BAC One-Eleven, G-BJRT: Main document

Aircraft Accident Report No. 1/92 - (EW/C1165)

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

Contents

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: 540 34' North
	Longitude: 0010 10' West
Date and Time:	10 June 1990 at 0733 hrs
	All times in this report are UTC

Synopsis

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

Mr D F King, Principal Inspector of Air Accidents (Engineering)

Mr R St J Whidborne, Senior Inspector of Air Accidents (Operations)

Mr S R Culling, Senior Inspector of Air Accidents (Engineering)

Mr R J Vance, Senior Inspector of Air Accidents (Flight Recorders)

The investigation was assisted by:

Mr I J Weston, Air Traffic Control (ATC) Investigations, SafetyRegulation Group, Civil Aviation Authority (CAA)

Dr A J F MacMillan, Royal Air Force (RAF) - Rapid Decompression

Mr R Green, Aviation Medicine - Human Factors

The accident happened when the aircraft was climbing through 17,300feet on departure from Birmingham International Airport en routefor Malaga, Spain. The left windscreen, which had been replacedprior to the flight, was blown out under effects of the cabinpressure when it overcame the retention of the securing bolts,84 of which, out of a total of 90, were of smaller than specifieddiameter. The commander was sucked halfway out of the windscreenaperture and was restrained by cabin crew whilst the co-pilotflew 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', wasundertaken by one individual who also carried total responsibilityfor the quality achieved and the installation was not tested untilthe aircraft was airborne on a passenger carrying flight.

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

The British Airways local management, Product Samples and QualityAudits had not detected the existence of inadequate standardsemployed by the Shift Maintenance Manager because they did notmonitor directly the working practices of Shift Maintenance Managers.

Eight Safety Recommendations were made during the course of theinvestigation.

1 Factual Information

1.1 History of the flight

The accident occurred during a scheduled flight (BA 5390) fromBirmingham to Malaga, Spain. With 81 passengers, four cabin crewand two flight crew the aircraft took off from Birmingham InternationalAirport at 0720 hrs and, having been transferred by ATC to theDaventry and then the Bristol Sector Controller of London AirTraffic Control Centre (LATCC), was cleared to Flight Level (FL)140.A number of radar headings were ordered until the flight was instructedto maintain a radar heading of 1950M and cleared for a furtherclimb to FL 230. The co-pilot had been the handling pilot duringthe take-off and, once established in the climb, the commanderwas handling the aircraft in accordance with the operator's normaloperating procedures. At this stage both pilots had released theirshoulder harness, using the release bar on the buckle, and thecommander 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 pressurealtitude, there was a loud bang and the fuselage filled with condensationmist. It was at once apparent to the cabin crew that an explosivedecompression had occurred. The commander had been partially suckedout of his windscreen aperture and the flight deck door had beenblown onto the flight deck where it lay across the radio and navigationconsole. The No 3 steward, who had been working on the cabin sideof the door, rushed onto the flight deck and grasped the commanderround his waist to hold onto him. The purser meanwhile removedthe debris of the door and stowed it in the forward toilet. Theother two cabin staff instructed the passengers to fasten theirseat 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 displacementof the control column during the commander's partial egress andmade a distress call on the frequency in use but he was unableto hear its acknowledgment due to the noise of rushing air onthe flight deck. There was some delay in establishing two-waycommunications and consequently the Bristol Sector Controllerwas not immediately aware of the nature of the emergency. Thisled indirecty to the LATCC Watch Supervisor not advising the aircraftoperator of the incident, as required by the Manual of Air TrafficServices (MATS) part 1. Consequently the initiation of the BritishAirways Emergency Procedure Information Centre plan was delayed.Meanwhile the purser re-entered the flight deck and, having hookedhis arm through the seat belts of the fourth crew member jumpseat which was located behind the left-hand pilot's seat, wasable to assist the No 3 steward in the restraint of the commander.

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

Meanwhile, the aircraft had descended to FLl00 and slowed to about150 knots(kt). The co-pilot had requested radar vectors to thenearest airport and had been turned towards Southampton Airportand eventually transferred to their approach frequency. Havingverified that there was sufficient runway length available fora landing, the co-pilot manoeuvred the aircraft onto a visualfinal approach to runway 02 and completed a successful landingand stop on the runway at 0755 hrs. The engines were shut downbut the Auxiliary Power Unit, which the co-pilot had started upduring the descent, was left running to provide electrical powerto certain aircraft systems. As soon as the aircraft came to ahalt, passengers were disembarked from the front and rear airstairswhile the airport and local fire services recovered the commanderback into the aircraft from his position half out of the windscreenframe, where he had remained throughout the descent and landing.He was taken to Southampton General Hospital suffering from bonefractures in his right arm and wrist, a broken left thumb, bruising,frostbite and shock. The other crew members and passengers weremedically examined but apart from one steward who had cuts andbruising to his arm there were no other injuries.

RETURN TO INDEX

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 foundin the window frame, this had retained a portion of the rubberseal and a metal bush from the windscreen. The bolt was not newand its countersunk head had pulled through the windscreen. Theaircraft window frame was checked for distortion and found tobe satisfactory.

Other damage to the aircraft consisted of:-

The High Frequency (HF) aerial, stretching from a forward positionon the top of the fuslage to a fitting close to the tailplanebullet, was missing and the fittings damaged. There was a denton the top left side of the fuselage approximately 3 inches longabout 3 feet above the overwing emergency exit and a scratch onthe top left side of the fuselage. Minor damage to several itemson 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 until 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 limitati
Flying experience	
Total	7,500 hours
On type	1,100
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 inthe current year.

1.6 Aircraft information

1.6.1 General information

Manufacturer	British Aircraft Corporation (BAC) Ltd
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 weights and centre of gravity

Maximum Take-off Weight Authorised	44,000 kg
Dry Operating Weight	25,818 kg
Zero Fuel Weight	32,925
Payload	7,197 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, thereforefuel used during the flight was 2,180 kg.

1.6.3 General description

The BAC One-Eleven 500 series is a twin-engined, passenger aircraftpowered by Rolls Royce Spey turbofans. The fuselage is pressurisedand air-conditioned; 8,000 feet conditions being obtainable at35,000 feet, under which conditions the pressure differentialis 7.5 psi.

The pilots' windscreens are of five-ply glass/polyvinyl-butylconstruction, the innermost (glass) laminate being low-temperedto form a splinter shield in the event of a bird strike. Windscreenheating is applied, primarily to improve the impact resistanceof the windscreen at low outside air temperatures. The windscreenis not designed on the 'plug' principal, where cabin pressureeffectively contributes to holding it in place, but is fittedfrom the outside of the aircraft and is secured by means of 90countersunk bolts, also fitted from the outside. The large numberof bolts are required to prevent leakage of pressurised air throughthe window seal but the force of internal air pressure could besatisfactorily resisted by far fewer bolts.

RETURN TO INDEX

1.7 Meteorological information

1.7.1 Synoptic situation

High pressure existed to the west of Ireland with a light northerlyflow over the Didcot area There was a possibility of broken Stratuswith a base at 600 feet and scattered Altocumulus with base at12,000 feet and tops at 15,000 feet with a thin layer of Cirrusabove 25,000 feet. Visibility was about 10 kilometres. At 18,000feet the wind was 360° at 17 kt and the air temperature wasminus 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 TrafficArea Radar Control Service from the Bristol sector of LATCC ona frequency of 132.80 MHz. The flight came under the control ofSouthampton Zone on frequency 131.00 MHz at 0744 hrs. A transcriptof ATC recorded transmissions from the onset of the emergencyis reproduced at Appendix A.

The co-pilot made a 'Mayday' call and declared that the aircrafthad suffered an emergency depressurisation and was descendingto FL100 on a heading of 195°M. The controller acknowledgedreceipt of the 'Mayday' call from BA 5390 but did not attemptto establish if the aircraft could still receive his communicationsand, although he alerted his Chief Sector Controller (CSC), tookno further action since he was waiting for further informationabout the emergency. He continued to operate the sector as ifno emergency existed, accepting further aircraft onto the frequencywith no attempt to off-load traffic or minimise radiotelephonyactivity. However, fortunately there was no conflicting trafficand the CSC had advised the neighbouring sectors of the emergencydescent and told the LATCC watch supervisor and the RAF Distressand Diversion Cell about the emergency call. Just prior to thehandover to Southampton, BA 5390 was descended to an altitudeof 4,000 feet in error rather than FM0 as had been co-ordinated,despite the Bristol Sector Controller not being aware of the airfield'sQNH. This difficulty was resolved when the flight was transferredto the Southampton Zone Controller who had been alerted to thepossibility of the aircraft landing there and had taken alertingaction following a telephone call from LATCC.

The co-pilot did not select the special purpose Secondary SurveillanceRadar transponder code (7700) to indicate an emergency conditionbut retained the code that had been already ailocated to the flight.This accorded with the United Kingdom Aeronautical InformationPublication RAC 7-4 which states : '....if the aircraft is alreadytransmitting a code and receiving an air traffic service thatcode will normally be retained.'

1.9.2 ATC handling of emergencies

Guidance to controllers on the handling of emergency traffic iscontained 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 isin an emergency, the controller must decide whether or not totransfer the aircraft to another agency. The choice of agencywill depend upon the circumstances and no hard and fast rulesapply. The following guidance material wrn help controllers tomake this decision:

Retaining Control

If the controller can offer immediate assistance the aircraftshould normally be retained on the frequency. If necessary imposea radio silence on other aircraft or transfer them to anotherfrequency.

Alternatively it may be nrore expedient to transfer the emergencyaircraft to a discrete frequency, particularly if a radio silencewould endanger other traffic.

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

Transferring Control

If a controller considers that another unit may be able to givemore assistance than he can himself, and in the circumstancesit is reasonable to ask the pilot to change frequency, he shalleither;

(a) Consult the Air Traffic Control Centre Supervisor and transferthe aircraft according to his instructions, or

(b) Alert the nearest suitable unit and transfer the aircraftto a common frequency, giving assistance to that unit as required.

Before transferring aircraft, controllers should obtain sufficientinformation from the pilot to be convinced that the aircraft willreceive more assistance from another unit. If a change of frequencyis desirable the pilot must be instructed to revert immediatelyif there is no reply on the new frequency. Controllers shouldthen listen out on the original frequency until the aircraft isknown to be in two way communication.'

1.9.3 ATC training

An ATC service in the United Kingdom may be provided only by aperson who holds an Air Traffic Controller's licence with theappropriate rating made valid at the ATC unit at which the serviceis to be provided. The Air Navigation Order authorises the grantof licences to persons who demonstrate their knowledge, experience,competence, skill and physical and mental fitness to the satisfactionof the CAA. The CAA publication CAP 160 details the evidence whichmust be furnished, the examinations which must be passed and otherrequirements which must be met before licences, ratings, validationsand endorsements are issued.

An applicant for a licence is required to demonstrate his or herknowledge 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 serviceat 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 courseand examination for the issue of an Area Procedural and Area Radarrating at the National Air Traffic Services (NATS) College ofAir Traffic Control (CATC) in May 1985 and was then posted toLATCC for validity training. This was successfully completed andled to the rating being validated on the Bristol Sector position.

Prior to the mid 1980's the Area Radar rating examination hadincluded an emergency exercise. Both the CATC and the ATC LicencingBranch informally agreed that the inclusion of an aircraft emergencyduring the examination placed undue emphasis on the emergencyand worked against assessing the examinee's ability to handleroutine traffic situations. In order to overcome this problem,an agreement was reached between the College and ATC LicensingBranch that the emergency would be removed from the examinationbut that appropriate training for such events would continue tobe given. The Bristol Sector Controller on duty at the time ofthe emergency had undertaken his course in 1985 but the precisecontent of his course could not be established as the recordsof courses conducted at that time were not available.

This situation is believed to have continued until 1988 when theATC Licensing Branch was removed from NATS and placed within theCAA Safety Regulation Group, eventually becoming part of the AirTraffic Services Standards Department (ATSSD). Due in part tothat change, the CATC, which remained within NATS, was requiredto submit to annual inspections by the ATSSD so that approvedcourses might continue. In contrast to other ATC courses whichhave a published syllabus (CAP 390 - ATC Training Manual) no suchpublication is made for Area Procedural/Area Radar Courses. Asthe CATC was the only establishment to provide such courses, individualsyllabuses were agreed between ATS SD and the College. No mentionof practical emergency training is given in this syllabus forarea radar nor in the course approval which was given after theATSSD inspection in 1989. The syllabus did require certain partsof MATS Part 1 relating to emergency training to be covered, butinstructors took a wider view and also tended to discuss the handlingof emergency situations during theoretical lessons. The instructors,however, found it more difficult to incorporate emergency situationsinto routine practical exercises as they found it was likely todisrupt the learning process. Such training tended to be injectedat a relatively early stage of the course with little opportunityfor later consolidation. Therefore, the course manager was allowedto omit certain emergency situations. As a consequence, trainingin practical emergencies could be reduced to such an extent thatit was non-effective. As the syllabus did not require practicalemergency instruction, the CATC management did not inform ATSSDwhere such training was not given. ATSSD was not aware that suchdecisions had been taken and believed the situation remained asper the agreement following the removal of emergencies from theexamination. Once a student leaves the College there appears tobe no requirement to undergo any emergency training or periodicappraisal on emergency procedures in order to maintain an Area/AreaRadar validated rating.

1.10 Aerodrome information

The single concrete runway, 02/20, at Southampton Airport is 1,723metres long. The landing distance available on runway 02 is 1,650metres. A VOR/DME (SAM 113.35 MHz) is located on the airfieldwhich 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 A1OO four channel CVR was fitted and a satisfactoryreplay of the 30 minute audio record was obtained. Channel allocationwas

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 signalon the area microphone channel but it was clearly audible on bothcrew hot microphone channels.

1.11.2 Universal Flight Data Recorder (UFDR)

A Sundstrand UFDR was fitted. A satisfactory replay was obtainedfrom the following recorded parameters:- Indicated Airspeed, Altitude,Heading, Normal acceleration, Flap position, Pitch attitude, Rollattitude, No 1 engine P7, No 2 engine P7, VHF transmit discrete.

Recorded data showed the aircraft climbing at 300 kt IndicatedAirspeeed (IAS) through 17,300 feet at the time of the loss ofthe windscreen. As the control column was pushed forwards, probablydue to the movement of the commander through the windscreen frame,the aircraft pitched 60 nose down and banked 250 to the right.When the co-pilot took control and closed both throttles, thespeed was allowed to increase to 340 kt as the aircraft descendedat 4,600 feet per minute to FL110. On reaching this level thespeed was reduced to 266 kt with a further decrease to 163 ktas flaps were extended according to the normal operating scheduleand then power was applied to maintain this height and speed.The time elapsed from the depressurisation to level flight atFL110 was 148 seconds.

1.12 Wreckage and impact information

The aircraft was brought to rest on the runway and electricalpower turned off The aircraft was towed off the runway and parked.

1.12.1 Examination of the left windscreen and attaching bolts

The windscreen was found near Cholsey, Oxfordshire, along withthe windscreen outboard corner post fairing strip and some associatedbolts.

Of the 90 bolts used to attach the windscreen to the aircraft,11 had remained in the windscreen and 18 were found loose nearby;one had remained in the aircraft window frame.

Twenty-six of the bolts recovered with the windscreen were newbolts identified against the British Standard as having the partnumber A211-8C. The remaining four bolts recovered were re-usedbolts identified as having the part number A211-7D. The IllustratedParts Catalogue (1PC) specifies that the attaching bolts shouldbe part number A211-8D. The specifications for these bolts are:-

Part No	Shank length (inches)	Diameter (inches)
A211-8D	0.8	0.1865-0.1895
A211-8C	0.8	0.1605-0.1639
A211-7D	0.7	0.1865-0.1895
UNF = Unified Fine		UNC = Unified Coar

The bolts engage with 10 UNF Kaylock floating anchor nuts mountedon the inside of the windscreen frame. The replacement windscreenhad been installed with 84 bolts (A211-8C) whose diameters wereapproximately 0.026 of an inch below the diameters of the specifiedbolts but of the same thread pitch, and six bolts (A211-7D) whichwere of the correct diameter, but 0.1 of an inch too short.

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

1.13 Medical and pathological information

Not relevant.

1.14 Fire

There was no fire.

RETURN TO INDEX

1.15 Survival aspects

Following the loss of the left windscreen and subsequent decompressionof the fuselage, the commander found himself half way out of theaircraft through his windscreen aperture. He recalls the impressionof lying on his back against the upper surface of the flight deckexterior and, realising that he was still able to breathe, heconcentrated on this until he assumes he lost consciousness. Heregained consciousness after the aircraft had landed and whenhe was being recovered by fire and ambulance staff inside theflight deck prior to be being placed on a stretcher and takento hospital.

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

The aircraft was not fitted with an automatic presentation oxygensystem in the cabin and this was not required to be fitted underthe original requirements for the issue of the aircraft's Certificateof Airworthiness. Therapeutic oxygen was available in the cabinand consisted of 18 sets of facemasks and four portable oxygencylinders. The oxygen system supplied gaseous oxygen to the crewand passengers if decompression occurred and for therapeutic purposes.Oxygen cylinders were mounted underfloor in the forward fuselagein the electrics bay. From the cylinders the oxygen was pipedthrough in-line filters to the control panel in the flight deckright hand console. For therapeutic supply, an outlet from thedouble pressure regulator connected to an isolation valve (normallyclosed) and thence to a ring main which served twinflow socketsin selected passenger service panels. With the crew shut off valveand passenger isolation valve open, oxygen was obtained by connectinga therapeutic mask to an outlet point. Therapeutic masks werestowed in the aft stowage compartment. Immediately following theloss of pressurisati on, the No 2 steward went and sat in seat20D whilst donning the mask of a portable set that was stowednearby. Oxygen masks were available to the flight deck crew butthe co-pilot elected not to don his mask since he realised thatthe aircraft would soon reach FL100 (see paragraph 1.17.7 below).He also did not want to impede his ability to communicate withthe 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 with10 UNF anchor nuts

During the course of the investigation British Airways carriedout a simulation of the window fitting procedure to determinethe torque that could be applied to 8 UNC countersunk head boltsfitting into 10 UNF Kaylock type anchor nuts. A 24 anchor nuttest piece was used as follows:

To determine the torque at thread slip of twenty 8 UNC bolts in10 UNF Kaylock nuts. This was found to be in the range of 1 to7 lbf in.

To determine the torque required to engage the bolt in the lockingmechanism of the nut, four 10 UNF bolts were fitted in 10 UNFKaylock nuts. This torque was found to be in the range of 10 to11 lbf in.

A further, more representative test was carried out in the presenceof AAIB using a BAC One-Eleven in which 32 bolts (A21 1-8C) wereused to fasten a window and seal in an aircraft. In this testtorque figures ranging between 0 and 12 lbf in were achieved beforethe threads slipped.

A third test was carried out using some of the anchor nuts removedfrom G-BJRT to ensure that no unforeseen effect could have madethe G-BJRT window unrepresentative; ten 8 UNC bolts were fittedand these slipped at torques ranging from 0 to 6 lbf in.

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

It was noted that the thread range 4 UNC to 1/2 inch UNF, commonlyused on aircraft bolts, contains three adjacent pairs of sizeswith similar thread pitches which allow the smaller bolt to engagein the larger Kaylock nut.

1.16.2 Examination of the torque limiting screwdriver used tofit the windscreen

Tests on a similar torque limiting screwdriver to that used tofit the windscreen showed that at a low setting (5 lbf in) thefeel of the screwdriver clutch slipping was indistinguishablefrom 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 feltas the screwdriver clutch released.

The actual torque limiting screwdriver used had a high level ofresidual friction (typically 7 lbf in at a setting of 20 lbf in)after the set value had been achieved and was therefore takento the manufacturer for examination in the presence of AAIB andBritish Airways. The torque limiting screwdriver employed a camplate with three lobes to retain three ball bearings which weredisplaced against the action of a spring to release at the settorque. Once released, the drive shaft carrying the ball bearingsrotated through a third of a revolution until the balls reindexedagainst the cam. Thus, in use, the torque should build up to theset value, slip and reduce to a residual value whilst the ballsmove across the constant radius section of the cam to the nextindexing position.

The residual torque was confirmed as being high at a value ofapproximately 30 per cent of the torque set, rather than the usualvalue of between 5 and 10 per cent. Subsequent discussions withthe manufacturer disclosed that the specification for the grease,used in the assembly of the torque limiting screwdriver, had beenchanged approximately five years ago because of problems of thegrease breaking down with age. At this time retrospective actionfor those torque drivers already sold was considered impracticalbecause of the large numbers involved and the lack of informationabout their location. The screwdriver under test was atleast five years old and strip examination revealed that the excessivefriction was caused by deterioration of the old specificationgrease. No significant wear was evident on the cam or the ballbearings, and when rebuilt with the correct grease the torquelimiting screwdriver performed satisfactorily.

The high residual torque occurred after the set value had beenachieved (ie 20 lbf in) and did not affect the torque atwhich the screwdriver operated. The residual torque would nothave been felt before the set torque was reached.

1.16.3 Special checks called for on windscreen bolts after theaccident

Before the diameter of the replacement bolts had been establishedBritish Airways issued an instruction to be carried out on allits BAC One-Elevens before the next flight, to remove every fourthbolt from the No 1 left-hand and No 1 right-hand windscreens tocheck for correct length.

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

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

When the smaller diameter bolts were identified in the detachedwindow British Airways called for a 100 per cent visual inspectionof bolt head diameter; this check utilised the fact that the smallerbolt head had 27 per cent less area than the head of the correctbolt. 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 BritishCivil Airworthiness Requirements (BCAR) Section D in 1970 whichcalls up duplicate inspections after certain safety critical maintenanceoperations. However the glazing elements of windscreens are notidentified as principal structural elements, nor does the applicationof this duplicate inspection philosophy attempt to cover possiblesafety critical situations caused by servicing errors.

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

The BAC One-Eleven windscreen was designed to be secured withcountersunk head bolts to British Standard A211-8D. This BritishStandard specifies that the British Standard number and the boltpart number shall not be applied on the bolts, but shall be clearlymarked 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 inan aircraft to be made after initial assembly and before the firstflight after overhaul, repair, replacement, modification or adjustrnent.In September 1985 BCARs introduced a requirement for duplicateinspections of 'Vital Points', which are defined as any pointon 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 referto multiple fastened parts of the structure, but only appliesto a single point, usually in a control system.

The regulations contain a waiver making the definition of 'VitalPoints' nonmandatory for aircraft with a Maximum Take-off WeightAuthorised of over 5,700 kg which were manufactured in accordancewith a Type Certificate issued prior to 1st January 1986. Thiswaiver includes the BAC One-Eleven. However, even had it not,British Aerospace would not expect the pilots' windscreens toappear 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 becalled up after work has been carried out on the pressure hull.There is no specific company policy on leak checks within BritishAerospace. Such checks are written into the aircraft MaintenanceManual at the discretion of the aircraft design team, and werenot called up on the BAC One-Eleven.

1.17.1.3 Quality Requirements for Airlines

CAA approval of Aeroplane Maintenance Organisations, such as BritishAirways, includes a requirement for a company exposition containingdetails 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 Assuranceshould be such that the prime objective is to maintain a continuouscheck on the effectiveness of the maintenance organisation andon the procedures and systems employed to ensure that all CAArequirements as well as those of the Organisation itself are met.

When assessing an Organisation for approval the CAA will examinethe systems used to control all maintenance activities, includingQuality Control and Assurance. The certification procedures usedby many airlines, including British Airways, and approved by theCAA, allow a single authorised engineer to undertake most aircraftwork within his trade boundaries, and sign for it, without supervisionor independent checking. The exception to this, on the BAC One-Eleven, is the requirement for duplicate inspection of controlsystems.

1.17.1.4 Maintenance Engineer Licencing

Aircraft maintenance licences are issued for a period of two yearsand renewed for a maximum period of five years. Licences willnormally be renewed on application provided that, during the 24months preceding the date of expiry of the licence, the holderhas been engaged for periods totalling at least six months onappropriate work. No medical standards are specified for issueor renewal, neither are any examinations associated with the renewalof licences. No periodic training or tests are required on individualmaintenance engineers.

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

a. Licence Without Type Rating (LWTR)

The LWTR does not in itself confer any certification responsibilitiesor privileges but is a prerequisite for the granting of the relevantType Ratings which confer the privileges of certification appropriateto that Type Rating. The LWTR is also a prerequisite for issuingan approved company authorisation in the appropriate licence category.

b. Type Ratings

Type Ratings confer on the holder of a licence privileges andcertification responsibilities in respect of certain aircraftregistered in the United Kingdom.

1.17.1.5 Company Authorisations

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

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

The holding of company authorisations allows the engineer to makemaintenance certifications affecting the airworthiness of theaircraft. Therefore, such an engineer carries some of the responsibilityfor 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 accordancewith the BAC Maintenance Manual, which contains chapters coveringeach system in the aircraft, each chapter providing: a detaileddescription of the system and its operation, with sufficient detailfor diagnostic use by the aircraft maintenance engineers; specificvalues to be achieved during servicing, ie torque loadings,pressures, dimensional checks, timings, etc; procedural informationcontaining detailed sequences of the steps to be followed duringthe removal and replacement of significant items. The MaintenanceManual is complemented by the IPC, which contains detailed drawingsof all parts of the aircraft and identifies the components usedby manufacturers' part numbers.

Although the Maintenance Manual breaks the windscreen removal/replacementtask into a series of individual steps, the British Airways maintenancedocumentation at that time treated the task as a single stageoperation.

1.17.2 British Airways' infrastructure

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

1.17.2.1 Quality Monitoring Procedure (QMP) - The System

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

a. The local Exposition

Each Departmental Head is required to raise a local Expositionwhich lists the functions for which he or she is responsible andthe geographic locations where the work is carried out. The functionsare allocated to managers, by name, and the procedures that areused to control tools, equipment, procedural and documentary amendments,modifications, special processes, etc. are defined. Each localExposition is registered with the CAA and, in conjunction withother documents, forms the British Airways' submission for requestingapproval for the various engineering functions that are carriedout.

b. Continuous Monitoring

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

The QMP system is confined to airworthiness related items anddoes not duplicate other reporting systems. It can, however, reportthe shortcomings in other Systems where this is appropriate inairworthiness terms.

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

c. Product Sampling

In addition to the Continuous Monitoring process there is animposed Product Sample that has to be carried out at set periodsto satisfy the requirement of an independent assessment of work.Product

Sampling is seen as a check on the effectiveness of theContinuous Monitoring system and all sample reports are submittedto the Chief Quality Engineer for evaluation; some of which arepassed 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 qualityperformance, for assessing standards and for maintaining a qualityawareness in all his staff. Through the Local Exposition, theDepartmental Head declares the staff, facilities, equipment andsystems for which he is responsible and sets down how QualityMonitoring is to be implemented throughout his area of responsibility.He holds regular briefings to ensure that Continuous Monitoringis being correctly applied, and monthly summary reports of theQMP system are submitted to him by his staff. From this monthlysummary it is possible to deduce the amount of QMP activity, interms of numbers of deficiencies raised by Continuous Monitoringand by Product Sampling.

Every quarter the Departmental Head summarises all of the QMPactivity for his area by completing a Quarterly Report. The QuarterlyReport is sent to the British Airways Audit Unit who compile statisticsfrom the reports and report those statistics to the Quality Forum.Forum meetings are arranged monthly and are chaired by the ChiefEngineer of Quality and Training Services on behalf of the EngineeringDirector. The CAA Surveyors in charge of both the Heathrow andGatwick offices participate in these meetings.

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

1.17.2.3 Auditing the Process

The effectiveness of the QMP is assessed although independentaudits which are conducted by a small group of quality engineersfrom the Quality Audit Unit, a paperwork exercise every six monthsand a visit every two years. In addition they will act in an advisorycapacity on airworthiness matters and on the management of theQMP system. The independence of the Audit Unit from the engineeringoperation has been accepted by the CAA, who check on this aspectthrough regular surveys on the Audit Group.

The Audit Unit is also empowered to carry out traditional 'systemsaudits' if sufficient grounds exist to suspect that functionsor procedures are not properly controlled. The results of suchaudits are reported to the appropriate Departmental Head so thatthe necessary corrective action can be taken. As a last resort,the result can also be reported to the Quality Forum, for correctiveaction 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 isa closed-loop system which is continuously reviewed by engineeringmanagement to ensure that aircraft technical performance is satisfactory.As part of the programme, the following performance parametersare 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 definedtargets or alert levels. All of these parameters are evaluatedand reported on for all fleets and corrective action taken througha series of structured MCP committees, which in turn report toan Engineering Control Review Board who meets formally twice peryear 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 notificationof defects found during work on aircraft or aircraft componentswhich are considered worthy of special attention. The system isalso used for the notification of 'Ground Found' Mandatory OccurrenceReports as required by the Air Navigation Order and Regulationsand 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 E1022action 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 secondarystructure, structural corrosion or deformation greater than expected

Failures or damage likely to weaken attachments of major structuralitems 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, believedto have become detached in flight

Overheating of primary or secondary structure

Unreported damage

Defects that cannot be cured by normal replacements or repairs

The correct assembly

Use of incorrect fuel, oil or other vital fluids

Failure of any emergency equipment that would prevent or seriouslyimpair its use

Critical failures or malfunction of equipment used to test aircraftsystems 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 Inspectionor 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 andrectification of the 13 BAC One-Eleven fleet, and flight servicingand rectification for other British Airways aircraft (HS 748 andATP) and other contracting airlines. The first batch of the BritishAirways One-Eleven fleet depart between 0630 hrs and 0730 hrseach weekday morning.

For operational reasons most of the maintenance work on the BACOne-Eleven fleet was carried out at night and consequently theShift Maintenance Managers on the night shift usually had morework available to them than they could satisfy. This requiredthe allocation of task priorities and the night shift manpowerwas usually sufficient to complete all the necessary airworthinessengineering tasks with only minor Acceptable Deferred Defectsbeing left to be dealt with by a subsequent night shift. Indeed,in order to curb over-enthusiasm engendered by the pride feltby the shifts in their ability to satisfy the task, the managementat Birmingham repeatedly stressed that night shifts should notattempt to do more than was prudent.

1.17.3.2 Facilities

At the time of the accident Birmingham Airport was undergoingextensive works services to increase its capacity. The BritishAirways engineering facilities comprised accommodation at twolocations:-

a. Under the International Pier

Office accommodation plus an unmanned store with an adjacentsmall workshop area which contained a carousel with 408 drawersholding consumable Aircraft General Spares (AGS).

b. Eastern Apron

A hangar bay large enough to contain a BAC One-Eleven, with atail dock containing staging allowing access to the tail. TheEastern Apron used to be the terminal area and the bay containedaccommodation previously used by the engineering department. Thisfacility housed a manned store and engineering accommodation suitablefor work in the area.

The geographical location of these areas is shown at AppendixB.

1.17.3.3 Manpower

The engineering establishment comprised

a. An Area Maintenance Manager with responsibilities for outstationsin 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 BritishAirways scheduled operations, although British Airways charterflights may have landed there occasionally. British Airways hadno engineering staff at these stations which were served as necessaryby agencies, appointed by the Area Maintenance Manager, or visitingengineers for specific flights. Jersey was a transit station with,at most, one aircraft stopping overnight. Therefore more than80 per cent of the Area Maintenance Managers time and attentionwas devoted to Birmingham. He was specifically responsible forthe control and effectiveness of the Quality Monitoring systemin maintaining the established quality performance targets andwas to conduct regular checks throughout the organisation assignedto him to ensure that quality performance targets were achieved.

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

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

d. A permanent night shift of four engineers to supplement theduty night shift and three double day shifts of three men to augmentday work.

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

1.17.3.4 Station Organisation

The Station Maintenance Manager and the Shift Maintenance Managersall reported directly to the Area Maintenance Manager. The onlyTerms of Reference that were available for the engineering maintenancepersonnel employed by British Airways at Birmingham were thosewhich appeared in their Union agreement, however their job specificationsmay have appeared in recruitment advertisements issued locally.

a. Shifts

The shift pattern worked by the five rotating shifts gave 24hour cover over a 35 day cycle. The duty shift was augmented bythe various standing shifts in a system designed to provide optimumcover at the times when it is needed, primarily for aircraft handlingduring the day and rectification at night. Reduced cover was providedover the weekends. A diagrammatic representation of the shiftsystem 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 practicesof his subordinates, but relied on the trending of parameterssuch as numbers of Acceptable Deferred Defects, repeated defects,and failures to meet schedules as indicators of quality. (Thetotal list of parameters is at 1.17.3.6 b).

Although the Station Maintenance Manager was responsible for thetechnical activities on the Unit, he was the same grade as, andreceived the same pay as, the Shift Maintenance Managers underhim. He worked on aircraft when the need arose and so was closerto the day-to-day standards used, however the organisation structurewas such that Shift Maintenance Managers often communicated directlywith the Area Maintenance Manager. Because of his day time dutiesthe Station Maintenance Manager rarely had the opportunity tooobserve the workings of shifts at night, especially during theearly 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 itemwhose part number has been identified can be located down to thedrawer containing the stock. All parts and materials are requestedby description and part number as specified in the IPC which isavailable at all work stations.

AGS are contained within a dispenser with a stores identificationlabel 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 hangarunder 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 descriptionand bar code; the drawers frequently contained the identifyinglabels from the packs. There was, however, no way, other thanmeasurement, of identifying the contents after they had been removedfrom the packs.

Minimum stock levels per drawer were usually set at between 50and 100 items depending on bulk and usage. The hangar carouselscontained 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 drawerswhich were not labelled and some which contained a mixture ofitems. 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 drawerlabel).

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

The uncontrolled nature of this carousel had been recognised bysome 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 Training

The initial training for QMP consisted of 1.1/2 days of externaltraining for middle management who provided ad hoc training toforemen and supervisors in the local area, based on a standardpackage consisting of a video plus viewfoils. The foremen in turnwere 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 Companyin June 1988, identified a shortfall; the Quality Forum directedeach Department to carry out QMP training, and an illustrated'Guide to QMP' was produced. A further QMP survey in January 1989identified that improvements had been achieved but that a lackof comprehension still existed. At the time of the accident, actionto remedy this was still under discussion.

b. The Birmingham Exposition

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

The completed Product Sample proforma were distributed to theArea Maintenance Manager, the British Airways Quality Forum andsome to the CAA.

A British Airways Engineering Department procedure stated thatthe Area Maintenance Managers were responsible for maintainingthe 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 staffstressed the need for an open reporting system using QMDRs. Overa 39 month period, ending in April 1990, 36 QMDRs were raisedon local issues at Birmingham. Eleven of these were as a resultof the monthly Product Samples, and the other 25were raisedby the British Airways employees, of whom approximately a quarterhad been active in the system. The Area Maintenance Manager statedthat there was less of a need to complete QMDRs as some faultscould be identified and actioned immediately as he had controlof the Birmingham engineering budget.

d. Product Samples from Birmingham

British Airways produced ten copies of Product Samples carriedout at Birmingham, seven of these related to the period beforethe 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 raiseda total of 65 deficiencies which were of a minor nature.

The CAA produced six copies of Product Samples carried out atBirmingham before the accident; three of these duplicated copiesprovided by British Airways, and the additional three, from early1989, were similar in content to the others.

e. British Airways Quality Audit at Birmingham

Paperwork audits of the Engineering function at Birmingham toassess the use of and adherence to monitoring procedures, requiredunder QMP procedures, were scheduled and performed at six monthlyintervals. A physical audit of the Birmingham station, in theform of a two day visit, was last carried out prior to the accidentby a representative of the British Airways Quality Audit Uniton 15/16 June 1988, when it was reported that the engineeringfacility was to a high standard. Seven observations were raisedrelating 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 supervisoryvisits to survey the engineering services provided by BritishAirways 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 theaccident took place on 22 June 1989 , followed a proforma schedule,lasted for approximately half a day and did not detect any significantengineering problems.

1.17.3.7 Use of E1022 Procedure at Birmingham

Over the same 39 month period in which 36 QMDRs were raised, 365E1O22s 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 underthe International Pier 45 minutes earlier than his shift starttime in order to allow himself time to catch up with the paperworkand establish the shift work content; this included three significantdefects, routine items and various minor cabin defects.

A Supervisory Aircraft Engineer and a further Licenced AircraftEngineer, normally part of the shift, were not available thatnight and, although the work outstanding remained the same, theFriday night shift was routinely not supported by the four mannight shift supplement because there was reduced scheduled flyingon 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 MaintenanceManager carried on with the administration and the task of enteringthe contents of the aircraft technical logs into the computer.At about midnight, the Shift Maintenance Manager spent some timewith the Licenced Aircraft Engineer on a steering defect and thecompletion of this coincided with the arrival of a Tunisair Boeing737 which the shift had to handle. As none of the engineers hadBoeing 737 experience the Shift Maintenance Manager carried outthe pre-departure inspection and the refuelling in conjunctionwith the Licenced Aircraft Engineer to give him experience. Allthis activity took place at various locations around the airfieldand was co-ordinated using radio.

The departure of the Tunisair Boeing 737 at around 0145 hrs coincidedwith the meal break, which the Shift Maintenance Manager spentworking on administration whilst he ate his sandwiches. Afterthe break he directed his two airframe engineers onto a galleywater leak on one of the BAC One-Eleven aircraft which neededrectifying before the aircraft departed the following morning.

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

The aircraft was located in the No 2 bay, off the Eastern Apronon the other side of the airfield, and was parked tail into thehangar with the nose by the doors. In retrospect the Shift MaintenanceManager could not recall exactly what the weather was, but thoughtthat 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 0300hrs and 0500 hrs on the Saturday morning.

1.17.4.2 Procedures used

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

Maintenance Manual

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

b. IPC

The IPC was available on a microfiche reader, but was not usedto identify the part number of the bolts to be replaced, consequentlya stock check, using TIME, to assess the availability and locationof replacement bolts was not carried out. The Shift MaintenanceManager justified this omission by saying that he was quite satisfiedthat the bolts that he had removed were the correct bolts, andthat it would take so much time to find the correct numbers inthe IPC that he did not feel justified in using the IPC in thecircumstances of the job in question.

The page of the IPC for the 528 series aircraft shows a sketchof the pilot's No 1 windscreen and the adjacent DV window, butonly illustrates one bolt - that in the DV window, which is anA21l-7D. The components for the pilot's No 1 window are listedin the text, along with several alternative modification states,and its bolts are defined as 'attaching parts' and are identifiedas A211-8Ds. The IPC for the 510 series, in contrast, is veryclear in identifying the correct bolts.

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

c. Bolt selection

The Shift Maintenance Manager removed the windscreen with theaid of the Avionics Supervisor, who also disconnected the electricalconnectors of the screen heaters. The bolts were 'on condition'items, and as some of the paintfilled bolt heads had been damagedduring removal, and others showed signs of corrosion, the ShiftMaintenance Manager decided to replace them and took one of thebolts to the store to identify it by comparison with those heldin the carousel. The carousels were under the control of a storemanand had drawers which were clearly labelled with a location codeto which engineers were directed, after entering the part numberinto the adjacent stores computer terminal.

Because of their small head size the bolts do not carry individualidentification, but the Shift Maintenance Manager accurately matchedthe removed bolt by going through several trays, and comparingthe removed bolt with the drawer contents. He then identifiedthe part number of the bolt as A21l-7D by looking at the storesissue note in the drawer (the windscreen should have been fittedusing A21 1-8Ds). The Stores Supervisor, who had been in the jobfor about 16 years, informed him that A211-8Ds were used to fitthat windscreen, but did not press the point. The Shift MaintenanceManager decided that as A21l-7D bolts had come Out, he would replacethem with bolts of the same size.

The minimum stock level in the carousel for A211-7D bolts was50, but there were only four or five bolts in the drawer (whenchecked by the AAIB the following Monday it contained four). TheShift Maintenance Manager drove to the unsupervised carousel underneaththe International Pier, taking the removed bolt with him. Thedrawers in this carousel were labelled with the part number ofthe contents, although the labels were old and faded. The ambientillumination in this area was poor and the Shift Maintenance Managerhad to interpose himself between the carousel and the light sourceto gain access to the relevant carousel drawers. He did not usethe drawer labels, even though he now knew the part number ofthe removed bolt, but identified what he thought were identicalbolts by placing the bolts together and comparing them. He alsopicked up six A211-9Ds, thinking that the attachment of the outboardcorner 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 theelectrical connections made.

d. Torque loading of the bolts

The aircraft manual calls for a torque of 15 lbf in to be appliedto the bolts, which are then retorqued to 5 lbf in after 100 flyinghours. The Shift Maintenance Manager's experience told him thatmany of the bolts would be found up to three turns loose duringthe retorque procedure, so he decided to increase the initialtorque to 20 lbf in.

The British Airways toolstore at Birmingham held a calibrateddial indicating torque wrench to cover the range of 5 to 120 lbfin, but the retorque requirement of 5 lbf in was at the bottomof the range and the dial indicating torque wrench was not consideredsuitable for this task. Two calibrated torque checking gaugeswere available at Birmingham to allow engineers to confirm thewrench accuracy.

The calibrated dial-indicating torque wrench was not availableon the toolboard that night, but the Stores Supervisor had recentlyacquired from British Airways at London, on his own initiative,a torque limiting screwdriver specifically for the windscreentask, but on receipt it was found to be out of calibration dateand it was therefore not cleared for use. It was not the companypolicy at Birmingham to allow the engineers to adjust torque wrenchesas and when required, but rather to have the wrenches adjustedin a standards room and then issued for use at that specific setting.It was therefore the intention of the Stores Supervisor to haveit set in the London standards room before issue, but, in theabsence of any suitable alternative, the storeman set this screwdriverto the figure of 20 lbf in requested and gave it to the ShiftMaintenance Manager, who checked the setting using both torquechecking gauges.

The Shift Maintenance Manager used a 1/4 inch bi-hexagonal socketto hold the No 2 Phillips screwdriver bit onto the speedbraceused to run the screws down into the countersinks. The socketdid not have any means, such as a spring clip, to retain the screwdriverbit, consequently the Shift Maintenance Manager found that duringthe two-handed operation of using the speedbrace the bit fellout several times and he had to descend from the safety raiser(mobile staging) and retrieve it from the floor. To overcome thisproblem when using the same V4 inch bi-hexagonal socket with thetorque limiting screwdriver, he held the screwdriver in his righthand 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 thesafety rail provided by the safety raiser. This situation wasexacerbated by the fact that the safety raiser was incorrectlypositioned alongside the aircraft. His left hand obscured hisview of the bolt head, and the need to stretch removed the operationfrom his direct vision.

He fitted the windsreen using 84 of the bolts collected from theInternational Pier carousel and obtained a similar feel from thetorque limiting screwdriver for each one; a feel that met hisexpectations. When he came to the outboard corner post fairingstrip he realised that the A21l-9D bolts were too long, descendedfrom the staging and retrieved and refitted the six old boltsthat 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 thosespecified and within 0.050 of an inch in length to the A211-7Dbolts removed from the window. The bolts engage in 10 UNF 'Kaylock'floating anchor nuts; the self locking action is the result ofpart of the nut being an elliptical shape prior to the insertionof the bolt. Some of the anchor nuts were attached directly tothe inside of the aircraft window frame and some were carriedon strips, themselves attached to the window frame. The outboardcorner post fairing strip interposed an additional thickness andrequired A21l-8D bolts, and these were specified for the attachmentof the whole windscreen, even though in the majority of locationsapproximately five threads would be visible below an anchor nutfastened directly to the frame when used with an A21l-8D bolt.The amount of thread in safety would be reduced when used withthe backing strips and the outboard corner post fairing.

e. Missed cues

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

The window was finished in primer and had countersunk holes forthe bolts; an A21l-8C bolt head sits significantly further belowthe surface of the window, down in the countersink, than doesan A21 1-8D bolt head, leaving an annulus of unfilled countersinkwhich is easily discernible 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 filledthe countersinks, were close to those of the left hand window,and, although painted, the difference is perceptible under normalcircumstances. The Shift Maintenance Manager missed this differencein depth of the bolt heads in the windscreen centre column. (Seephotograph in Appendix E).

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

The following night the Shift Maintenance Manager carried outanother windscreen change, this time a right hand one. The jobhad been set up before he arrived and he noticed that the boltswere A21l-8Ds. He recalled fitting A21l-7D bolts the previousnight, but he rationalised that the aircraft were old and of differingmodification states and the previous night he had an aircraftmodification standard requiring A211-7D bolts and that night hehad an aircraft requiring A211-8D bolts.

f. Documentation

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

DEFECT SYMPTOM

SYSTEM Port Windscreen

During cruise darkening & bubbling noted in small area on bottom LH port windscreen. Q.R.H. drill carried out

Signed by Reporting Captain

THE WORK RECORDED ABOVE HAS BEEN CARRIED OUT IN ACCORDANCE WITH THE REQUIREMENTS O
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 MaintenanceManagers 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 theoperator's engineering facility at Birmingham were made, the ShiftMaintenance Manager who changed the windscreen was interviewedand informal interviews conducted with the other maintenance managersin order to provide a context for the actions of the engineerwho undertook the windscreen replacement task. Subsequently thesemanagers provided written signed statements, mostly concernedwith the range of issues raised at the interviews.

The overriding impression given by the Maintenance Managers wasthat morale was high and that they were proud of their recordin 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 deprivationand circadian effects were acknowledged and various strategieswere cited to cope with the situation.

During the initial part of the investigation the Shift MaintenanceManager who carried out the windscreen fit did not appear to graspthe lack of care that his actions implied. He co-operated fullyin the investigation and, when shown the full list of errors andomissions that he had made, offered an explanation for each individualaction.

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

Four of the six Maintenance Managers who subsequently gave writtenstatements raised the issue of the large numbers of E1022 formsoriginated at Birmingham and concluded that these indicated theirconcern for quality and general standards.

One Maintenance Manager stated that he felt that the QMP systemwas in its infancy at the time of the accident but that the E1022process was well known. He went on to say that the staff at Birminghamfelt more comfortable with the E1022 system because they knewexactly how it worked and they knew that they would get a response.

Another Maintenance Manager also concluded that when he returneddamaged parts through the E1022 system he had direct contact withthe development engineer by telephone and his requests were actionedwithout them being channelled through a third party. The E1022system was therefore more effective, the QMPs took longer to actionand 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 Managerholding authorisations on BAC One-Eleven, Boeing 737, Boeing 757,HS 748 and with transit authorisations on L-1011 Tristar, Boeing747 and a CAA licence holder for airframe and engines on the Viscount.His experience included 10 years in the RAF, followed by 23 yearswith British Airways. He appeared to be a mature, dedicated engineerwho was well respected by flightcrew and engineers alike. No domesticor financial distractions were identified, either by British Airwaysmanagement, the Behavioural Psychologist engaged by the AAIB whointerviewed him or the AAIB Inspectors; the Shift MaintenanceManager denied any such problems.

He had been on leave over the period of the last night shift carriedout by his shift and so the Friday/Saturday night shift duringwhich the windscreen was fitted was his first night work for approximatelyfive weeks. He had had a normal nights sleep the previous nightand had gone to bed at about 1730 hrs, and had slept for 1.1/2hours, getting up at 2030 hrs. He said that he would have beenhappier if he had slept for an hour longer, but wasn't dismayedthat he had not. The last shift worked by the Shift MaintenanceManager was on Tuesday 5 June from 0630 hrs to 1500 hrs.

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

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

1.17.6.2 Behavioural Psychologist's Report

A Behavioural Psychologist interviewed the Shift Maintenance Managerwho carried out the windscreen fitting task and was present duringAAIB interviews with him and informal interviews with the otherMaintenance Managers. His report is included at Appendix F.

1.17.6.3 Ophthalmologist's Report

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

If he were to read small print or figures without his readingglasses, he would have difficulty. With his reading glasses andin 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 inindustrial situations have shown that for every serious accidentthere can be between 400 to 600 near misses. These figures indicatethat, in an industrial context, degraded standards may exist forsome time before a serious accident occurs or the situation becomesapparent to an independent observer.

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

1.17.7 The effects of rapid decompression

In an attempt to analyse and quantify the dynamic forces and physiologicaleffects caused by the loss of the windscreen, all the availabledata was presented to the Aircrew Systems Division of the RAFInstitute of Aviation Medicine, RAE, Farnborough.

The conclusions drawn suggested that the critical factors affectingthe survivability of all the aircraft occupants were the timeof decompression and file final cabin altitude. Those affectingthe commander were the time of decompression and the final altitudeof exposure, together with the low temperature and the aerodynamicforces to which he was exposed during the remainder of the flight.

Calculation provided that the duration of the decompression waslikely to have been in the region of 1.13 to 1.46 seconds, andthis was supported by the duration of the rapid changes of aircraftattitude. The maximum cabin altitude, achieved during this timeperiod, depended upon the interaction between the ram effect ofthe outside airflow and the airflow provided by the internal pressurisationsystems. Analysis suggested that this was unlikely to have beengreater than 13,000 to 13,500 feet which, when followed by thedescent profile flown, would not have promoted sufficient hypoxiato impair either the passengers or the crew.

The forces acting upon the commander, to project him through thewindscreen aperture, were a function of the differential pressurebetween the inside and outside of the cabin and are calculatedas having a force of approximately 5,357 pounds (depending uponhis exact proximity to the aperture). This would be quite adequateto drive a person weighing 70 kg from his seat and through theaperture, whereafter the ram effect of the airstream would pinhim to the fuselage and seriously impair movement.

RETURN TO INDEX

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 successfullyaverted what could have been a major catastrophe. The fact thatall those on board the aircraft survived is a tribute to theirquick thinking and perseverance in the face of a shocking experience.

Up to the time of the loss of the windscreen, the flight had proceededuneventfully and in accordance with the company's normal procedures.It was quite in order for the flight crew to release their shoulderharnesses once they were established in the climb and, for reasonsof comfort, the commander loosened his lap strap as he nearedthe cruising phase of the two and a half hour flight to Malaga.Therefore, when the left windscreen was blown out, it was notsurprising that the commander, who was very lightly built, wasdrawn partially through the windscreen aperture. It is not certainwhat prevented his complete egress from the aircraft but, sincethe No 2 steward later bad to free his legs from a position betweenthe control column and the flight deck coaming, it is likely thathe had been restrained by his legs during the initial stage ofthe emergency. Later, he was restrained simply by the effortsof the No 2 steward who was holding on to both of his legs.

The co-pilot immediately took control of the aircraft and wasable to establish a rapid descent despite the disorientating effectsof the dramatically transformed cockpit environment coupled witha push over and right roll. It was fortunate that he was an experiencedpilot with more than 1,000 hours experience of flying the BACOne-Eleven aircraft. Thus he was able to handle the aircraft onhis own and complete the normal operating procedures from memorywithout the assistance of another pilot. He alone was faced witha double emergency, namely rapid decompression and incapacitationof the handling pilot. He rejected the idea of donning his oxygenmask in favour of being able to shout instructions to his cabincrew. In the event, this was probably sensible but if the depressurisationhad occurred at a greater height, say above 20,000 feet, it wouldhave been imperative for him to don the oxygen mask to avoid incapacitationto 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. Thewindscreen fitting process was characterised by a series of poorwork practices, poor judgements and perceptual errors, each oneof which eroded the factors of safety built into the method ofoperation promulgated by British Airways:-

a. During the fitment of the windscreen to G-BJRT the Shift MaintenanceManager was confronted with certain situations which made hisjob more difficult

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

Insufficient stock of A211-7D bolts, incorrect but demonstrablyadequate, existed in the carousel in the bay stores at the EasternApron.

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

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

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

The stores TIME system, available to identify the stock leveland 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 A21 1-9Ds to fit through the corner fairingtook place

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

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

An uncontrolled torque limiting screwdriver was set up outsidethe Calibration Room.

d. Use of unsuitable equipment took place:-

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

A Safety Raiser which provided inadequate access to the job wasused.

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

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

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

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

The difference in torque and the amount of countersink remainingunfilled between the new bolts and old bolts used in the cornerfairing went unnoticed

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

The difference between the bolt thread stripping in/through thenut and the torque limiting screwdriver 'breaking' was not recognisedeven though the bi-hexagonal socket and screwdriver bit, locatedby his left hand, were still rotating. However, the high residualtorque of the particular screwdriver resulted in a less positive'break' and, although the break torque was never achieved withthe 8 UNC bolts, it was when setting the screwdriver and wheninstalling the fairing. This screwdriver, on reaching the settorque may have felt more like the thread stripping than wouldone with a more 'snappy' break.

2.2.2 The windscreen replacement task

The windscreen is part of the aircrafts pressurised hull and isattached from the outside by 90 bolts. It may be the only criticalitem on the aircraft that was susceptible to failure through thechain of circumstances listed above, in that:-

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

b. The wrong diameter bolts engaged with the anchor nuts, andhad the same thread pitch.

c. The bolts were not special to type items needing a part numberto identify and obtain replacements, but were general use items,obtainable from an uncontrolled carousel.

d. The windscreen was not designed on the plug principle suchthat internal air pressure would hold it in place, but was fittedfrom 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 workon the night shift was not subject to the review of a maintenancemanager.

The windscreen may therefore have been unique in that it alone,of all the critical components, could have accommodated the errorswhich occurred during its fitment, to expose them so dramaticallythe first time that the windscreen was called upon to resist cabinpressure. Had it been any other item, the selection of the wrongbolts 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 sparesis a recognised and necessary part of aircraft engineering practice.Small units can rarely afford to keep a full-time storekeeperto administer a dispenser, or even a store, and good trade practicehas to be relied upon. Before the Shift Maintenance Manager wentto the unmanned carousel he knew the part number of the boltshe was seeking, and although they were too short, similar boltshad held the old windscreen in place for four years. Despite thepoor segregation, labelling and lighting, the selection of thewrong 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 Managerreviewed the work of his shift, this review augmented the selfcertification task required of the engineers by British Airways'maintenance policy. Once he had decided to carry out rectificationwork himself, he withdrew from the active supervision of the restof the shift. The task of the windscreen installation was notdesignated a 'Vital Point' and consequently no duplicate inspectionwas called for and none took place, nor was the work of the ShiftMaintenance Manager subject to review by another manager.

Thus the Shift Maintenance Manager had no backstop with any chanceof detecting his errors. Errors that were made more likely bythe sleep deprivation and circadian effects associated with theend 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 manufacturingindustry has typically resulted in savings, mainly arising throughreduction in scrap and in the achievement of higher manufacturingefficiency. Nevertheless, at the end of the production line theproduct is normally still tested, before being despatched. Someaircraft maintenance tasks which may be undertaken using selfcertification procedures do not allow for the testing of the endproduct before it is flown.

It could be argued that the concept of self certification suffersfrom the drawback that the expectations of the engineer are suchthat he is unlikely to detect an error of his own making; theapplication of self certification reduces the level of inspectionand supervision.

It is recommended that the applicability of self certificationto aircraft engineering safety critical tasks following whichthe components or systems are cleared for service without functionalchecks, should be reviewed by the CAA. Such a review should includethe interpretation of 'single mal-assembly' within the contextof 'Vital Points' and the requirements which include a waivermaking the definition of 'Vital Points' non-mandatory for aircraftwith a Maximum Take-Off Weight Authorised of over 5,700 kg whichwere manufactured in accordance with a Type Certificate issuedprior to 1 January 1986.

2.2.4.2 Feedback

A fundamental requirement of any management process is a feedbackloop to detect the success or failure of the system, and two typesof feedback are available - a formal feedback through auditing/monitoringactivities and an informal feedback through free discussion amongstengineers discussing their work problems in an open forum.

Some feedback was generated by the monitoring of a series of performanceparameters which were airline parameters with quality overtonesrather than parameters capable of giving a comprehensive pictureof the engineering quality built into tasks. The crucial elementmissing was direct assessment of the standards used by the ShiftMaintenance Managers to perform their tasks.

Whilst literature circulated by British Airways stressed the needfor open reporting through QMDRs, a number of the MaintenanceManagers indicated that they felt more comfortable with the E1022,Ground Occurrence Report Form, with which they were particularlyfamiliar, finding it a more direct and responsive reporting system.The findings at Birmingham are consistent with the British AirwaysAudit Team sampling of QMP awareness in 1988 and a further QMPsurvey in 1989 which identified that a lack of comprehension stillexisted. At the time of the accident action to remedy this wasstill under discussion within British Airways.

The E1022 system was well established and understood when QMPwas introduced three years before the accident. The statementsof the Birmingham Maintenance Managers indicate that at leastsome of them still prefer, and may use, the E1022 system in instanceswhen a QMDR might be more appropriate. The list of circumstancesunder which an El 022 is to be used appears to overlap into proceduralareas which might be thought of as the domain of the QMP system.

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

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

Inadequate access available to certain areas of the aircraftfrom 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 Assurancesystem and the relative roles of ElO22s and QMDRs be clarifiedand that they continue to educate and encourage their engineersto provide feedback from the shop floor.

At the time of the accident a physical audit of the Birminghambase was about due according to the QMP schedule. The BritishAirways Quality Audit Unit had last visited Birmingham two yearsbefore the accident over a two day period and were satisfied withthe engineering standards.

It is recommended that British Airways should review the ProductSample procedure with a view to achieving an independent assessmentof standards and conduct an in-depth audit into the work practicesat 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 BritishAirways engineering facility at Birmingham was given a half-dayvisit approximately a year before the accident. The visit, inview of the time allocated, was necessarily superficial and onlylikely to have picked up gross discrepancies.

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

2.2.5 Technical standards

Every engineer was responsible for the quality of his own workunder the British Airways QMP. Quality standards at Birminghamwere the responsibility of the local management; the Area Managerand his deputy, the Station Maintenance Manager, as part of theirroutine daily management task. Additionally the monthly ProductSamples looked at methods and standards of work. Further qualitymonitoring was conducted during audits by the British AirwaysQuality Audit Unit and supervisory visits by the CAA. Thus anyexplanation of how inadequate work standards came to be employedon the night in question would also have to explain how the variousquality and management monitors failed to detect earlier evidenceof such inadequate standards. This could have been because theShift Maintenance Manager had generally maintained high standardsand his actions on the night were not representative of his normalstandards or the monitoring procedures had failed to detect inadequatestandards employed by him for some time, or some combination ofthe 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 hadnot been any previous symptoms to alert management/quality monitors.

b. The Systems Failure Theory

The lapses were typical of standards employed by the shift MaintenanceManager, which were either known to the management/quality monitors,who condoned them, or were not known to them because they hadbeen unable to monitor the situation satisfactorily.

The track record of the One-Eleven fleet at Birmingham, in termsof the engineering criteria monitored, indicated that standardswere generally good and the Produce Samples and Continuous Monitoringreported only minor discrepancies. This impression of a satisfactoryoperation, gained from in-house sampling at Birmingham, was supportedby independent information from the physical audit carried outby British Airways Quality Audit Unit and the visit by the CAA. However, such quality lapses as those perpetrated by the ShiftMaintenance Manager would not have been apparent to other thandetailed observation until combined with such a task as the windscreenchange. (See Paragraphs 2.2.1 and 2.2.2).

Some studies on the effects of human error on industrial safetyindicate that the ratio of near misses to serious accidents couldbe as high as 600:1, therefore inadequate standards can be appliedover a considerable period of time without becoming apparent.

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

The Behavioural Psychologist described the Shift Maintenance Manageras conscientious and pragmatic rather than conscientious and meticulous. The behaviour of a man who, based on experience, changed themandatory torque setting for the bolts, visually matched the replacementbolts, and arbitrarily selected A211-9D bolts for the fairingis compatible with that description only if he believed that thesepractices were accepted at Birmingham (whether or not they werein fact accepted).

Many of the actions taken that night by the Shift MaintenanceManager may be described as evidence of a lack of sufficient carein the execution of his responsibilities. Such a catalogue ofevents does not equate to a momentary lapse in behaviour but ismore indicative of the approach of a conscientious and pragmaticengineer working in an non-procedural manner. Such a descriptionof the individual is not necessarily inconsistent with his 'exemplaryrecord', because until matched with a task such as this windscreenchange, his approach was capable of going undetected by anythingother than a close observation of his work practices.

At no time was any evidence presented to indicate that the standardsand practices used on that night were in any way different fromthose used generally by the Shift Maintenance Manager. Nor wereany external or job-related pressures identified which may havecaused a lack of concentration. Indeed, even when shown the fulllist of errors and omissions that he had made, he still offeredan explanation for each individual action.

The number of errors perpetrated on the night of this job cameabout because procedures were abused, 'short-cuts' employed andmandatory instructions ignored. Even when doubt existed aboutthe correct size of bolt to use, the authoritative documents werenot consulted. After the event the Shift Maintenance Managerconcerned demonstrated a lack of appreciation of the significanceof failure to adhere to the specified procedures, good trade practicesand even the requirements of the Maintenance Manual. This makesit most unlikely, in the view of the AAIB, that the practiceswhich permitted such errors were 'one-offs' but supports the argumentfor a longer term failure by the Shift Maintenance Manager toobserve the promulgated procedures.

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

Thus the explanation of how the catalogue of errors occurred onthe night in question lies somewhere on the continuum betweenthe stated extremes of Random and System Theories with contributionsfrom each. The system element being that which accommodated theapplication of inadequate standards by the Shift Maintenance Managerfor some time and the perceptual errors contributing the randomelement.

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 standardisationchecks, and engineers who are not subjected to any comparablestandardisation or refresher checks.

An experienced Licenced Engineer with an exemplary record demonstratedan abuse of procedures, employed short cuts, ignored mandatoryinstructions and failed to conform with what is generally regardedas 'good trade practice'. Therefore, it is recommended that theneed for periodic training and testing of maintenance engineersshould be reviewed by the CAA.

2.2.6.2 Check lists and technical documentation

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

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

2.2.6.3 Eyesight standards

The Shift Maintenance Manager required mild corrective lensesto read small print or figures and he did not use his glasseswhilst performing the windscreen replacement. The lack of correctiveglasses cannot account for the majority of the errors made thatnight, but may have subconsciously influenced the Shift MaintenanceManager in short circuiting some of the procedures which relyon adequate eyesight.

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

2.3 ATC Emergency procedures

In the circumstances it was imperative that the co-pilot was givenall the help that could be made available. In this case the BristolSector Controller neither complied with the co-pilot's specificrequest for radar navigational assistance, nor did he advise theflight of its position or give any relevant information regardingSouthampton, such as current weather, runway in use, pressuresettings, etc, as would have been expected

Given that emergencies are rare, it is inadvisable to leave tochance the possibility of a controller having experience in sucha situation. The provision of training in the handling of emergenciesand other infrequent occurrences is therefore considered to beessential. A persuasive argument in favour of emergency trainingis that adequate preparation can lessen the stress which may beinduced in the real situation. While such an argument has a gooddeal 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 hisability to handle real events. Emergency evacuation and fife drillsare conducted on this premise.

It is sometimes argued that training for emergencies is not possiblebecause all emergencies are essentially different from each other,cannot be anticipated and therefore cannot be programmed intoa course of training. The fact that emergencies will differ indetail or in the precise accumulation of events which lead totheir occurrence, does not, however, negate the value of training.All too often emergency training focuses on the use of a limitednumber of problem situations. These become familiar to traineesand are seldom updated from one training course to the next. Notonly will trainees lack the ability to cope with other events,but this method encourages a tendency to fit novel situationsinto known patterns using strategies which have worked in thepast but may not be applicable to the current problems. Duringtraining a variety of scenarios should be employed to provideboth experience in coping with a number of different situationsand the opportunity to build confidence in handling them.

Whilst no two emergencies may be identical, there are a numberof basic steps which have to be taken in dealing with them. InATC terms this would include ensuring that there are no otherconflicting aircraft, ascertaining the extent of the problem,informing the appropriate emergency services, etc. If these predictableelements of emergency handling are well trained and automaticthey release 'spare capacity' which can be devoted to coping withthe unanticipated or unique aspects of each case.

The Bristol Sector Controller quite properly intended to allowhis actions to be guided by the decisions of the co-pilot andthe Bristol CSC but he formulated no specific plan of action todeal 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 bothinitial training and as part of a systematic pattern of refreshertraining and skill maintenance may help controllers involved inincidents to realise that such events can happen and would preparethem to accept the reality of the situation and to cope with itmore effectively.

It is recommended that the Authority ensure that prior to theissue of an ATC rating a candidate shall undergo an approved coursewhich includes training in both the theoretical and practicalhandling of emergency situations. This training should then beenhanced at the validation stage and later by regular continuationand refresher exercises.

RETURN TO INDEX

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 1950M, the left windscreen was bl 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 dec
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 in
descent.

(vi) The remaining crew and passengers suffered no ill effects from the rapid decompression and lack of oxygen.
calculated that the cabin altitude was unlikely to have been greater than 13,000 to 13,500 feet, achieved withi
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
appropriate British Airways authorisation 27 hours before the accident flight and the aircraft had not flown si
replacement.

(viii) The replacement windscreen had been installed with 84 bolts (A21 l-8C) whose diameters were approximatel
an inch below the diameters of the specified bolts (A21 1-8D), and 6 bolts (A21 1-7D) which were of the cor
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 per
errors, each one of which eroded the factors of safety built into the method of operation promulgated by Briti

(x) A series of cues were available to the Shift Maintenance Manager to draw attention to the use of incorrect bol
went unnoticed or unheeded.

(xi) Although an independent final inspection would have had a high probability of detecting the error, the task of
windscreen installation was not designated a 'Vital Point' and consequently no duplicate inspection was called
none took place.

(xii) The work of the Shift Maintenance Manager was not subject to review by another manager and thus the there
backstop with any chance of detecting his errors. Errors that were made more likely by the sleep deprivation a
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
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
inadequate standards by the Shift Maintenance Manager, because they did not monitor directly the working p
Shift Maintenance Managers.

(xv) The windscreen replacement task may have been unique in that it alone could accommodate the errors associ its fitment, such that they were exposed so dramatically the first time that the windscreen was called upon to pressure.

(xvi) The CAA supervisory visit was superficial and as such did not monitor the working practices of Shift Mainte Managers.

(xvii) The British Airways local Product Samples at Birmingham did not provide an independent assessment of sta 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 nu Maintenance Managers indicated that they felt more comfortable with the E1022, Ground Occurrence Report 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 whilst performing the windscreen replacement.

(xx) Following receipt of the co-pilot's distress message, and when two way communication had been re-establish 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 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 p carrying flight.

(ii) The Shift Maintenance Manager's potential to achieve quality in the windscreen fitting process was eroded by inadequate care, poor trade practices, failure to adhere to company standards and use of unsuitable equipmen 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 c inadequate standards employed by the Shift Maintenance Manager because they did not monitor directly the w 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 follo 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 making the definition of 'Vital Points' non-mandatory for aircraft with a Maximum Take-Off Weight Authorise 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 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 Shift Maintenance Manager and above.

4.4 It is recommended that British Airways should review the Product Sample procedure with a view to achieving 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 unde aircraft engineering tasks.

4.8 The CAA should ensure that, prior to the issue of an ATC rating, a candidate shall undergo an approved cours includes training in both the theoretical and practical handling of emergency situations. This training should th enhanced at the validation stage and later by regular continuation and refresher exercises.

D F KING

Inspector of Air Accidents

Air Accidents Investigation Branch

Department of Transport

January 1992

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