One-Eleven.

b. Cabin Pressure Checks

There are no CAA requirements for a cabin pressure check to be called up after work has been carried out on the pressure hull. There is no specific company policy on leak checks within British Aerospace. Such checks are written into the aircraft Maintenance Manual at the discretion of the aircraft design team, and were not called up on the BAC One-Eleven.

1.17.1.3 Quality Requirements for Airlines

CAA approval of Aeroplane Maintenance Organisations, such as British Airways, includes a requirement for a company exposition containing details of the systems and procedures for the control of matters, including Quality Control, directly affecting continuing airworthiness. The systems established for Quality Control and Quality Assurance should be such that the prime objective is to maintain a continuous check on the effectiveness of the maintenance organisation and on the procedures and systems employed to ensure that all CAA requirements as well as those of the Organisation itself are met.

When assessing an Organisation for approval the CAA will examine the systems used to control all maintenance activities, including Quality Control and

Assurance. The certification procedures used by many airlines, including British Airways, and approved by the CAA, allow a single authorised engineer to undertake most aircraft work within his trade boundaries, and sign for it, without supervision or independent checking. The exception to this, on the BAC One - Eleven, is the requirement for duplicate inspection of control systems.

1.17.1.4 Maintenance Engineer Licencing

Aircraft maintenance licences are issued for a period of two years and renewed for a maximum period of five years. Licences will normally be renewed on application provided that, during the 24 months preceding the date of expiry of the licence, the holder has been engaged for periods totalling at least six months on appropriate work. No medical standards are specified for issue or renewal, neither are any examinations associated with the renewal of licences. No periodic training or tests are required on individual maintenance engineers.

The CAA issue aircraft maintenance engineer's licences in several categories, of which category 'A' applies to aeroplanes. Generally there are two parts to each category:-

a. Licence Without Type Rating (LWTR)

The LWTR does not in itself confer any certification responsibilities or privileges but is a prerequisite for the granting of the relevant Type Ratings which confer the privileges of certification appropriate to that Type Rating. The LWTR is also a prerequisite for issuing an approved company authorisation in the appropriate licence category.

b. Type Ratings

Type Ratings confer on the holder of a licence privileges and certification responsibilities in respect of certain aircraft registered in the United Kingdom.

1.17.1.5 Company Authorisations

Certain aircraft types may be maintained only by organisations which are specifically approved by the CAA for that purpose - BCAR chapter A8-13 refers. Licence Type Ratings are not granted for these types. In accordance with the procedures associated with this CAA approval the organisation may grant authorisation to persons to issue Certificates of Release to Service for specific aircraft types to suitable engineers who hold a LWTR.

The organisation can also issue such authorisations to cover aircraft types for which a Licence Type Rating is available. British Airways is such an approved company and the fitting of the windscreen and its certification were in accordance with these procedures.

The holding of company authorisations allows the engineer to make maintenance certifications affecting the airworthiness of the aircraft. Therefore, such an engineer carries some of the responsibility for the day-to-day airworthiness of the aircraft.

1.17.1.6 Maintenance Manuals

The CAA requires the BAC One-Eleven to be serviced in accordance with the BAC Maintenance Manual, which contains chapters covering each system in the aircraft, each chapter providing: a detailed description of the system and its operation, with sufficient detail for diagnostic use by the aircraft maintenance engineers; specific values to be achieved during servicing, *ie* torque loadings, pressures, dimensional checks, timings, etc; procedural information containing detailed sequences of the steps to be followed during the removal and replacement of significant items. The Maintenance Manual is complemented by the IPC, which contains detailed drawings of all parts of the aircraft and identifies the components used by manufacturers' part numbers.

Although the Maintenance Manual breaks the windscreen removal/replacement task into a series of individual steps, the British Airways maintenance documentation at that time treated the task as a single stage operation.

1.17.2 *British Airways' infrastructure*

Paragraphs 1.17.2.1 to 1.17.2.3 contain extracts from a much longer internal British Airways document.

1.17.2.1 Quality Monitoring Procedure (QMP) - The System

British Airways policy is that quality cannot be policed into a product. The QMP system, which was introduced in 1987, was developed actively to pursue a policy of encouraging staff to 'wear the mantle of Quality Assurance' as they went about their work tasks. QMP forms the structure on which all of the monitoring activity is based and has three main components, these are: The Local Exposition; Continuous Monitoring; and Product Sampling.

a. The Local Exposition

Each Departmental Head is required to raise a Local Exposition which lists the functions for which he or she is responsible and the geographic locations where the work is carried out. The functions are allocated to managers, by name, and the procedures that are used to control tools, equipment, procedural and documentary amendments, modifications, special processes, etc. are defined. Each Local Exposition is registered with the CAA and, in conjunction with other documents, forms the British Airways' submission for requesting approval for the various engineering functions that are carried out.

b. Continuous Monitoring

The second requisite is the availability of a reporting system through which all staff can register deficiencies as they occur (by raising a Quality Monitoring Deficiency Report (QMDR)), this is a 'closed loop' system which informs the originator of the action that has been taken to rectify the problem. This is known as Continuous Monitoring.

The QMP system is confined to airworthiness related items and does not duplicate other reporting systems. It can, however, report the shortcomings in other systems where this is appropriate in airworthiness terms.

The role of the individual is crucial to the success of the QMP system. The QMP system gives each person the responsibility of reporting deficiencies in the quality of the services and procedures which are provided to them and on which they depend in order to produce their goods or services at the proper level of quality. By so doing, they are given a formal device for influencing their working environment.

c. Product Sampling

In addition to the Continuous Monitoring process there is an imposed Product Sample that has to be carried out at set periods to satisfy the requirement of an independent assessment of work. Product Sampling is seen as a check on the effectiveness of the Continuous Monitoring system and all sample reports are submitted to the Chief Quality Engineer for evaluation; some of which are passed on to the CAA in support of their approval of British Airways' maintenance arrangements.

1.17.2.2 The Management Role in QMP

The Departmental Head is responsible for his organisation's quality performance, for assessing standards and for maintaining a quality awareness in all his staff. Through the Local Exposition, the Departmental Head declares the staff, facilities, equipment and systems for which he is responsible and sets down how Quality Monitoring is to be implemented throughout his area of responsibility. He holds regular briefings to ensure that Continuous Monitoring is being correctly applied, and monthly summary reports of the QMP system are submitted to him by his staff. From this monthly summary it is possible to deduce the amount of QMP activity, in terms of numbers of deficiencies raised by Continuous Monitoring and by Product Sampling.

Every quarter the Departmental Head summarises all of the QMP activity for his area by completing a Quarterly Report. The Quarterly Report is sent to the British Airways Audit Unit who compile statistics from the reports and report those statistics to the Quality Forum. Forum meetings are arranged monthly and are chaired by the Chief Engineer of Quality and Training Services on behalf of the Engineering Director. The CAA Surveyors in charge of both the Heathrow and Gatwick offices participate in these meetings.

The Quality Forum ensures that Departmental Heads are accountable for the QMP process and provides the opportunity for quality objectives and performance to be discussed and acted upon.

1.17.2.3 Auditing the Process

The effectiveness of the QMP is assessed through independent audits which are conducted by a small group of quality engineers from the Quality Audit Unit, a paperwork exercise every six months and a visit every two years. In addition they will act in an advisory capacity on airworthiness matters and on the management of the QMP system. The independence of the Audit Unit from the engineering operation has been accepted by the CAA, who check on this aspect through regular surveys on the Audit Group.

The Audit Unit is also empowered to carry out traditional 'systems audits' if sufficient grounds exist to suspect that functions or procedures are not properly controlled. The results of such audits are reported to the appropriate Departmental Head so that the necessary corrective action can be taken. As a last resort, the result can also be reported to the Quality Forum, for corrective action to be allocated.

1.17.2.4 The Maintenance Control Programme (MCP)

British Airways is approved by the CAA as a maintenance organisation; as part of that approval, the MCP has been developed. This is a closed-loop system which

is continuously reviewed by engineering management to ensure that aircraft technical performance is satisfactory. As part of the programme, the following performance parameters are measured and monitored:-

- Aircraft technical delays
- Aircraft systems performance
- Engine in-flight shutdowns
- Unscheduled component removals
- Repetitive defects
- Air/Ground incident reports.

These parameters are analysed, and where appropriate have defined targets or alert levels. All of these parameters are evaluated and reported on for all fleets and corrective action taken through a series of structured MCP committees, which in turn report to an Engineering Control Review Board who meets formally twice per year to review the effectiveness of the MCP.

1.17.2.5 Ground Occurrence Report Form E1022

Ground Occurrence Report Form E1022 is used for the notification of defects found during work on aircraft or aircraft components which are considered worthy of special attention. The system is also used for the notification of 'Ground Found' Mandatory Occurrence Reports as required by the Air Navigation Order and Regulations and to highlight any technical or other matter which, if unreported, could lead to a potential airworthiness hazard.

All British Airways' Engineering staff are required to take E1022 action when encountering deficiencies of the type listed below, unless the subject of an Air Safety Report:-

- Failure, potential failure or obstruction of any aircraft system

- Defects in aircraft structure such as cracks in primary or secondary structure, structural corrosion or deformation greater than expected

- Failures or damage likely to weaken attachments of major structural items including flying controls, landing gear, power plants, windows, doors, galleys, seats and heavy items of equipment

- When any component part of the aircraft is missing, believed to have become detached in flight

- Overheating of primary or secondary structure

- Unreported damage

Defects that cannot be cured by normal replacements or repairs

Incorrect assembly

Use of incorrect fuel, oil or other vital fluids

Failure of any emergency equipment that would prevent or seriously impair its use

Critical failures or malfunction of equipment used to test aircraft systems or aircraft units

Actual/potential fires

Items rejected ex-stores and low life failures

Lack of clarity or conflict between technical procedures

Spillages in aircraft

Any defects found as a result of a Special Mandatory Inspection or Check

Any other occurrence or defect considered to require such notification.

1.17.3 British Airways' Organisation at Birmingham

1.17.3.1 Task

The task includes flight servicing, scheduled maintenance and rectification of the 13 BAC One-Eleven fleet, and flight servicing and rectification for other British Airways aircraft (HS 748 and ATP) and other contracting airlines. The first batch of the British Airways One-Eleven fleet depart between 0630 hrs and 0730 hrs each weekday morning.

For operational reasons most of the maintenance work on the BAC One-Eleven fleet was carried out at night and consequently the Shift Maintenance Managers on the night shift usually had more work available to them than they could satisfy. This required the allocation of task priorities and the night shift manpower was usually sufficient to complete all the necessary airworthiness engineering tasks with only minor Acceptable Deferred Defects being left to be dealt with by a subsequent night shift. Indeed, in order to curb over-enthusiasm engendered by the pride felt by the shifts in their ability to satisfy the task, the management at Birmingham repeatedly stressed that night shifts should not attempt to do more than was prudent.

1.17.3.2 Facilities

At the time of the accident Birmingham Airport was undergoing extensive works services to increase its capacity. The British Airways engineering facilities comprised accommodation at two locations:-

a. Under the International Pier

Office accommodation plus an unmanned store with an adjacent small workshop area which contained a carousel with 408 drawers holding consumable Aircraft General Spares (AGS).

b. Eastern Apron

A hangar bay large enough to contain a BAC One-Eleven, with a tail dock containing staging allowing access to the tail. The Eastern Apron used to be the terminal area and the bay contained accommodation previously used by the engineering department. This facility housed a manned store and engineering accommodation suitable for work in the area.

The geographical location of these areas is shown at Appendix B.

1.17.3.3 Manpower

The engineering establishment comprised :-

a. An Area Maintenance Manager with responsibilities for outstations in Mid/South England; these included Birmingham, Jersey, Southampton, Cardiff, East Midlands and Bristol Airports. However Southampton, Cardiff, East Midlands and Bristol were not served by British Airways scheduled operations, although British Airways charter flights may have landed there occasionally. British Airways had no engineering staff at these stations which were served as necessary by agencies, appointed by the Area Maintenance Manager, or visiting engineers for specific flights. Jersey was a transit station with, at most, one aircraft stopping overnight. Therefore more than 80 per cent of the Area Maintenance Manager's time and attention was devoted to Birmingham. He was specifically responsible for the control and effectiveness of the Quality Monitoring system in maintaining the established quality performance targets and was to conduct regular checks throughout the organisation assigned to him to ensure that quality performance targets were achieved.

b. A Station Maintenance Manager of foreman grade, who acted as deputy to the Area Maintenance Manager.

c. Five rotating shifts, comprising a Shift Maintenance Manager of foreman grade and approximately six engineers and a storekeeper.

d. A permanent night shift of four engineers to supplement the duty night shift and three double day shifts of three men to augment day work.

These figures are establishments, manning levels on shifts may be depleted by leave, sickness, etc.

1.17.3.4 Station Organisation

The Station Maintenance Manager and the Shift Maintenance Managers all reported directly to the Area Maintenance Manager. The only Terms of Reference that were available for the engineering maintenance personnel employed by British Airways at Birmingham were those which appeared in their Union agreement, however their job specifications may have appeared in recruitment advertisements issued locally.

a. Shifts

The shift pattern worked by the five rotating shifts gave 24 hour cover over a 35 day cycle. The duty shift was augmented by the various standing shifts in a system designed to provide optimum cover at the times when it is needed, primarily for aircraft handling during the day and rectification at night. Reduced cover was provided over the weekends. A diagrammatic representation of the shift system is shown at Appendix C.

b. Workload

The workload for all levels of management at Birmingham was high; the Area Manager did not monitor the day-to-day work practices of his subordinates, but relied on the trending of parameters such as numbers of Acceptable Deferred Defects, repeated defects, and failures to meet schedules as indicators of quality. (The total list of parameters is at 1.17.3.6 b).

Although the Station Maintenance Manager was responsible for the technical activities on the Unit, he was the same grade as, and received the same pay as, the Shift Maintenance Managers under him. He worked on aircraft when the need arose and so was closer to the day-to-day standards used, however the organisation structure was such that Shift Maintenance Managers often

communicated directly with the Area Maintenance Manager. Because of his day time duties the Station Maintenance Manager rarely had the opportunity to observe the workings of shifts at night, especially during the early hours of the morning.

1.17.3.5 Stores procedures

The stores computer based Total Inventory Management for Engineering (TIME) system employed by British Airways is such that an item whose part number has been identified can be located down to the drawer containing the stock. All parts and materials are requested by description and part number as specified in the IPC which is available at all work stations.

AGS are contained within a dispenser with a stores identification label and issue may either be over the counter, or self service. This method used to dispense AGS is common throughout airlines. At Birmingham three carousels were employed, two in the hangar under the control of a storeman, integrated in the TIME system, and labelled with drawer location codes, and one, uncontrolled, under the International Pier with drawers labelled with part numbers.

AGS generally arrived in transparent plastic packs of 100 items, the packs containing a label or a computer produced description and bar code; the drawers frequently contained the identifying labels from the packs. There was, however, no way, other than measurement, of identifying the contents after they had been removed from the packs.

Minimum stock levels per drawer were usually set at between 50 and 100 items depending on bulk and usage. The hangar carousels contained drawers with stock levels well below the resupply level; no instances were found of incorrect contents in the hangar carousels. The uncontrolled carousel, on the other hand, had some drawers which were not labelled and some which contained a mixture of items. The 408 drawers in this carousel were categorised as follows:-

No label, no contents	46
No label, contained stock	25
Labelled, no contents	68
Labelled, contained stock	269

The last category was further broken down showing that:-

In 251 drawers the majority of the contents were as the label, (163 drawers contained solely the contents described on the drawer label).

In 18 drawers the majority of the stock was wrongly labelled, (in 9 drawers none of the contents were as described on the drawer label).

The uncontrolled nature of this carousel had been recognised by some British Airways personnel, who had reported the problem informally. There was no record of this problem in the QMDRs at Birmingham, a system specifically designed to receive reports of this nature.

1.17.3.6 Quality Assurance Practice

a. Training

The initial training for QMP consisted of 1½ days of external training for middle management who provided ad hoc training to foremen and supervisors in the local area, based on a standard package consisting of a video plus viewfoils. The foremen in turn were required to train the subordinate grades.

Continuation training in QMP was carried out as and when required. The Audit Team, through sampling of QMP awareness across the Company in June 1988, identified a shortfall; the Quality Forum directed each Department to carry out QMP training, and an illustrated 'Guide to QMP' was produced. A further QMP survey in January 1989 identified that improvements had been achieved but that a lack of comprehension still existed. At the time of the accident, action to remedy this was still under discussion.

b. The Birmingham Exposition

Product Samples were required from Birmingham on a monthly basis and prior to each aircraft Certificate of Airworthiness renewal. They were carried out by the Station Maintenance Manager and a nominated Shift Maintenance Manager. The quality monitoring schedule for the Product Sample is at Appendix D.

The completed Product Sample proforma were distributed to the Area Maintenance Manager, the British Airways Quality Forum and some to the CAA.

A British Airways Engineering Department procedure stated that the Area Maintenance Managers were responsible for maintaining the established quality targets with respect to the following:-

- Technical Despatch Reliability
- Acceptable Deferred Defect levels
- Repetitive Defects
- Air Safety Reports
- Significant Technical Defects sent for investigation (E1022's)
- Product Samples
- QMDRs
- Quality Audit Reports
- Technical Log entries.

c. Continuous Monitoring Reports from Birmingham

British Airways literature circulated amongst engineering staff stressed the need for an open reporting system using QMDRs. Over a 39 month period, ending in April 1990, 36 QMDRs were raised on local issues at Birmingham. Eleven of these were as a result of the monthly Product Samples, and the other 25 were raised by the British Airways employees, of whom approximately a quarter had been active in the system. The Area Maintenance Manager stated that there was less of a need to complete QMDRs as some faults could be identified and actioned immediately as he had control of the Birmingham engineering budget.

d. Product Samples from Birmingham

British Airways produced ten copies of Product Samples carried out at Birmingham, seven of these related to the period before the accident and were carried out during work packages involving; Acceptable Deferred Defect Clearance, Base Checks and Modifications, and Ramp Checks. The seven pre-accident product samples raised a total of 65 deficiencies which were of a minor nature.

The CAA produced six copies of Product Samples carried out at Birmingham before the accident; three of these duplicated copies provided by British Airways, and the additional three, from early 1989, were similar in content to the others.

e. British Airways Quality Audit at Birmingham

Paperwork audits of the Engineering function at Birmingham to assess the use of and adherence to monitoring procedures, required under QMP procedures, were scheduled and performed at six monthly intervals. A physical audit of the Birmingham station, in the form of a two day visit, was last carried out prior to the accident by a representative of the British Airways Quality Audit Unit on 15/16 June 1988, when it was reported that the engineering facility was to a high standard. Seven observations were raised relating to minor, non-aircraft, matters.

f. CAA Supervisory Visit to British Airways Engineering at Birmingham

One of the duties of the CAA's Flight Operations Inspectorate (FOI 7) was (at the time of the accident) to carry out supervisory visits to survey the engineering services provided by British Airways at Birmingham in support of their Air Operator's Certificate. The last FOI 7 visit, an 'Air Operator's Certificate: Supervision of Operator's Line Maintenance Station', before the accident took place on 22 June 1989, followed a proforma schedule, lasted for approximately half a day and did not detect any significant engineering problems.

1.17.3.7 Use of E1022 Procedure at Birmingham

Over the same 39 month period in which 36 QMDRs were raised, 365 E1022s were raised at Birmingham.

1.17.4 *Fitting the windscreen*

1.17.4.1 History of the shift

The Shift Maintenance Manager arrived at work in the offices under the International Pier 45 minutes earlier than his shift start time in order to allow himself time to catch up with the paperwork and establish the shift work content; this included three significant defects, routine items and various minor cabin defects.

A Supervisory Aircraft Engineer and a further Licenced Aircraft Engineer, normally part of the shift, were not available that night and, although the work outstanding remained the same, the Friday night shift was routinely not supported by the four man night shift supplement because there was reduced scheduled flying on Saturday and Sunday. The shift consisted of:-

- The Shift Maintenance Manager
- 1 Licenced Aircraft Engineer
- 1 unlicenced engineer airframe/engines
- 1 Supervisory Aircraft Engineer (Avionics)
- 1 Avionics engineer.

The engineers were directed to their tasks whilst the Shift Maintenance Manager carried on with the administration and the task of entering the contents of the aircraft technical logs into the computer. At about midnight, the Shift Maintenance Manager spent some time with the Licenced Aircraft Engineer on a steering defect and the completion of this coincided with the arrival of a Tunisair Boeing 737 which the shift had to handle. As none of the engineers had Boeing 737 experience the Shift Maintenance Manager carried out the pre-departure inspection and the refuelling in conjunction with the Licenced Aircraft Engineer to give him experience. All this activity took place at various locations around the airfield and was co-ordinated using radio.

The departure of the Tunisair Boeing 737 at around 0145 hrs coincided with the meal break, which the Shift Maintenance Manager spent working on administration whilst he ate his sandwiches. After the break he directed his two airframe engineers onto a galley water leak on one of the BAC One-Eleven aircraft which needed rectifying before the aircraft departed the following morning.

Although there was no operational requirement for G-BJRT the next day, the Shift Maintenance Manager knew that the oncoming morning shift were also depleted and that an aircraft wash had been booked, using overtime, at 0630 hrs the following morning. Whilst no external pressure had been put on him, he was aware that the previous week the wash team had been brought in on a similar basis and not used. In order to achieve the windscreen change during his shift and have the aircraft ready for the wash team, he decided to carry out the windscreen change himself.

The aircraft was located in the No 2 bay, off the Eastern Apron on the other side of the airfield, and was parked tail into the hangar with the nose by the doors. In retrospect the Shift Maintenance Manager could not recall exactly what the weather was, but thought that it was raining; in which case he would have closed the doors, leaving a few feet between the nose of the aircraft and the doors. The windscreen change was carried out between approximately 0300 hrs and 0500 hrs on the Saturday morning.

1.17.4.2 Procedures used

British Airways statistics show that 12 No 1 windscreens, left or right, had been changed on their BAC One-Eleven aircraft over the last year, and a similar number the year before. The Shift Maintenance Manager had carried out about six windscreen changes on BAC One-Eleven aircraft whilst employed by British Airways.

a. Maintenance Manual

The Shift Maintenance Manager glanced briefly at the Maintenance Manual as he had not changed a windscreen for about two years and wanted to refresh his memory. This check confirmed his impression that it was a straightforward job with no apparent difficulties.

b. IPC

The IPC was available on a microfiche reader, but was not used to identify the part number of the bolts to be replaced, consequently a stock check, using TIME, to assess the availability and location of replacement bolts was not carried out. The Shift Maintenance Manager justified this omission by saying that he was quite satisfied that the bolts that he had removed were the correct bolts, and that it would take so much time to find the correct numbers in the IPC that he did not feel justified in using the IPC in the circumstances of the job in question.

The page of the IPC for the 528 series aircraft shows a sketch of the pilot's No 1 windscreen and the adjacent DV window, but only illustrates one bolt - that in the DV window, which is an A211-7D. The components for the pilot's No 1 window are listed in the text, along with several alternative modification states, and its bolts are defined as 'attaching parts' and are identified as A211-8Ds. The IPC for the 510 series, in contrast, is very clear in identifying the correct bolts.

The bolts actually fitted to the defective windscreen were, in the main, A211-7Ds, the bolts illustrated as applicable to the DV window. That is bolts of the correct diameter but 0.1 of an inch shorter than those specified.

c. Bolt selection

The Shift Maintenance Manager removed the windscreen with the aid of the Avionics Supervisor, who also disconnected the electrical connectors of the screen heaters. The bolts were 'on condition' items, and as some of the paint-filled bolt heads had been damaged during removal, and others showed signs of corrosion, the Shift Maintenance Manager decided to replace them and took one of the bolts to the store to identify it by comparison with those held in the carousel. The carousels were under the control of a storeman and had drawers which were clearly labelled with a location code to which engineers were directed, after entering the part number into the adjacent stores computer terminal.

Because of their small head size the bolts do not carry individual identification, but the Shift Maintenance Manager accurately matched the removed bolt by going through several trays, and comparing the removed bolt with the drawer contents. He then identified the part number of the bolt as A211-7D by looking at the stores issue note in the drawer (the windscreen should have been fitted using A211-8Ds). The Stores Supervisor, who had been in the job for about 16 years, informed him that A211-8Ds were used to fit that windscreen, but did not press the point. The Shift Maintenance Manager decided that as A211-7D bolts had come out, he would replace them with bolts of the same size.

The minimum stock level in the carousel for A211-7D bolts was 50, but there were only four or five bolts in the drawer (when checked by the AAIB the following Monday it contained four). The Shift Maintenance Manager drove to the unsupervised carousel underneath the International Pier, taking the removed bolt with him. The drawers in this carousel were labelled with the part number of the contents, although the labels were old and faded. The ambient illumination in this area was poor and the Shift Maintenance Manager had to interpose himself between the carousel and the light source to gain access to the relevant carousel drawers. He did not use the drawer labels, even though he now knew the part number of the removed bolt, but identified what he thought were identical bolts

by placing the bolts together and comparing them. He also picked up six A211-9Ds, thinking that the attachment of the outboard corner post fairing strip would need longer bolts.

The old seal was found to be serviceable, so the new windscreen, which weighed 60 pounds, was manoeuvred into position and the electrical connections made.

d. Torque loading of the bolts

The aircraft manual calls for a torque of 15 lbf in to be applied to the bolts, which are then retorqued to 5 lbf in after 100 flying hours. The Shift Maintenance Manager's experience told him that many of the bolts would be found up to three turns loose during the retorquing procedure, so he decided to increase the initial torque to 20 lbf in.

The British Airways toolstore at Birmingham held a calibrated dial indicating torque wrench to cover the range of 5 to 120 lbf in, but the retorquing requirement of 5 lbf in was at the bottom of the range and the dial indicating torque wrench was not considered suitable for this task. Two calibrated torque checking gauges were available at Birmingham to allow engineers to confirm the wrench accuracy.

The calibrated dial-indicating torque wrench was not available on the toolboard that night, but the Stores Supervisor had recently acquired from British Airways at London, on his own initiative, a torque limiting screwdriver specifically for the windscreen task, but on receipt it was found to be out of calibration date and it was therefore not cleared for use. It was not the company policy at Birmingham to allow the engineers to adjust torque wrenches as and when required, but rather to have the wrenches adjusted in a standards room and then issued for use at that specific setting. It was therefore the intention of the Stores Supervisor to have it set in the London standards room before issue, but, in the absence of any suitable alternative, the storeman set this screwdriver to the figure of 20 lbf in requested and gave it to the Shift Maintenance Manager, who checked the setting using both torque checking gauges.

The Shift Maintenance Manager used a ¼ inch bi-hexagonal socket to hold the No 2 Phillips screwdriver bit onto the speedbrace used to run the screws down into the countersinks. The socket did not have any means, such as a spring clip, to retain the screwdriver bit, consequently the Shift Maintenance Manager found that during the two-handed operation of using the speedbrace the bit fell out several times and he had to descend from the safety raiser (mobile staging) and retrieve it from the floor. To overcome this problem when using the same ¼ inch bi-hexagonal socket with the torque limiting screwdriver, he held the screwdriver in his right hand and used his left hand to hold the bit in the socket. Additionally,

to reach most of the bolts with both hands from the safety raiser, he had to stretch across the nose of the aircraft, outside the safety rail provided by the safety raiser. This situation was exacerbated by the fact that the safety raiser was incorrectly positioned alongside the aircraft. His left hand obscured his view of the bolt head, and the need to stretch removed the operation from his direct vision.

He fitted the windscreen using 84 of the bolts collected from the International Pier carousel and obtained a similar feel from the torque limiting screwdriver for each one; a feel that met his expectations. When he came to the outboard corner post fairing strip he realised that the A211-9D bolts were too long, descended from the staging and retrieved and refitted the six old bolts that he had removed with the fairing.

The new bolts that he had fitted were in fact A211-8C bolts - one size down in diameter but with the same thread pitch as those specified and within 0.050 of an inch in length to the A211-7D bolts removed from the window. The bolts engage in 10 UNF 'Kaylock' floating anchor nuts; the self locking action is the result of part of the nut being an elliptical shape prior to the insertion of the bolt. Some of the anchor nuts were attached directly to the inside of the aircraft window frame and some were carried on strips, themselves attached to the window frame. The outboard corner post fairing strip interposed an additional thickness and required A211-8D bolts, and these were specified for the attachment of the whole windscreen, even though in the majority of locations approximately five threads would be visible below an anchor nut fastened directly to the frame when used with an A211-8D bolt. The amount of thread in safety would be reduced when used with the backing strips and the outboard corner post fairing.

e. Missed cues

The safety raiser used by the Shift Maintenance Manager did not give easy access across to the centreline of the aircraft, and he had to stretch over the aircraft nose to accomplish the task. Due to the inadequate access to the job and the obscuring effect of his left hand the Shift Maintenance Manager was not in a position to observe that the bolt thread was slipping in the anchor nut thread, instead of the torque limiting screwdriver allowing its shaft to remain stationary while the handle rotated. However, the bit and socket would have continued to rotate in his left hand.

The window was finished in primer and had countersunk holes for the bolts; an A211-8C bolt head sits significantly further below the surface of the window, down in the countersink, than does an A211-8D bolt head, leaving an annulus of unfilled countersink which is easily discernable when viewed under good conditions. This excessive annulus of unfilled countersink was not seen.

When the bolts were being fitted to the windscreen centre column, the bolts from the right hand window, the heads of which filled the countersinks, were close to those of the left hand window, and, although painted, the difference is perceptible under normal circumstances. The Shift Maintenance Manager missed this difference in depth of the bolt heads in the windscreen centre column. (See photograph in Appendix E).

When fitting the outside corner post fairing with the six bolts previously removed from it, the Shift Maintenance Manager failed to notice the difference in torque achieved or the difference in countersink fit of the bolt heads between the old and new bolts.

The following night the Shift Maintenance Manager carried out another windscreen change, this time a right hand one. The job had been set up before he arrived and he noticed that the bolts were A211-8Ds. He recalled fitting A211-7D bolts the previous night, but he rationalised that the aircraft were old and of differing modification states and the previous night he had an aircraft modification standard requiring A211-7D bolts and that night he had an aircraft requiring A211-8D bolts.

f. Documentation

The documentation used to report and clear the defect stated:-

DEFECT SYMPTOM	ACTION TAKEN
SYSTEM Port Windscreen	
During cruise darkening & bubbling noted in small area on bottom LH port windscreen. Q.R.H. drill carried out.	Windscreen replaced. A.S.R. Actioned. F/Check satis
SIGNED BY REPORTING CAPTAIN	SIGNED BY ENGINEER
	(SUBJECT TO THE FOLLOWING DECLARATION)

THE WORK RECORDED ABOVE HAS BEEN CARRIED OUT IN ACCORDANCE WITH THE REQUIREMENTS OF THE AIR NAVIGATION ORDER FOR THE TIME BEING IN FORCE AND IN THAT RESPECT THE AIRCRAFT/EQUIPMENT IS CONSIDERED FIT FOR RELEASE TO SERVICE

Note:

- Q.R.H Quick Reference Handbook.
- A.S.R Air Safety Report, raised by the captain. The Shift Maintenance Manager's action was to clear the defect.
- F/Check Functional check of the windscreen heating system.

1.17.5 *Prevalent attitudes*

During the course of the investigation a number of visits to the operator's engineering facility at Birmingham were made, the Shift Maintenance Manager who changed the windscreen was interviewed and informal interviews conducted with the other maintenance managers in order to provide a context for the actions of the engineer who undertook the windscreen replacement task. Subsequently these managers provided written signed statements, mostly concerned with the range of issues raised at the interviews.

The overriding impression given by the Maintenance Managers was that morale was high and that they were proud of their record in meeting the task and of the way that they went about it.

The Shift Maintenance Managers did not criticise the shift system, however the potential problems associated with sleep deprivation and circadian effects were acknowledged and various strategies were cited to cope with the situation.

During the initial part of the investigation the Shift Maintenance Manager who carried out the windscreen fit did not appear to grasp the lack of care that his actions implied. He co-operated fully in the investigation and, when shown the full list of errors and omissions that he had made, offered an explanation for each individual action.

The Area Manager was aware of the pressures to produce aircraft that the Shift Maintenance Managers worked under, and continually stressed that there were other objectives besides maximising the work throughput on the shifts.

Four of the six Maintenance Managers who subsequently gave written statements raised the issue of the large numbers of E1022 forms originated at Birmingham and concluded that these indicated their concern for quality and general standards.

One Maintenance Manager stated that he felt that the QMP system was in its infancy at the time of the accident but that the E1022 process was well known. He went on to say that the staff at Birmingham felt more comfortable with the E1022 system because they knew exactly how it worked and they knew that they would get a response.

Another Maintenance Manager also concluded that when he returned damaged parts through the E1022 system he had direct contact with the development engineers by telephone and his requests were actioned without them being channelled through a third party. The E1022 system was therefore more

effective, the QMPs took longer to action and were, in his opinion, clearly for non-urgent quality lapses.

1.17.6 Human factors

1.17.6.1 Personal details

The person who fitted the windscreen was a Shift Maintenance Manager holding authorisations on BAC One-Eleven, Boeing 737, Boeing 757, HS 748 and with transit authorisations on L-1011 Tristar, Boeing 747 and a CAA licence holder for airframe and engines on the Viscount. His experience included 10 years in the RAF, followed by 23 years with British Airways. He appeared to be a mature, dedicated engineer who was well respected by flightcrew and engineers alike. No domestic or financial distractions were identified, either by British Airways management, the Behavioural Psychologist engaged by the AAIB who interviewed him or the AAIB Inspectors; the Shift Maintenance Manager denied any such problems.

He had been on leave over the period of the last night shift carried out by his shift and so the Friday/Saturday night shift during which the windscreen was fitted was his first night work for approximately five weeks. He had had a normal nights sleep the previous night and had gone to bed at about 1730 hrs, and had slept for 1½ hours, getting up at 2030 hrs. He said that he would have been happier if he had slept for an hour longer, but wasn't dismayed that he had not. The last shift worked by the Shift Maintenance Manager was on Tuesday 5 June from 0630 hrs to 1500 hrs.

The Shift Maintenance Manager made limited use of a fairly weak prescription for reading glasses, but did not habitually use them at work and was not wearing them when making the bolt selection.

His record with British Airways has been reported as exemplary and he had received commendations during this period.

1.17.6.2 Behavioural Psychologists's Report

A Behavioural Psychologist interviewed the Shift Maintenance Manager who carried out the windscreen fitting task and was present during AAIB interviews with him and informal interviews with the other Maintenance Managers. His report is included at Appendix F.

1.17.6.3 Ophthalmologist's Report

The Shift Maintenance Manager was examined by a consultant in ophthalmology who concluded that his eyes were normal with full central fields and normal ocular muscle balance. He had full stereoscopic vision and his intra-ocular pressures were normal. However he was presbyopic and for this he needed glasses for close work, and his own half-eye reading glasses were perfectly adequate for his needs.

If he were to read small print or figures without his reading glasses, he would have difficulty. With his reading glasses and in good lighting, he would have no problems.

1.17.6.4 Relationship between Serious Accidents and Near Misses

Two analyses of groups of accidents and incidents occurring in industrial situations have shown that for every serious accident there can be between 400¹ to 600² near misses. These figures indicate that, in an industrial context, degraded standards may exist for some time before a serious accident occurs or the situation becomes apparent to an independent observer.

The experience of accidents involving aircraft maintenance shows that an accident usually occurs as a result of a series of errors, and that the probability of the accident occurring is low compared with the probabilities of the individual failures in the chain of events leading to it. The incorrect installation of the windscreen resulted from a sequence of contributory events (para 1.17.4.2), any one of which, if identified and eliminated from the chain could have prevented the windscreen loss.

1.17.7 *The effects of rapid decompression*

In an attempt to analyse and quantify the dynamic forces and physiological effects caused by the loss of the windscreen, all the available data was presented to the Aircrew Systems Division of the RAF Institute of Aviation Medicine, RAE Farnborough.

The conclusions drawn suggested that the critical factors affecting the survivability of all the aircraft occupants were the time of decompression and the final cabin altitude. Those affecting the commander were the time of

¹ Per Tye/Pearson

² Per Frank Bird

decompression and the final altitude of exposure, together with the low temperature and the aerodynamic forces to which he was exposed during the remainder of the flight.

Calculation provided that the duration of the decompression was likely to have been in the region of 1.13 to 1.46 seconds, and this was supported by the duration of the rapid changes of aircraft attitude. The maximum cabin altitude, achieved during this time period, depended upon the interaction between the ram effect of the outside airflow and the airflow provided by the internal pressurisation systems. Analysis suggested that this was unlikely to have been greater than 13,000 to 13,500 feet which, when followed by the descent profile flown, would not have promoted sufficient hypoxia to impair either the passengers or the crew.

The forces acting upon the commander, to project him through the windscreen aperture, were a function of the differential pressure between the inside and outside of the cabin and are calculated as having a force of approximately 5,357 pounds (depending upon his exact proximity to the aperture). This would be quite adequate to drive a person weighing 70 kg from his seat and through the aperture, whereafter the ram effect of the airstream would pin him to the fuselage and seriously impair movement.

1.18 New investigation techniques

None.

2 Analysis

2.1 General

The crew were faced with an instantaneous and unforeseen emergency. The combined actions of the co-pilot and cabin crew successfully averted what could have been a major catastrophe. The fact that all those on board the aircraft survived is a tribute to their quick thinking and perseverance in the face of a shocking experience.

Up to the time of the loss of the windscreen, the flight had proceeded uneventfully and in accordance with the company's normal procedures. It was quite in order for the flight crew to release their shoulder harnesses once they were established in the climb and, for reasons of comfort, the commander loosened his lap strap as he neared the cruising phase of the two and a half hour flight to Malaga. Therefore, when the left windscreen was blown out, it was not surprising that the commander, who was very lightly built, was drawn partially through the windscreen aperture. It is not certain what prevented his complete egress from the aircraft but, since the No 2 steward later had to free his legs from a position between the control column and the flight deck coaming, it is likely that he had been restrained by his legs during the initial stage of the emergency. Later, he was restrained simply by the efforts of the No 2 steward who was holding on to both of his legs.

The co-pilot immediately took control of the aircraft and was able to establish a rapid descent despite the disorientating effects of the dramatically transformed cockpit environment coupled with a push over and right roll. It was fortunate that he was an experienced pilot with more than 1,000 hours experience of flying the BAC One-Eleven aircraft. Thus he was able to handle the aircraft on his own and complete the normal operating procedures from memory without the assistance of another pilot. He alone was faced with a double emergency, namely rapid decompression and incapacitation of the handling pilot. He rejected the idea of donning his oxygen mask in favour of being able to shout instructions to his cabin crew. In the event, this was probably sensible but if the depressurisation had occurred at a greater height, say above 20,000 feet, it would have been imperative for him to don the oxygen mask to avoid incapacitation to the extent that he could not fly the aircraft.

2.2 Engineering Factors

2.2.1 *The selection and use of the wrong bolts*

The windscreen was lost because it had been secured by bolts, the vast majority of which were of an incorrect diameter. The windscreen fitting process was characterised by a series of poor work practices, poor judgements and perceptual errors, each one of which eroded the factors of safety built into the method of operation promulgated by British Airways:-

a. During the fitment of the windscreen to G-BJRT the Shift Maintenance Manager was confronted with certain situations which made his job more difficult:-

Incorrect bolts, A211-7D had been used in the previous installation

Insufficient stock of A211-7D bolts, incorrect but demonstrably adequate, existed in the carousel in the bay stores at the Eastern Apron.

Nevertheless, problems of this type are not unusual and cannot be used to explain the subsequent chain of events which led to the loss of the windscreen.

b. A number of procedures were ignored and some poor trade practices followed:-

The IPC, available to identify the required bolts' part number was not used

The stores TIME system, available to identify the stock level and location of the required bolts, was not used

Physical matching of old and new bolts by touch and eye was attempted, leading to a mismatch with bolts from the International Pier carousel

Arbitrary choice of A211-9Ds to fit through the corner fairing took place

An increase in bolt torque over that stated in the Maintenance Manual was used.

c. Non conformity with British Airways standards was also demonstrated:-

An uncontrolled torque limiting screwdriver was set up outside the Calibration Room.

d. Use of unsuitable equipment took place:-

A bi-hexagonal bit holder was used leading to occasional loss of the bit and covering of the bolt head during the torquing process

A Safety Raiser which provided inadequate access to the job was used.

e. A number of cues were either ignored or missed:-

The warning from the Storekeeper that A211-8D bolts were required did not influence the choice of bolts

The amount of unfilled countersink left by the small boltheads was not recognised as excessive

The increased amount of unfilled countersink with the new bolts, compared to the flush fitting of adjacent, correctly sized bolt heads in the windscreen centre column, went unnoticed

The difference in torque and the amount of countersink remaining unfilled between the new bolts and old bolts used in the corner fairing went unnoticed

The use of, as he thought, A211-7Ds when using A211-8Ds the next night was not questioned

The difference between the bolt thread stripping in/through the nut and the torque limiting screwdriver 'breaking' was not recognised even though the bi-hexagonal socket and screwdriver bit, located by his left hand, were still rotating. However, the high residual torque of the particular screwdriver resulted in a less positive 'break' and, although the break torque was never achieved with the 8 UNC bolts, it was when setting the screwdriver and when installing the fairing. This screwdriver, on reaching the set torque may have felt more like the thread stripping than would one with a more 'snappy' break.

2.2.2 *The windscreen replacement task*

The windscreen is part of the aircraft's pressurised hull and is attached from the outside by 90 bolts. It may be the only critical item on the aircraft that was susceptible to failure through the chain of circumstances listed above, in that:-

- a. Its replacement required the renewal of the majority of the bolts in the judgement of the Shift Maintenance Manager.

- b. The wrong diameter bolts engaged with the anchor nuts, and had the same thread pitch.
- c. The bolts were not special to type items needing a part number to identify and obtain replacements, but were general use items, obtainable from an uncontrolled carousel.
- d. The windscreen was not designed on the plug principle such that internal air pressure would hold it in place, but was fitted from the outside.
- e. The windscreen replacement was not designated a 'Vital Point' task, therefore no duplicate inspection was required.
- f. The Shift Maintenance Manager was the only person whose work on the night shift was not subject to the review of a maintenance manager.

The windscreen may therefore have been unique in that it alone, of all the critical components, could have accommodated the errors which occurred during its fitment, to expose them so dramatically the first time that the windscreen was called upon to resist cabin pressure. Had it been any other item, the selection of the wrong bolts may have been unmistakably apparent during the fitting process, or the subsequent failure may not have been so obvious or traumatic.

2.2.3 *Relevant British Airways' Procedures*

2.2.3.1 AGS dispensing

The use of unsupervised dispensers for aircraft general spares is a recognised and necessary part of aircraft engineering practice. Small units can rarely afford to keep a full-time storekeeper to administer a dispenser, or even a store, and good trade practice has to be relied upon. Before the Shift Maintenance Manager went to the unmanned carousel he knew the part number of the bolts he was seeking, and although they were too short, similar bolts had held the old windscreen in place for four years. Despite the poor segregation, labelling and lighting, the selection of the wrong bolts cannot be explained by the carousel system.

2.2.3.2 Work by Shift Maintenance Managers

During the course of his duties the Shift Maintenance Manager reviewed the work of his shift, this review augmented the self certification task required of the engineers by British Airways' maintenance policy. Once he had decided to carry out rectification work himself, he withdrew from the active supervision of the rest of the shift. The task of the windscreen installation was not designated a

'Vital Point' and consequently no duplicate inspection was called for and none took place, nor was the work of the Shift Maintenance Manager subject to review by another manager.

Thus the Shift Maintenance Manager had no backstop with any chance of detecting his errors. Errors that were made more likely by the sleep deprivation and circadian effects associated with the end of a first night shift.

2.2.4 *Quality Assurance*

2.2.4.1 Application of Self Certification to Aircraft Engineering

The adoption of self certification systems within manufacturing industry has typically resulted in savings, mainly arising through reduction in scrap and in the achievement of higher manufacturing efficiency. Nevertheless, at the end of the production line the product is normally still tested, before being despatched. Some aircraft maintenance tasks which may be undertaken using self certification procedures do not allow for the testing of the end product before it is flown.

It could be argued that the concept of self certification suffers from the drawback that the expectations of the engineer are such that he is unlikely to detect an error of his own making; the application of self certification reduces the level of inspection and supervision.

It is recommended that the applicability of self certification to aircraft engineering safety critical tasks following which the components or systems are cleared for service without functional checks, should be reviewed by the CAA. Such a review should include the interpretation of 'single mal-assembly' within the context of 'Vital Points' and the requirements which include a waiver making the definition of 'Vital Points' non-mandatory for aircraft with a Maximum Take-Off Weight Authorised of over 5,700 kg which were manufactured in accordance with a Type Certificate issued prior to 1 January 1986.

2.2.4.2 Feedback

A fundamental requirement of any management process is a feedback loop to detect the success or failure of the system, and two types of feedback are available - a formal feedback through auditing/monitoring activities and an informal feedback through free discussion amongst engineers discussing their work problems in an open forum.

Some feedback was generated by the monitoring of a series of performance parameters which were airline parameters with quality overtones rather than

parameters capable of giving a comprehensive picture of the engineering quality built into tasks. The crucial element missing was direct assessment of the standards used by the Shift Maintenance Managers to perform their tasks.

Whilst literature circulated by British Airways stressed the need for open reporting through QMDRs, a number of the Maintenance Managers indicated that they felt more comfortable with the E1022, Ground Occurrence Report Form, with which they were particularly familiar, finding it a more direct and responsive reporting system. The findings at Birmingham are consistent with the British Airways Audit Team sampling of QMP awareness in 1988 and a further QMP survey in 1989 which identified that a lack of comprehension still existed. At the time of the accident action to remedy this was still under discussion within British Airways.

The E1022 system was well established and understood when QMP was introduced three years before the accident. The statements of the Birmingham Maintenance Managers indicate that at least some of them still prefer, and may use, the E1022 system in instances when a QMDR might be more appropriate. The list of circumstances under which an E1022 is to be used appears to overlap into procedural areas which might be thought of as the domain of the QMP system.

Some evidence of a quality problem within the British Airways engineering unit at Birmingham is provided by the failure of the unit to use the Continuous Monitoring system to report some of the problems seen during investigation of the windscreen fitment:-

The poor labelling and segregation of parts in the uncontrolled carousel under the International Pier

Inadequate access available to certain areas of the aircraft from the work platform

Inadequate tools to achieve some specific torque loading

Windscreen attachment bolts found loose at the 100 hour re-torque.

It is recommended that British Airways review their Quality Assurance system and the relative roles of E1022s and QMDRs be clarified and that they continue to educate and encourage their engineers to provide feedback from the shop floor.

2.2.4.3 Local Management

The Area Maintenance Manager did not directly observe the work methods of the engineers at Birmingham. His involvement in monitoring consisted of processing the monthly Product Samples and the QMDRs raised by his staff, along with monitoring levels and trends of a set of performance parameters on the BAC One-Eleven fleet. Whilst these parameters may form part of a quality monitoring system they are inadequate to inform management about the standards used by individual Shift Maintenance Managers.

The Station Maintenance Manager was directly responsible for the work of the Shift Maintenance Managers, and he was also responsible for carrying out Product Samples on his area. Because his job required him to work during the day he was rarely present during the night shift. No evidence was presented of any 'in-place' system to monitor the standards used by individual Shift Maintenance Managers.

The relationship between the Station Maintenance Manager and the Shift Maintenance Managers was ill-defined, there was no clear delegation of duties, itemised terms of reference were not available and the duties of the Shift Maintenance Managers were not documented.

As a result of the lack of specific direction of duties neither the Area Maintenance Manager nor the Station Maintenance Manager observed the standards employed by individual Shift Maintenance Managers.

It is recommended that British Airways should review the need to introduce job descriptions/terms of reference for engineering grades of Shift Maintenance Manager and above.

2.2.4.4 Product Samples and Quality Audits

The principle that personnel carrying out quality audits should be independent of the specific activities or areas being monitored is reflected in British Airways' documentation. The same principle of independence should apply to the Product Samples, even though they were a check on standards rather than an audit. However, not only were the Product Samples at Birmingham carried out by the person who had direct managerial responsibility for the tasks, but the results were sent to the British Airways Quality Audit Unit for the attention of the CAA. It is unreasonable to expect that someone who has condoned, or not recognised, the practice as a manager will report it under the aegis of his quality assurance responsibilities to such bodies.

At the time of the accident a physical audit of the Birmingham base was about due according to the QMP schedule. The British Airways Quality Audit Unit had last visited Birmingham two years before the accident over a two day period and were satisfied with the engineering standards.

It is recommended that British Airways should review the Product Sample procedure with a view to achieving an independent assessment of standards and conduct an in-depth audit into the work practices at Birmingham.

2.2.4.5 CAA Supervisory Visits

The CAA supervision of the engineering functions of operators, away from their main bases, is undertaken by FOI 7, and the British Airways engineering facility at Birmingham was given a half-day visit approximately a year before the accident. The visit, in view of the time allocated, was necessarily superficial and only likely to have picked up gross discrepancies.

It is recommended that the CAA should review the purpose and scope of the FOI 7 Supervisory Visit.

2.2.5 *Technical standards*

Every engineer was responsible for the quality of his own work under the British Airways QMP. Quality standards at Birmingham were the responsibility of the local management; the Area Manager and his deputy, the Station Maintenance Manager, as part of their routine daily management task. Additionally the monthly Product Samples looked at methods and standards of work. Further quality monitoring was conducted during audits by the British Airways Quality Audit Unit and supervisory visits by the CAA. Thus any explanation of how inadequate work standards came to be employed on the night in question would also have to explain how the various quality and management monitors failed to detect earlier evidence of such inadequate standards. This could have been because the Shift Maintenance Manager had generally maintained high standards and his actions on the night were not representative of his normal standards or the monitoring procedures had failed to detect inadequate standards employed by him for some time, or some combination of the two. The two extreme explanations are categorised as follows:-

a. The Random Failure Theory

The lapses on that night were a 'one-off' and therefore there had not been any previous symptoms to alert management/quality monitors.

b. The Systems Failure Theory

The lapses were typical of standards employed by the Shift Maintenance Manager, which were either known to the management/quality monitors, who condoned them, or were not known to them because they had been unable to monitor the situation satisfactorily.

The track record of the One-Eleven fleet at Birmingham, in terms of the engineering criteria monitored, indicated that standards were generally good and the Product Samples and Continuous Monitoring reported only minor discrepancies. This impression of a satisfactory operation, gained from in-house sampling at Birmingham, was supported by independent information from the physical audit carried out by British Airways Quality Audit Unit and the visit by the CAA. However, such quality lapses as those perpetrated by the Shift Maintenance Manager would not have been apparent to other than detailed observation until combined with such a task as the windscreen change. (See Paragraphs 2.2.1 and 2.2.2).

Some studies on the effects of human error on industrial safety indicate that the ratio of near misses to serious accidents could be as high as 600:1, therefore inadequate standards can be applied over a considerable period of time before giving rise to a reportable accident or notifiable occurrence. This implies that a series of degraded procedures could be applied over a period of time without becoming apparent.

British Airways point to the exemplary record of the Shift Maintenance Manager throughout his service with them as being proof of the continuing satisfaction of local management with the Shift Maintenance Manager's standards, and that record as being incompatible with anything other than an isolated example of inadequate work standards.

The Behavioural Psychologist described the Shift Maintenance Manager as conscientious and pragmatic rather than conscientious and meticulous. The behaviour of a man who, based on experience, changed the mandatory torque setting for the bolts, visually matched the replacement bolts, and arbitrarily selected A211-9D bolts for the fairing is compatible with that description only if he believed that these practices were accepted at Birmingham (whether or not they were in fact accepted).

Many of the actions taken that night by the Shift Maintenance Manager may be described as evidence of a lack of sufficient care in the execution of his responsibilities. Such a catalogue of events does not equate to a momentary lapse in behaviour but is more indicative of the approach of a conscientious and

pragmatic engineer working in a non-procedural manner. Such a description of the individual is not necessarily inconsistent with his 'exemplary record', because until matched with a task such as this windscreen change, his approach was capable of going undetected by anything other than a close observation of his work practices.

At no time was any evidence presented to indicate that the standards and practices used on that night were in any way different from those used generally by the Shift Maintenance Manager. Nor were any external or job-related pressures identified which may have caused a lack of concentration. Indeed, even when shown the full list of errors and omissions that he had made, he still offered an explanation for each individual action.

The number of errors perpetrated on the night of this job came about because procedures were abused, 'short-cuts' employed and mandatory instructions ignored. Even when doubt existed about the correct size of bolt to use, the authoritative documents were not consulted. After the event the Shift Maintenance Manager concerned demonstrated a lack of appreciation of the significance of failure to adhere to the specified procedures, good trade practices and even the requirements of the Maintenance Manual. This makes it most unlikely, in the view of the AAIB, that the practices which permitted such errors were 'one-offs' but supports the argument for a longer term failure by the Shift Maintenance Manager to observe the promulgated procedures.

Such compromised standards on the part of the Shift Maintenance Manager cannot explain all of the errors which led to the accident, such as his failure to react to the various cues indicating that something was wrong. However, they did reduce his potential to achieve quality in the task and provided a context in which mistakes could go undetected, building into a critical chain.

Thus the explanation of how the catalogue of errors occurred on the night in question lies somewhere on the continuum between the stated extremes of Random and System Theories with contributions from each. The system element being that which accommodated the application of inadequate standards by the Shift Maintenance Manager for some time and the perceptual errors contributing the random element.

2.2.6 *Engineering Requirements*

2.2.6.1 Periodic training and testing

There is clear evidence of a different philosophy applied to pilots, who are required to undergo regular line and base standardisation checks, and engineers who are not subjected to any comparable standardisation or refresher checks.

An experienced Licenced Engineer with an exemplary record demonstrated an abuse of procedures, employed short cuts, ignored mandatory instructions and failed to conform with what is generally regarded as 'good trade practice'. Therefore, it is recommended that the need for periodic training and testing of maintenance engineers should be reviewed by the CAA.

2.2.6.2 Check lists and technical documentation

The work of flightcrew during routine and emergency operations is highly formalised, with check lists to be followed at critical stages of the flight. Even though they may have already performed the operation several times previously that day, the flightcrew will still follow a check list, item by item, on each occasion, and in some cases individual responses will be monitored by another crew member. Whilst the use of the Maintenance Manual is mandatory and some of the processes detailed in it are complex, apart from work on flying and engine controls, and 'Vital Points' (if defined) an authorised engineer may work on an aircraft unsupervised and unchecked.

In spite of the itemised nature of the procedures detailed in the Maintenance Manual, in some areas on work not involving flying and engine controls, including the BAC One-Eleven windscreen change, an engineer may clear the documentation with a one line statement saying in effect, 'Defect cleared', with a pre-printed Release to Service certificate contained on the form. The use of an itemised servicing procedure in the form of a document that requires signatures at each stage is considered to be a valuable aid to ensuring that the correct process has been acknowledged and signed for.

2.2.6.3 Eyesight standards

The Shift Maintenance Manager required mild corrective lenses to read small print or figures and he did not use his glasses whilst performing the windscreen replacement. The lack of corrective glasses cannot account for the majority of the errors made that night, but may have subconsciously influenced the Shift Maintenance Manager in short circuiting some of the procedures which rely on adequate eyesight.

It is recommended that the CAA should recognise the need for the use of corrective glasses, if prescribed, in association with the undertaking of aircraft engineering tasks.

2.3 ATC Emergency procedures

In the circumstances it was imperative that the co-pilot was given all the help that could be made available. In this case the Bristol Sector Controller neither complied with the co-pilot's specific request for radar navigational assistance, nor did he advise the flight of its position or give any relevant information regarding Southampton, such as current weather, runway in use, pressure settings, etc, as would have been expected

Given that emergencies are rare, it is inadvisable to leave to chance the possibility of a controller having experience in such a situation. The provision of training in the handling of emergencies and other infrequent occurrences is therefore considered to be essential. A persuasive argument in favour of emergency training is that adequate preparation can lessen the stress which may be induced in the real situation. While such an argument has a good deal of face validity, supporting data are not easy to find. Nevertheless, experiencing similar situations in training and learning to cope, should instil in the individual a degree of confidence in his ability to handle real events. Emergency evacuation and fire drills are conducted on this premise.

It is sometimes argued that training for emergencies is not possible because all emergencies are essentially different from each other, cannot be anticipated and therefore cannot be programmed into a course of training. The fact that emergencies will differ in detail or in the precise accumulation of events which lead to their occurrence, does not, however, negate the value of training. All too often emergency training focuses on the use of a limited number of problem situations. These become familiar to trainees and are seldom updated from one training course to the next. Not only will trainees lack the ability to cope with other events, but this method encourages a tendency to fit novel situations into known patterns using strategies which have worked in the past but may not be applicable to the current problems. During training a variety of scenarios should be employed to provide both experience in coping with a number of different situations and the opportunity to build confidence in handling them.

Whilst no two emergencies may be identical, there are a number of basic steps which have to be taken in dealing with them. In ATC terms this would include ensuring that there are no other conflicting aircraft, ascertaining the extent of the problem, informing the appropriate emergency services, etc. If these predictable elements of emergency handling are well trained and automatic they release 'spare capacity' which can be devoted to coping with the unanticipated or unique aspects of each case.

The Bristol Sector Controller quite properly intended to allow his actions to be guided by the decisions of the co-pilot and the Bristol CSC but he formulated no specific plan of action to deal with the emergency. No training programme, however well constructed, can guarantee the trainee's performance during a genuine emergency. However, more preparation for handling emergencies during both initial training and as part of a systematic pattern of refresher training and skill maintenance may help controllers involved in incidents to realise that such events can happen and would prepare them to accept the reality of the situation and to cope with it more effectively.

It is recommended that the Authority ensure that prior to the issue of an ATC rating a candidate shall undergo an approved course which includes training in both the theoretical and practical handling of emergency situations. This training should then be enhanced at the validation stage and later by regular continuation and refresher exercises.

3 Conclusions

(a) Findings

- (i) The crew were properly licenced, medically fit and rested to conduct the flight.
- (ii) The take-off and initial climb from Birmingham were uneventful.
- (iii) Whilst climbing through 17,300 feet pressure altitude and on a heading of 195°M, the left windscreen was blown out of its frame under the influence of cabin air pressure.
- (iv) The commander was sucked partially out of the windscreen aperture and blown backwards over the flight deck roof. He was restrained from further egress by the cabin staff who held onto him until after the aircraft had landed.
- (v) The co-pilot suffered a degree of disorientation but he was able to regain control of the aircraft and start an immediate descent.
- (vi) The remaining crew and passengers suffered no ill effects from the rapid decompression and lack of oxygen. It has been calculated that the cabin altitude was unlikely to have been greater than 13,000 to 13,500 feet, achieved within two seconds after the loss of cabin pressure.
- (vii) The left windscreen had been replaced and the task certificated by the same Shift Maintenance Manager with the appropriate British Airways authorisation 27 hours before the accident flight and the aircraft had not flown since its replacement.
- (viii) The replacement windscreen had been installed with 84 bolts (A211-8C) whose diameters were approximately 0.026 of an inch below the diameters of the specified bolts (A211-8D), and 6 bolts (A211-7D) which were of the correct diameter, but 0.1 of an inch too short.
- (ix) The windscreen fitting process was characterised by a series of poor work practices, poor judgements and perceptual errors, each one of which eroded the factors of safety built into the method of operation promulgated by British Airways.

- (x) A series of cues were available to the Shift Maintenance Manager to draw attention to the use of incorrect bolts but all went unnoticed or unheeded.
- (xi) Although an independent final inspection would have had a high probability of detecting the error, the task of the windscreen installation was not designated a 'Vital Point' and consequently no duplicate inspection was called for and none took place.
- (xii) The work of the Shift Maintenance Manager was not subject to review by another manager and thus there was no backstop with any chance of detecting his errors. Errors that were made more likely by the sleep deprivation and circadian effects associated with the end of a first night shift.
- (xiii) The practices employed by the Shift Maintenance Manager which permitted such errors were not considered to be 'one-offs' but were symptomatic of a longer term failure on his part to observe the promulgated procedures.
- (xiv) The British Airways local management, Product Samples and Quality Audits had not detected the application of inadequate standards by the Shift Maintenance Manager, because they did not monitor directly the working practices of Shift Maintenance Managers.
- (xv) The windscreen replacement task may have been unique in that it alone could accommodate the errors associated with its fitment, such that they were exposed so dramatically the first time that the windscreen was called upon to resist cabin pressure.
- (xvi) The CAA supervisory visit was superficial and as such did not monitor the working practices of Shift Maintenance Managers.
- (xvii) The British Airways local Product Samples at Birmingham did not provide an independent assessment of standards as they were carried out by the person who had direct managerial responsibility for the tasks.
- (xviii) Literature circulated by British Airways stressed the need for open reporting through QMDRs, however, a number of the Maintenance Managers indicated that they felt more comfortable with the E1022, Ground Occurrence Report Form, with which they were particularly familiar, finding it a more direct and responsive reporting system.

- (xix) The Shift Maintenance Manager required mild corrective lenses to read small print or figures but did not use his glasses whilst performing the windscreen replacement.
- (xx) Following receipt of the co-pilot's distress message, and when two way communication had been re-established, ATC facilitated diversion of the flight to Southampton Airport.
- (xxi) The nature of the emergency was never fully appreciated by LATCC.
- (xxii) The Bristol Sector Controller's training in the handling of emergency situations was probably inadequate.
- (xxiii) The recovery to Southampton was managed effectively by the co-pilot who was assisted by the Southampton Zone Controller.

(b) Causal factors:-

- (i) A safety critical task, not identified as a 'Vital Point', was undertaken by one individual who also carried total responsibility for the quality achieved and the installation was not tested until the aircraft was airborne on a passenger carrying flight.
- (ii) The Shift Maintenance Manager's potential to achieve quality in the windscreen fitting process was eroded by his inadequate care, poor trade practices, failure to adhere to company standards and use of unsuitable equipment, which were judged symptomatic of a longer term failure by him to observe the promulgated procedures.
- (iii) The British Airways local management, Product Samples and Quality Audits had not detected the existence of inadequate standards employed by the Shift Maintenance Manager because they did not monitor directly the working practices of Shift Maintenance Managers.

4 Safety Recommendations

- 4.1 The CAA should examine the applicability of self certification to aircraft engineering safety critical tasks following which the components or systems are cleared for service without functional checks. Such a review should include the interpretation of 'single mal-assembly' within the context of 'Vital Points' and the requirements which include a waiver making the definition of 'Vital Points' non-mandatory for aircraft with a Maximum Take-Off Weight Authorised of over 5,700 kg which were manufactured in accordance with a Type Certificate issued prior to 1 January 1986.
- 4.2 British Airways should review their Quality Assurance system and the relative roles of E1022s and QMDRs be clarified and they should continue to educate and encourage their engineers to provide feedback from the shop floor.
- 4.3 British Airways should review the need to introduce job descriptions/terms of reference for engineering grades including Shift Maintenance Manager and above.
- 4.4 It is recommended that British Airways should review the Product Sample procedure with a view to achieving an independent assessment of standards and conduct an in-depth audit into the work practices at Birmingham.
- 4.5 The CAA should review the purpose and scope of the FOI 7 Supervisory Visit.
- 4.6 The CAA should consider the need for the periodic training and testing of Engineers.
- 4.7 The CAA should recognise the need for the use of corrective glasses, if prescribed, in association with the undertaking of aircraft engineering tasks.
- 4.8 The CAA should ensure that, prior to the issue of an ATC rating, a candidate shall undergo an approved course which includes training in both the theoretical and practical handling of emergency situations. This training should then be enhanced at the validation stage and later by regular continuation and refresher exercises.

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January 1992

The Civil Aviation Authority's response to these Safety Recommendations is contained in CAA Follow-up on Accident Reports (FACTAR) No. 1/92, to be published coincident with this report.