FINAL REPORT

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Operator:	Air Zimbabwe
Manufacturer:	Boeing
Model:	707-330B
Nationality:	Zimbabwe
Registration:	Z-WKU
Location:	Shannon Airport, Ireland
Date/Time (UTC):	10 March 1997, 23.15 hrs

SYNOPSIS

Shannon Air Traffic Control (ATC) notified the Air Accident Investigation Unit (AAIU) and an investigation team arrived in Shannon at 11.00 hrs on 11 March 1997. The Director of Civil Aviation (DCA) Zimbabwe, National Transportation Safety Board (NTSB), USA and International Civil Aviation Organization (ICAO) Montreal, were notified on 13 March 1997. The AAIU team consisted of Mr Graham Liddy, Inspector-in-Charge, and Mr Frank Russell.

The aircraft had completed a refuelling stop at Shannon Airport and took off bound for Harare, Zimbabwe. Immediately after take-off fire was detected in the No. 3 engine. The fire was successfully extinguished and a number of other technical problems arose, necessitating two over-shoots. The aircraft finally landed safely at Shannon. No. 3 engine had suffered considerable fire damage. The investigation found that this engine had suffered a similar fire 11 days before this event. The fire originated in a poor welding repair of the engine diffuser casing. This repair was completed some considerable time prior to the fire.

1. FACTUAL INFORMATION

1.1 History of the Flight

1.1.1 Background

The aircraft was engaged on a tour of European States carrying the President of Zimbabwe and his staff. It had departed Zimbabwe on 2 March 1997 and arrived in Dublin, Ireland on 7 March 1997. It departed from Dublin at 21.15 hrs on 10 March 1997 and arrived at Shannon to refuel, prior to departure direct to Harare, Zimbabwe. At Shannon Airport the aircraft filled to maximum fuel load of 71 tonnes and was 150 tonnes gross weight, i.e. 450 kg below maximum take-off weight, when departing. The passengers stayed on board during the refuelling at Shannon Airport.

1.1.2 Incident Flight

The aircraft took off from Runway (RWY) 24 at Shannon Airport at 22.48 hrs. Because of the high weight the Captain used maximum Engine Pressure Ratio (EPR) settings for this take-off, (normal EPR settings were sufficient for the Dublin take-off). Immediately after take-off, at approximately 500 ft, the Captain was alerted to a fire in the No. 3 engine by audio and visual alarms. He continued to 1,000 ft, in order to gain safe altitude, whereupon he closed down No. 3 engine and initiated fire-extinguishing drill. He discharged one fire-extinguishing bottle into the engine, waited 30 seconds and then discharged the second bottle. He was informed by personnel in the cabin that flames had been seen under No. 3 engine, but that they had then disappeared. The fire warning light remained illuminated, but the Captain was aware that fire damage to the detection harness could cause the warning light to remain on. He then commenced a circuit and proceeded to dump fuel as the aircraft had taken off at almost maximum gross weight and full fuel. While there were no visual indicators of continued fire in No. 3 engine, the fire warning light was still on, and he decided to dump fuel only from the opposite, left, side of the aircraft. He lowered the left fuel dump chute and proceeded to dump fuel.

During this time the Captain assessed his landing options. The weather at Shannon Airport was deteriorating and there was a strong possibility that the airport would close shortly. Because of this, he did not have the option of loitering in the Shannon area to burn off fuel. Furthermore, because the B707 has only tank-to-engine cross-transfer (i.e. it is not possible to transfer fuel from right wing fuel tanks to left wing fuel tanks), it was not possible to dump right wing fuel from the left wing dump chute. The Captain was concerned that if he dumped 30 tons of fuel from the left dump chute to bring the aircraft weight below the maximum landing weight, the aircraft would then be suffering a lateral imbalance of nearly 30 tons, with the added complication that only one engine was operative on the heavy (right) side.

The Captain therefore decided to terminate the dumping after disposing of 10 tons of fuel and to land immediately thereafter at Shannon Airport. As he lined up for landing, at about 2,700 ft, he attempted to raise the left dump chute, which failed to retract. The Captain desired to raise the dump chute because deployment of the dump chute in the extended position would interfere with the selection of full flap. As the aircraft was still 30 tonnes above maximum landing weight of 112 tonnes, the Captain considered that he required full landing flap for landing in this condition. Because selection of full flap would result in damage to the extended dump chute, he elected to perform an overshoot in order to sort out the dump chute problem. After the over-shoot, a further attempt was made to retract the dump chute, and this was successful. During this phase of the flight, a fault also developed in the aircraft's Instrument Landing System (ILS) display.

The Captain then commenced a second approach. When he selected undercarriage down, the green lights that indicate that the main wheels were lowered and locked down illuminated, but the green indicator for the nose wheel did not illuminate. He again elected to overshoot. Minimum altitude on this approach was 1,700 ft. He selected undercarriage up. The main undercarriage retracted but the nose did not. Noise under the cockpit indicated that the nose undercarriage doors were still open.

The Captain then received ATC clearance to a holding area West of Shannon to consider the situation. He considered diverting to Gatwick, where Air Zimbabwe has a maintenance base, but Gatwick was subject to deteriorating weather and other airports such as Heathrow, Dublin and Cork were already closed due to poor visibility. Furthermore, there was continued concern regarding a possible deterioration of the weather at Shannon. When the aircraft was in the holding area, the undercarriage selection lever was moved, as normal, to the OFF position, having been previously on the UP position when the overshoot was initiated. The co-pilot then noticed that the nose green light had illuminated, indication that the nose wheel was now in the DOWN position. The flight engineer performed a visual inspection and confirmed that the nose undercarriage was down but not locked. When the undercarriage DOWN was then selected, the main wheel green lights also illuminated, and a visual inspection by the flight engineer confirmed that the nose undercarriage was now down and locked. The Captain then decided to return to Shannon. He set up a long 25-mile approach, and touched down smoothly, without any further problem. The Captain turned off the runway, and stopped while the attendant crash rescue service inspected the No. 3 engine for fire. Upon receiving a "no fire" report from the on-scene crash crews, the Captain decided against emergency evacuation of the aircraft. The aircraft then taxied to the terminal and the passengers disembarked normally.

1.2 Injuries To Persons

There were no injuries among the 12 crew and 41 passengers on board the aircraft. No injuries were reported to the investigation.

Injuries	**Crew**	**Passengers**	**Others**
Fatal	0	0	0
Serious	0	0	0
Minor	0	0	0
None	12	41	

1.3 Damage To Aircraft

The lower section of the left and right main engine cowling of the No. 3 engine was burnt through in the area of the blow-out vent door, which is underneath the engine main drain cluster. The ends of an aluminium alloy drainpipe had melted, and the fire detection harness in this area was broken, having burnt through and melted.

The nose undercarriage strut was found to have deflated.

1.4 Other Damage

No other damage was reported to the investigation.

1.5 Personnel Information:

1.5.1 Captain

Personal Details	Male Age 42
Licence	ALTP
Instrument Rating	Renewed 11/12/1996
Medical Certificate	Renewed 17/2/1997

Flying Experience:

Total all types PI	9,500	hours
Total on type P1	7,500	hours
Last 90 days	40	hours
Last 28 days	18	hours
Last 24 hours	2	hours

Duty Time:

Duty Time up to incident	6.30 hours
Rest period prior to duty	70 hours

1.5.2 First Officer

Personal Details	Male
Licence	ALTP
Instrument Rating	Renewed 19/5/96

Flying Experience:

Total all types PI	1,500	hours
Total on type	200	hours
Total on type PI	0	hours
Last 90 days	50	hours
Last 28 days	20	hours
Last 24 hours	2	hours

Duty Time:

Duty Time up to incident	6.30 hours
Rest period prior to duty	70 hours

1.6 Aircraft Information

1.6.1 Leading Particulars

Aircraft type	B707-330B
Manufacturer	Boeing
Constructor's number	18930

Year of manufacture	1966
Certificate of registration	Z-WKU issued 8 March 1982
Certificate of airworthiness	Issued by the CAA of Zimbabwe, on 12 April 1996, valid to 14 April 1997
Total airframe hours	85,631 hours
Total cycles	26,912 cycles
Engines	Pratt and Whitney JT3D-7 (four)
Aircraft weight at take-off	150,000 kg
Fuel load at take-off	71,000 kg
Maximum permissible landing weight	112,040 kg

1.6.2 General Information

1.6.2.1 The aircraft was purchased by Air Zimbabwe in 1982.

1.6.2.2 The engines fitted to the aircraft at the time of the event were four Pratt and Whitney JT3D-7.

1.6.2.3 The aircraft was originally manufactured with Pratt and Whitney JT3D-3B engines. The 3B engine was the only version authorised by Boeing for fitting to this version of the B707. However, the previous operators of the aircraft, Lufthansa, in conjunction with Boeing and the Bundesluftfahrtamt (the German Aviation Authority) completed all the requirements for the issue of a Supplementary Type Certificate for the engines to be upgraded from –3B to –7.

1.6.3 Maintenance Information

1.6.3.1 The last inspection undergone by the aircraft was a “C” check on 7 January 1997.

1.6.3.2 No 3 engine, serial number 654097, was installed on the aircraft at 84,036 airframe hours and 25,692 airframe cycles. This engine had a total of 56,406 hours and 18,393 cycles at the time of the event. It was due off at 85,735 airframe hours or 27,176 cycles. It had 94 hours service remaining to its next scheduled removal. The engine was fitted with a Diffuser Case part number 503995.

1.6.4 Engine Fuel System

1.6.4.1 Fuel is delivered to the Pressurisation & Dump (P&D) valve by engine driven pumps. The P&D valve is located directly below the engine diffuser casing, under the diffuser section of the engine. The current function of the P&D valve is only to regulate the flow of primary and secondary fuel to the engine: the dump function is no longer used. There are two fuel paths from the P&D valve that supply fuel to the internal fuel manifolds, which in turn dispenses fuel into the combustion cans.

The manifolds consist of 2 semi-circular rings, with nozzles located on various points, from which fuel is sprayed into the combustion cans. Each manifold has four nozzle clusters, each cluster comprising of six nozzles. Each nozzle has two jets; the inner being the primary fuel jet while the outer co-axial jet is for the secondary fuel. The primary fuel path supplies fuel continuously, whereas the secondary fuel path only supplies fuel when the fuel flow rate reaches 2,000 lbs per hour. This equates to an engine speed of about 75% (7,300 RPM) N2 or higher, which is approximately off-idle power or higher. The general layout of these components is shown in **Appendix A**

1.6.4.2 The attachment of the P&D Valve Assembly is shown in **Appendix B**. The fuel manifold comprises of a right hand section and a left hand section, and is clamped to a flat bearing surface, known as the mounting-boss, on the inside of the diffuser casing. Three 12-point bolts secure each section. A copper gasket seals this joint. A spacer assembly is fitted through a hole in the diffuser casing, located directly underneath the manifold assembly. The spacer assembly is secured to the manifold assembly by means of four socket head cap screw bolts. There are four fuel paths through the spacer assembly, into the manifolds. The front two paths supply primary fuel to the left and right fuel manifolds respectively, and the rear two paths supply secondary fuel, again one to each of the left and the right fuel manifolds. Each of these four fuel paths is sealed by a metal seal at the spacer/manifold interface. The P&D valve is then bolted, underneath, to the spacer assembly.

1.6.5 Hydraulic System

The aircraft is equipped with two engine driven hydraulic pumps, one fitted to each of the inboard engines, i.e. engines No 2 and 3. Two auxiliary electrically-powered hydraulic pumps are also fitted to this aircraft. The hydraulic system powers several systems on the aircraft, including the undercarriage lowering and retraction system, and the flaps actuators.

1.6.6 Aircraft Fuel System

The aircraft carries fuel in three tank groups. The left wing group consists of 3 tanks (Main No. 1, Main No. 2 and Reserve No. 1) holding a total of 20,797 kg of fuel. The right wing group consists of 3 tanks (Main No. 3, Main No. 4 and Reserve No. 2), and also holds a total of 20,797 kg of fuel. Thus the wing tanks hold a total of 41,594 kg of fuel. The seven-cell centre tank group has a capacity of 31,062 kg. Given that the total fuel load on take-off for this flight was 71,000kg, (71 tonnes), there was 29,406 kg of fuel in the centre tank.

1.6.7 Fuel Jettison System

The aircraft is equipped with two fuel jettison chutes, one on each wing. These chutes must be lowered behind the trailing edge of the wing before fuel can be jettisoned. The chutes can be deployed independently on each side. Each chute can only dump fuel from the fuel tanks on its side of the aircraft and/or from the centre tank. With both dump chutes deployed and feeding the chutes from all three fuel tanks, a dump rate of approximately 99,000 kg per hour is achieved when the tanks are full.

While it is possible to cross feed the engines, i.e. the left hand engines can be supplied with fuel from the right wing fuel tanks, it is not possible to transfer fuel from the right tanks to the left tanks, or in the opposite direction. When the jettison chutes are in the deployed position, they interfere with the flaps in the extended position. The Aircraft Flight Manual (AFM) contains a caution that the jettison chutes should not be deployed with flaps angles greater than 25º, and zero flaps is the recommended setting for fuel dumping. The AFM further states that the chutes, in an emergency, can be deployed with full flap, but that damage to the chutes will occur and that they must be replaced before the next flight. Furthermore, 240 kts is the maximum airspeed for extending and retracting the dump chutes while 275 kts is the maximum speed for dumping operations with the chutes extended and zero flaps selected.

1.6.8 Engine Fire Warming system

The engine is surrounded, inside the cowling, with a fire detection harness. As a result of an engine fire, the harness will conduct a current, thereby illuminating the fire warning light in the cockpit. If the harness is burnt through and broken as result of the fire, the current will no longer flow and the light will extinguish. However, if the harness is damaged by the fire so as to cause a short circuit, the light will remain on, even if the fire is extinguished.

1.7 Meteorological Information

1.7.1 Met Éireann, the Irish Meteorological Service, provided the following information after the incident.

At 2300 hours on 10 March 1997 the weather at Shannon Airport was: -

Surface Wind	110ºTrue/6 KT
Visibility	3,000 metres
Cloud	Few at 200 ft
	Broken at 1,100 ft
Temperature	7ºC
Dew Point	6ºC
Weather	Mist

At 00:00 hours at 11 March 1997 the Shannon Weather was: -

Surface Wind	140ºTrue/10 KT
Visibility	3,000 metres
Cloud	Scattered at 400 ft
	Overcast at 600 ft
Temperature	7ºC
Dew Point	6ºC
Weather	Mist

At 00:00 hours on 11 March 1997, Cork, Dublin and Heathrow airports were closed due to fog.

1.8 Aids to Navigation

Aids to navigation were not a factor.

1.9 Communications

Communications were not a factor.

1.10 Aerodrome Information

Shannon Airport is situated on the north shore of a large tidal estuary, and is just above sea level. The main runway is 23/05, which is 10,000 ft long. It is a fully equipped International Airport.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The aircraft was equipped with a Fairchild A 100 CVR, with modification state 30 and serial number 4904.

This unit recorded only the last half hour of cockpit audio. The CVR was not switched off until the aircraft had returned to the terminal, at approximately 00:28 hours. Thus the CVR contained flight information limited to the last 5 minutes of the actual flight. It contained no information pertinent to the investigation.

1.11.2 Flight Data Recorder

The aircraft was equipped with a Sundstrand FDR, Model FA 542 Part Number 101035-1, Serial Number 3908, modification state 18. There were approximately 150 hours remaining in the FDR at the time of the incident.

This FDR was a very old foil type recorder, and recorded only four parameters: - airspeed, altitude, heading and normal acceleration ("G"). It contained no engine information. The recorder was sent to the Air Accident Investigation Branch, at Farnborough, UK for analysis. No information useful to this investigation was obtained from the FDR.

1.12 Wreckage and Impact Information

A hole approximately 250 cm wide and 1 metre long had been burnt through the left cowling of the No. 3 engine immediately aft of the small blow out door vent. There was some minor heat damage to the right cowl. The lower fire detection harness was burnt away in the area of the firewall to the rear of the hydraulic pump. The end of an aluminium drainpipe had melted at the drain cluster, and the drain cluster support had heat damage. There was some surface heat damage to hydraulic lines leading to the hydraulic pump. Inspection of the cowlings showed that a significant repair had been recently completed in the area damaged by the fire. The nose undercarriage strut was found to have lost pressure, such that the strut was resting on the stop.

1.13 Medical Information

There were no medical or pathological aspects to the incident.

1.14 Fire

The only fire in this incident was that which occurred in No. 3 engine.

1.15 Survival Aspects

Not applicable to this incident

1.16 Tests and Research

1.16.1 The damaged engine was removed from the aircraft and shipped to Zimbabwe for further testing, following discussions between the operator, the AAIU and the CAA of Zimbabwe.

1.16.2 Preliminary visual inspection revealed no damage to the engine other than that noted above in Para 1.12. No obvious source of the fire was determined. It was mounted in a test cell for further testing.

1.16.3 The test-runs of the engine were conducted in the Air Zimbabwe facility in Harare under the supervision of an AAIU inspector and staff for the CAA of Zimbabwe. In the test cell, when the engine was run at idle power, a slight fuel leak was noted from the P&D valve. However, the rate of fuel leakage was totally insufficient to explain the in-flight fire. The engine power was then increased, and at approximately 75% N" speed, a cloud of fuel vapour was seen to be emitted, at high pressure, from the area immediately above the P&D valve. The engine was then returned to idle. The fuel vapour emission stopped. The engine casing above the P&D valve was closely examined. A small bolt head was found to be hanging on a piece of locking wire, and a blast of high-pressure air could be detected in the area of the engine diffuser casing, directly above the P&D valve.

1.16.4 The engine was again powered up, and identical results were obtained. The engine was then removed from the test cell and stripped down. It was determined that the failed bolt was one of the six 12 point bolts that secure the internal fuel manifolds to the boss of the engine diffuser casing. The copper gasket at this interface was found to have failed at the hole relating to the failed bolt. It was also noted that there was an area of soot accumulation at the interfaced between the fuel manifold and the P&D valve mounting-boss, between the secondary fuel line orifice and the failed bolt.

1.16.5 The fuel manifold was found to have suffered erosion type damage in the area surrounding the bolt-hole, which corresponded to the failed bolt. The hole in the diffuser casing, through which this bolt passed, had eroded in an elliptical pattern. The major and minor diameters of the worn hole were 3/8" by 5/8". The correct size of the hole should be nominal 5/16". Both the failed bolt head and the portion of the bolt threads that remained in the fuel manifold showed evidence of severe erosion. The condition of the failed bolt is shown in **Appendix F, Photo 1**. Measurements of the bearing face on the P&D valve mounting-boss on the inside of the diffuser casing, to which the fuel manifold was bolted, showed that the bearing face was not flat but distorted to the extent that the bearing area surrounding the failed bolt was, in places, up to .008", below the general level of the bearing face.

1.16.6 It was observed that a welding repair had been performed on the engine casing close to the area of the failed bolt. The repair consisted of the replacement/repair of two webs, which support the diffuser casing immediately to the rear of the fuel manifold boss. The repair weld showed evidence of abnormally high heating and failure to continuously fill the weld line, particularly close to the failed bolt. Inspection of the engines records failed to determine where and when this repair was performed. The repair of these webs is an approved P&W repair scheme.

1.16.7 The size of the air leak hole at the time of failure was measured at approximately 0.05 square inches cross sectional area. In consultation with the engine manufacturer, it was determined that a hole of this size would have had negligible effect on engine performance.

1.16.8 During the tear-down of the engine, it was noted that there were some indications of localised heating and burning on the heat shield of the fuel manifold near the base.

1.16.9 During subsequent investigation of the aircraft at Shannon, stiffness was detected in the nose undercarriage actuation linkage. This stiffness was associated with a lack of lubrication. The lubrication deficiency was then rectified and undercarriage retraction tests were performed using a hydraulic test rig. The results of the retraction tests were satisfactory.

1.16.10 During subsequent maintenance at Shannon the nose strut was re-pressurised and maintained pressure satisfactorily thereafter. The nose undercarriage was cycled, and found to function correctly. No fault was found in it. The pylon area of No. 3 engine position was inspected for fuel leaks. None were found.

1.16.11 Subsequently the aircraft was fitted with a replacement engine in the number 3 position and was ferried to Harare. During this and subsequent flights no problems were experienced with the nose undercarriage retraction or the nose strut pressurisation.

1.17 Organizational and Management Information

During the investigation, several Air Zimbabwe personnel drew attention to the special cabin configuration of this particular aircraft. Because of this layout it was perceived as the favourite aircraft for VIP transport. There appeared to be a strong commitment within the organisation to ensuring that this aircraft would be available when required for VIP operations.

1.18 Additional Information

1.18.1 Inspection of the technical log of the aircraft showed that the No. 3 engine had suffered a similar fire after take-off from Capetown, South Africa, on 27 February 1997, 11 days prior to the subject event in this investigation. The cowlings were extensively damaged in that fire. Subsequently a fuel drip leak, at the rate of approximately 20 drips per minute was found to be emanating from the gasket of the dump valve of the P & D valve. This gasket was replaced, and the cowlings were repaired.

1.18.2 During a ground run on 1 March 1997, following these repairs, fuel was found to be leaking from the area of the P&D valve. Some fuel fittings were found to be in need of tightening. This was done and following further ground runs, during which no leaks were found, the aircraft was returned to service on 2 March 1997, just in time for the VIP visit to Europe.

1.18.3 The last repair and inspection of the diffuser casing was on 25 September 1995, in the Air Zimbabwe facility at Harare. The log card is not specific on the areas of the casing that were repaired, but the repairs did involve welding and a subsequent pressure leak test, which it passed. The fuel manifold and nozzles were also checked for spray pattern and leaks at this time.

1.18.4 In the P&W JT3, the air in the diffuser casing at take-off power has a static pressure of approximately 190 Pounds per Square Inch (PSI) and a total pressure of approximately 200 PSI.

1.18.5 Pratt & Whitney have produced two service bulletins covering the repair of the diffuser casing by means of adding braces to support the boss, as was done on this casing. These are Pratt & Whitney SB 832 and SB 525. SB 525 requires dimensional checks to be performed on the boss, when the addition of the supports is accomplished subsequent to manufacture of the casing.

1.18.6 The Boeing manual for this aircraft forbids running the engine on the wing (as opposed to in a test cell) at high power settings when the engine cowlings are removed. This prohibition is partially due to the problems associated with the by-pass air from the engine fan disc.

1.19 Useful or effective investigation techniques

Nil

2. ANALYSIS

2.1 The Fire

2.1.1 The extent of the repairs undertaken following the Capetown fire and the area damaged in the Shannon fire indicated a high degree of similarity in terms of the location of both fires and the damage caused. It was also noted that both fires occurred in an almost identical configuration, i.e. at high take-off power and immediately after take-off.

2.1.2 The boss on the diffuser casing, onto which the P&D valve is mounted, had been repaired by the welding of the supports to the side of the boss. Even after an extended period of use, the poor quality of this weld was evident.

2.1.3 The mounting face for the P&D valve assembly, on the boss of the diffused casing had been distorted as a result of the welding repair.

2.1.4 The distortion of the mounting face for the P&D valve allowed P4 air, at a pressure of up to 175 PSI above ambient atmospheric pressure, to leak past the copper gasket, into the bolt hole in the diffuser casing and to escape under the bolt head. Furthermore, the distorted mounting face and the distortion of the boss would have exacerbated the possibility of a leak under the bolt head. Initially this leak would have been extremely small. The initial path of this leak is shown in **Appendix C.**

2.1.5 Over an extended period of operation this air leak, mixed with fuel, gradually eroded portions of the bolt, the bolt hole in the diffuser casing and the fuel manifold, producing a larger hole, and thereby increasing the rate of erosion. This situation is shown in **Appendix D**. The extent of the bolt erosion is shown in **Appendix F, Photo 1**.

2.1.6 Ultimately the cross-sectional area of the bolt was reduced by P4 air/fuel erosion to such an extent that it failed in tension. This allowed the corner of the base of the fuel manifold to distort away from the P&D valve spacer assembly. This distortion would have been exacerbated by thermal stresses but also by the pressure of the secondary fuel; that is when the secondary fuel supply was activated, the fuel pressure assisted in opening up a gap between the fuel manifold face and the spacer, through which secondary fuel was able to escape. The burning on the surface of the manifold heat shield would have increased the normal thermal stresses on the manifold area. This burning was probably caused by a faulty fuel nozzle allowing fuel to drip onto the manifold which would have ignited and burned on the hot surface of the shield. The path of the fuel leak is shown in **Appendix E**.

2.1.7 The test cell trial runs showed that no fuel was visible in the jet of escaping air until the engine power was increase to 75%, which is the power setting at which fuel is supplied through the secondary fuel path. This indicated that the source of the fuel leak was in the secondary fuel system.

2.1.8 The location of the fuel leak, and marking indications on the interface of the spacer assembly and the left fuel manifold, indicated that the metal seal at this interface was the source of the leak. The escaping fuel travelled along this interface and merged with the escaping P4 air, in the eroded bolt-hole, and emerged through the bolt-hole as a vapour cloud, comprising of fuel and high-energy air at a temperature of approximately 390°C.

2.1.9 This vapour cloud then ignited and burned its way through the bottom of the engine cowling. There were several possible ignition sources. It is possible that the vapour ignited when it came in contact with the outer casing of the combustion section of the engine. However it is most probable that the vapour escaped through the joints in the lower engine cowling, or through the blow–out door, and was ignited by the exhaust gases at the rear of the engine. The observations of the fire from the main cabin would support this probability. Thus it is probable that the fire had started externally, entered the cowling through the open blow-out door or cowling joints. At this point, the fire warning harness, within the cowlings, underneath the engine, detected the fire. By the time the fire was extinguished, the fire warning harness was burnt through, creating a short circuit. In this condition, the harness would have continue to illuminate the fire warning lights, even though the fire was extinguished.

2.1.10 In any event, the vapour would have ignited easily, because of the high temperature of the P4 air, at approximately 390ºc, which would have raised the temperature of the fuel to approximately the same temperature, thereby providing a highly volatile mixture.

2.1.11 The internal fire was concentrated in the area between the P&D valve and the lower cowling. The heat melted a hole through the cowling, and the fire continued to burn through this hole.

2.1.12 The fire was extinguished by the action of the pilot, when he closed down the engine, thereby cutting off the fuel supply to the fire, and this action also eliminated the blast of hot P4 air. The use of the engine fire extinguishers put out any secondary fire.

2.1.13 The records of the diffuser casing do not show when the welding repair to the boss support was done. However, during the course of the pressuring and leak testing of the case following the repairs in September 1995, it would have been necessary to remove the P&D valve support. If the air leak had been present at that time, it is probable that erosion of the bolt and the bolt-hole would have been found. This would indicate that the welding repair to the supports did not pre-date September 1995. The repair area is shown in **Appendix F, Photo 2**.

2.1.14 Due to the perception of Air Zimbabwe personnel that this particular aircraft was favoured for VIP transport, because of its cabin layout, there was probably pressure within the organisation to make this aircraft available for the Presidential visit to Europe. Given that the original fire occurred only three days before the start of this trip, there would have been considerable pressure to ensure that the aircraft was speedily repaired. This pressure would produce a situation whereby the problem initially located, i.e. the leak from the P&D valve seal, was accepted as the sole source of the problem, and that a deeper cause of the leak was not sought.

2.1.15 When a further leak from the P&D valve was subsequently found on 1 March, the day immediately before the scheduled departure on the European visit, a loose union was accepted as the source of the problem. Again the pressures of the upcoming trip would have militated against seeking the existence of a possible deeper cause.

2.1.16 The most critical situation following final failure of the bolt and resultant significant fuel leak and fire would have been during take-off, at very high power settings (highest fuel flow, P4 and T4), relatively low airspeed and higher ambient temperatures than at altitude. During climb, cruise and maximum reverse there would also be significant leakage following bolt failure, as they are set well above the off-idle and 75% N2 criteria necessary for the secondary nozzles to flow. However, it is probable that in climb or cruise, the combination of dilution of the fuel vapour as a result of the higher airspeed and the lower ambient air temperature would militate against ignition of the fuel vapour. Therefore, in the previous flights of the aircraft, if take-off was achieved without ignition of the fuel vapour, it was unlikely that a fire would occur at any other phase of flight.

2.1.17 During previous take-offs, such as that out of Dublin, lower take-off power settings were used, because of the lower gross weight of the aircraft when departing Dublin. Such lower take-off power settings would still be far above the 75% N2 speed, off-idle condition where the secondary nozzles begin to flow, but the flow rate through the leak would have been smaller, with higher air dilution ratios and reduced risk of ignition and fire.

2.1.18 The leak from the P&D valve observed during ground runs subsequent to the original fire was from a rubber seal in the P&D valve. This seal probably suffered heat damage in the original fire, causing it to leak. The operator's personnel found this leak when the engine was run at idling speeds with the cowling removed. This lured them into believing that this was the fuel leak that caused the original fire.

2.1.19 The prohibition in the Boeing manual in regard to running the engine on the wing at power settings above idle when the engine cowlings are removed, made it difficult to find the source of any fuel or air leaks during ground test of this engine following the original fire. In particular the detection of the source of a fuel leak that only occurred above idle, such as in this case, would have been very difficult. There is a known method for overcoming the problems associated with the by-pass air, but because this is not a procedure approved by Boeing, it is not used by Air Zimbabwe personnel.

2.2 Operational Aspects

2.2.1 The pilot was faced with a difficult dilemma immediately after the fire. No. 3 engine was closed down, but the fire warning light remained illuminated. It was therefore impossible to be sure that the fire was extinguished. There was a distinct possibility that Shannon Airport could be closed, due to deteriorating visibility, at any moment, and that widespread fog across Europe had closed, or would close, all alternative airports within a reasonable distance. Any delay could have resulted in a situation where no airport would be available for landing. This precluded the burn-off of fuel, to reduce the gross weight of the aircraft down to the maximum permitted landing weight, prior to landing.

2.2.2 The fire in No.3 engine had probably caused a short circuit to earth in the fire detection harness. This would result in the fire warning light remaining on, even if the fire was out. The Captain reported that this light had remained on. Thus he was unable to positively ascertain that the fire was totally extinguished. Re-ignition of the fire was a possibility. Furthermore if the fire re-ignited, he now had no warning system to detect a new fire from the cockpit. This precluded the use of the RH dump chute, i.e. close to a possible fire in No. 3 engine. Consequently fuel could be dumped safely only from the left side. Significant asymmetrical fuel dumping would compromise the lateral balance of the aircraft. Furthermore, the resultant heavy wing would be on the side of the closed-down No. 3 engine, thereby compounding control problems.

2.2.3 Given the fact that only the left dump chute could be used and that it could only be fed from two tank groups, the left wing and the centre line, it would have taken approximately one hour to reduce the aircraft gross weight to the maximum permissible landing weight.

2.2.4 For the foregoing reasons, the Captain had little option but to land the aircraft as soon as possible, notwithstanding that it was 30 tonnes above the maximum landing weight.

2.2.5 The size of the air leak was such as to have no discernable effect on engine performance. Therefore the cockpit crew could not detect the presence of the leak prior to the fire.

2.2.6 The unrelated failure of the ILS display would have heightened the Captain's concerns relating to the weather situation.

2.3 Crew Performance

2.3.1 In the events that unfolded, the seemingly unrelated but very real problems of:

- engine fire on take-off at Maximum Take-Off Weight (MTOW),
- restricted fuel dumping options,
- fuel dump chute retraction failure,
- undercarriage mal-function,
- ILS indicator mal-function,
- possibility that Shannon would imminently close due to weather,
- actual closure of alternative aerodromes due to weather,

the cockpit crew dealt with these diverse emergencies in a professional and effective manner and carried out a safe landing in difficult circumstances.

2.4 Other aircraft problems

2.4.1 The failure of the fuel jettison chutes to retract is not an unknown occurrence on the B707. In particular, this phenomenon is associated with higher airspeeds. The flight manual gives a maximum airspeed of 240 kts for retraction of the dump chutes. Because of its high weight, Z-WKU may have been close to, or even above, the speed limits for dump chute retraction when this problem was experienced.

2.4.2 When the Captain closed down No. 3 engine due to the fire, the available engine-driven hydraulic pumps were reduced to one, as only No. 2 and No. 3 engines on this aircraft are equipped with hydraulic pumps. It also appears probable that undercarriage down selection was made during flap deployment, before the flaps had reached the full down position. The reduction of hydraulic pump output, as a consequence of closing down No. 3 engine, may have produced a transient loss of hydraulic pressure resulting from a heavy demand during simultaneous lowering of the flaps and undercarriage. The situation was exacerbated by the stiffness of the nose undercarriage, which would have required higher than normal pressure to lower the nose wheel. This stiffness was caused by deficient lubrication of the nose undercarriage actuator linkage. The probable result of this stiffness was that the sequencing of the nose undercarriage was disrupted, resulting in the failure of this leg to lower correctly. When the undercarriage lever was moved to "OFF", i.e. hydraulic power was removed from the circuit, the leg gradually lowered itself under gravity, but could not lock down. When the lever was subsequently moved to "DOWN", the single operating pump was able to lock down the nose wheel, as the hydraulic system was not operating under heavy load at this time.

2.4.3 The collapse of the nose wheel shock absorber during the landing was probably due to the overload on the nose leg resulting from the landing and braking loads associated with an aircraft landing approximately 30 tonnes above maximum gross landing weight.

2.5 Other Aspects

2.5.1 The absence of CVR information relating to the actual fire incident, due to run-out of the half hour time limit could have hampered this investigation, particularly if the event had resulted in more serious consequences. By their nature, incidents frequently occur long before the aircraft is closed down and the CVR stopped and the over-writing process ceases. Consequently the ½ hour CVR recording limit causes data that could be essential to the investigation to be over-written, as occurred in this incident.

2.5.2 The FDR fitted to this aircraft did not provide any data that was of assistance to the investigation. This was due to the very limited number of recorded parameters on this old type of recorder.

3. CONCLUSIONS

3.1 Findings

3.1.1 The aircraft and crew were properly certificated for the flight.

3.1.2 The diffuser casing had undergone a welding repair in the area of the supports to the flanges of the P&D Valve Support Boss. This repair was poorly executed and caused distortion of the boss.

3.1.3 The defective repair was probably performed in the operator’s maintenance facility in September 1995

3.1.4 There was considerable pressure within the operator’s organisation to ensure that this aircraft was available for the VIP visit to Europe. This pressure militated against finding the real source of the original fire and the subsequent leak in the days immediately before this visit.

3.1.5 Given the restraints on fuel dumping rates and the deteriorating weather situation, the Captain’s decision to land, above the maximum permissible landing weight, was correct.

3.1.6 The crew were faced by a variety of diverse problems during this incident, which were handled in a most professional and competent manner.

3.2 **Causes**

3.2.1 The cause of the fire was a poorly executed welding repair of the diffuser casing in the area of the supports to the P&D Valve mounting-boss, which caused the distorting of the boss.

3.2.2 This distortion of the boss led to an air/fuel leak, which over a long period of time caused the erosion and failure of the bolt. Then when the escaping air/fuel mixture vapour reached a critical fuel/air ratio with the vented air-flow around the diffuser casing, the mixture ignited and caused the fire.

3.2.3 The inspection of the engine, following the previous events in relation to this engine, failed to detect the true nature of the fault in the engine.

4. SAFETY RECOMMENDATIONS

4.1 The operator should review the training of their line maintenance personnel with a view to improving diagnostic skills. **(SR 9 of 2002)**

4.2 The operator should review their operational procedures to ensure that operational pressures do not adversely affect defect analysis and rectification by line maintenance personnel. **(SR 10 of 2002)**

4.3 The operator should effect a quality audit in their workshops to ensure satisfactory standard of welding repairs and the accomplishment of dimensional checks, as specified by the manufacturer, following welding repairs of components. **(SR 11 of 2002)**

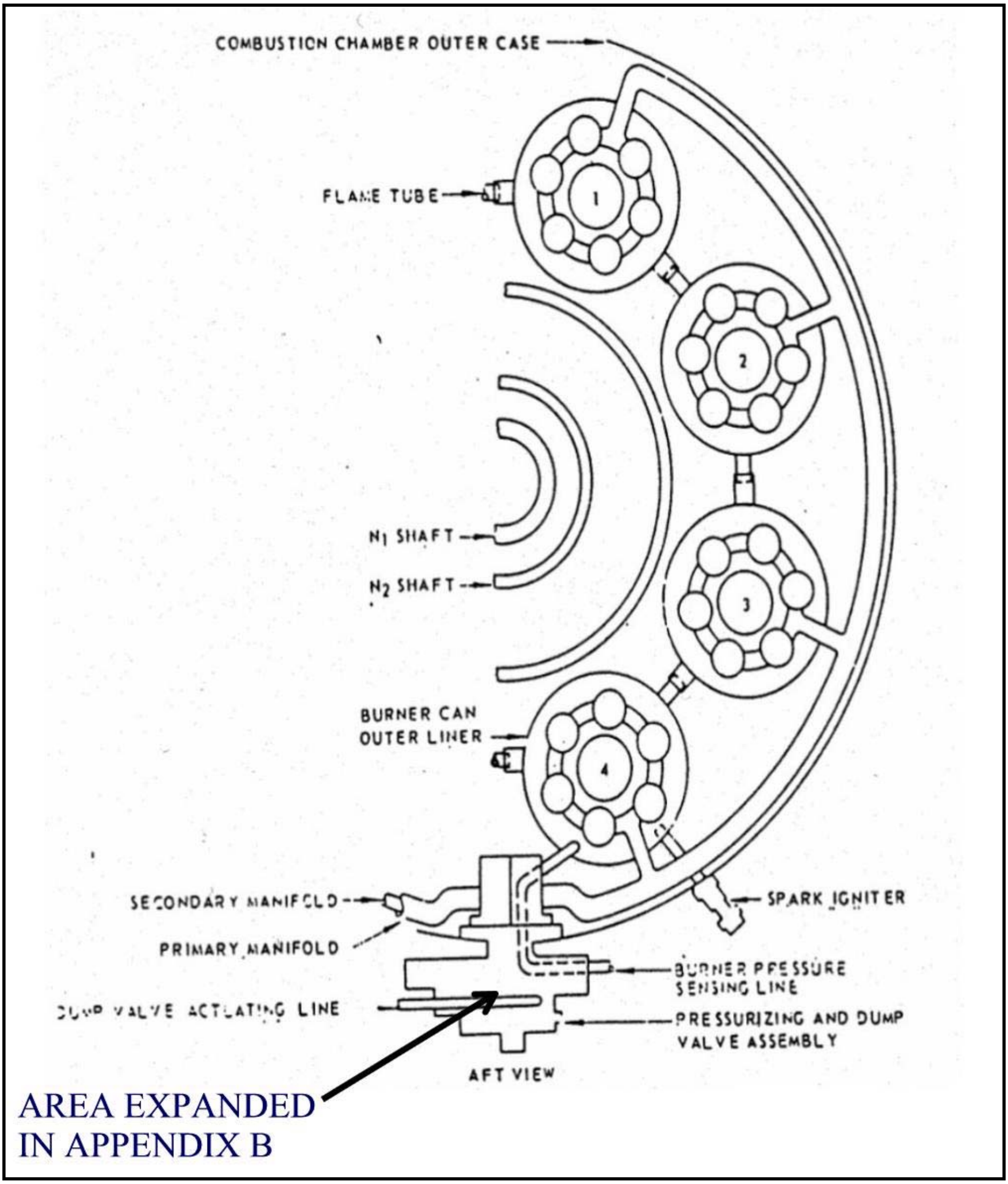
Air Zimbabwe has made the following responses to these Safety Recommendations:

SR 9 of 2002: Air Zimbabwe informed the AAIU by fax of 18/5/2001 that "Re-current training is being carried out because we now have in place effective reliability programme."

SR 10 of 2002: Air Zimbabwe informed the AAIU by fax of 18/5/2001 that "Line Maintenance Technical Procedures Manual has been produced and there is a procedure for handling defect analysis and rectification."

SR 11 of 2002: Air Zimbabwe informed the AAIU by fax of 18/5/2001 that "Effective Audit programme has been established in the workshops."

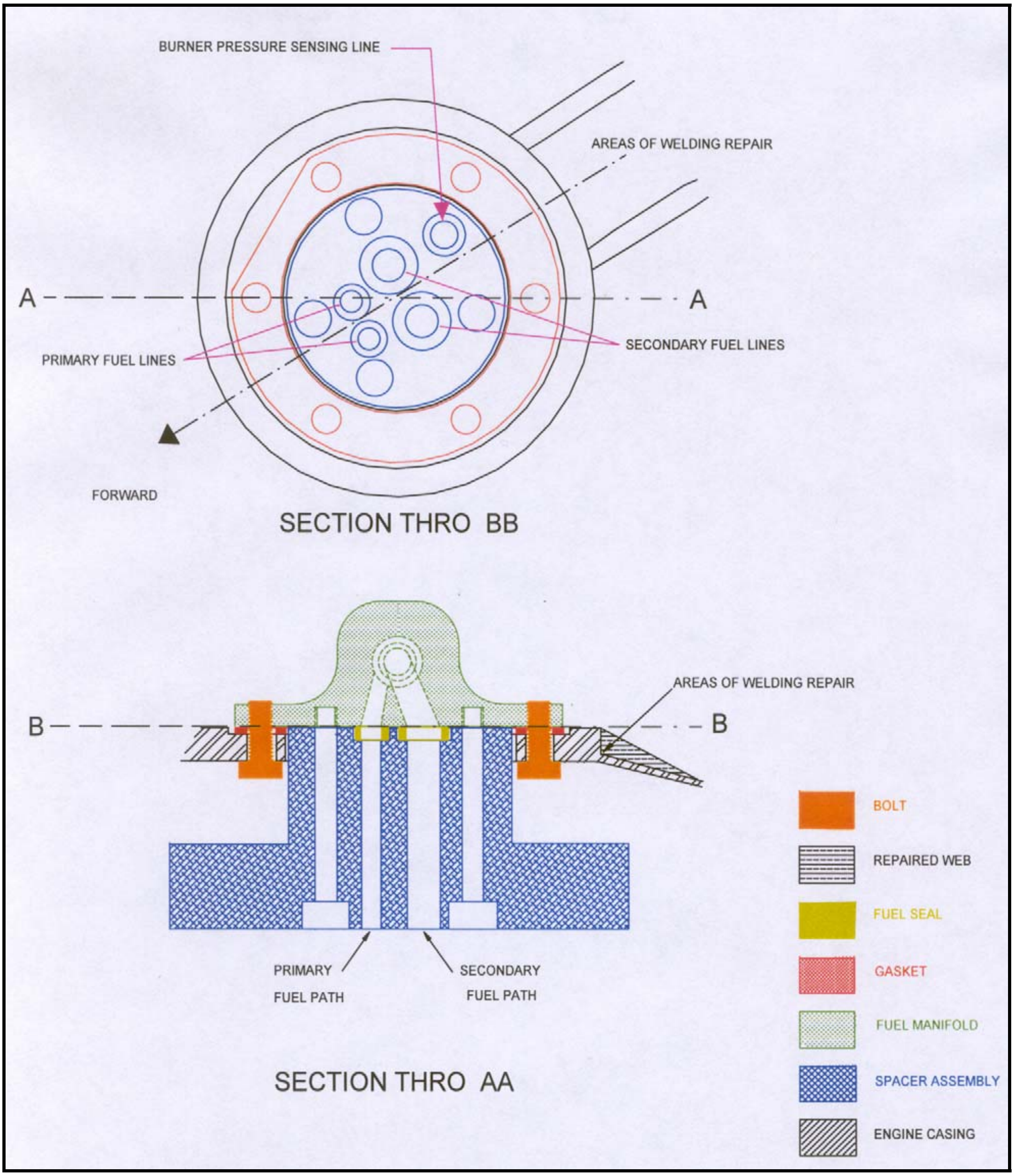
Appendix A



VIEW OF THE FUEL MANIFOLD ASSEMBLY

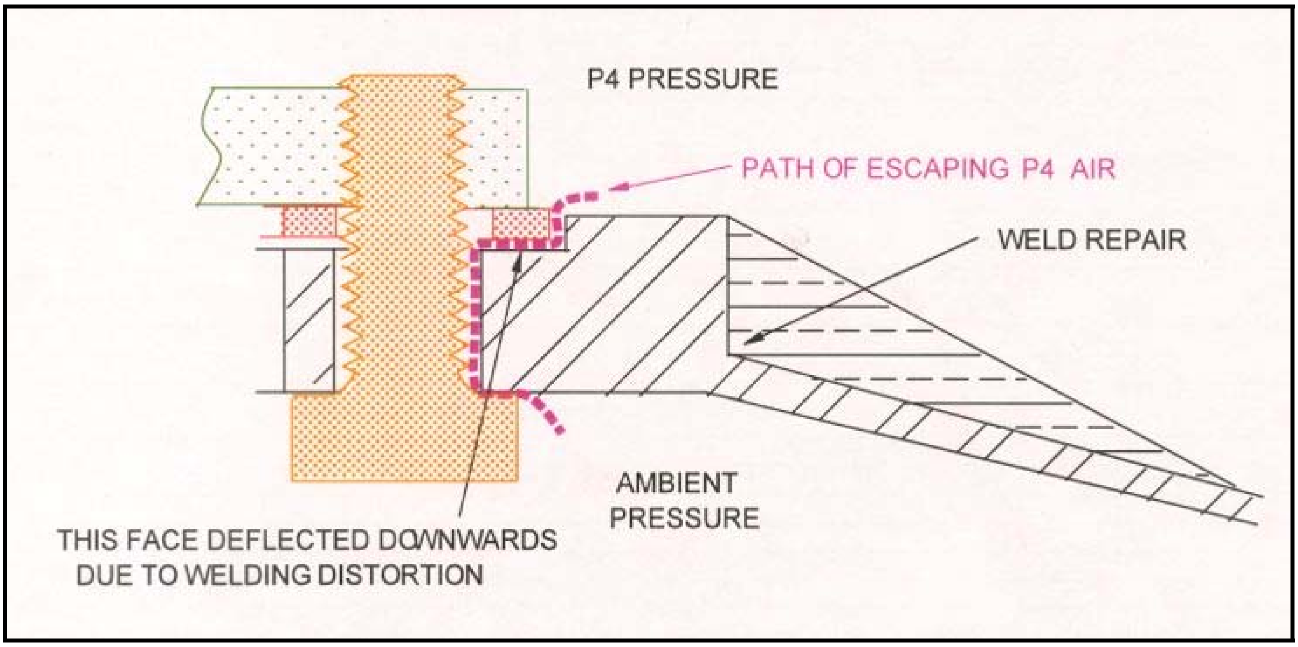
THE P&D VALVE IS AT THE BOTTOM OF THE DIAGRAM

Appendix B



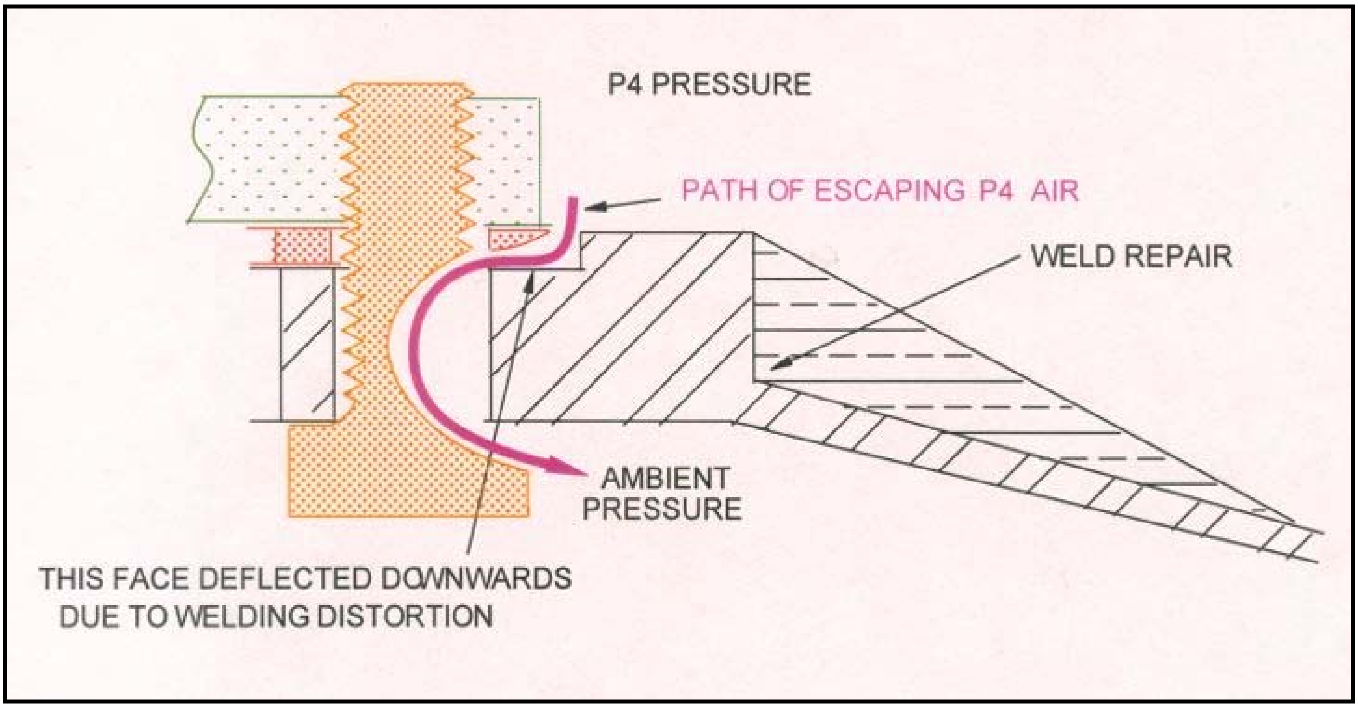
SKETCH OF THE P&D VALVE MOUNT LAYOUT

Appendix C



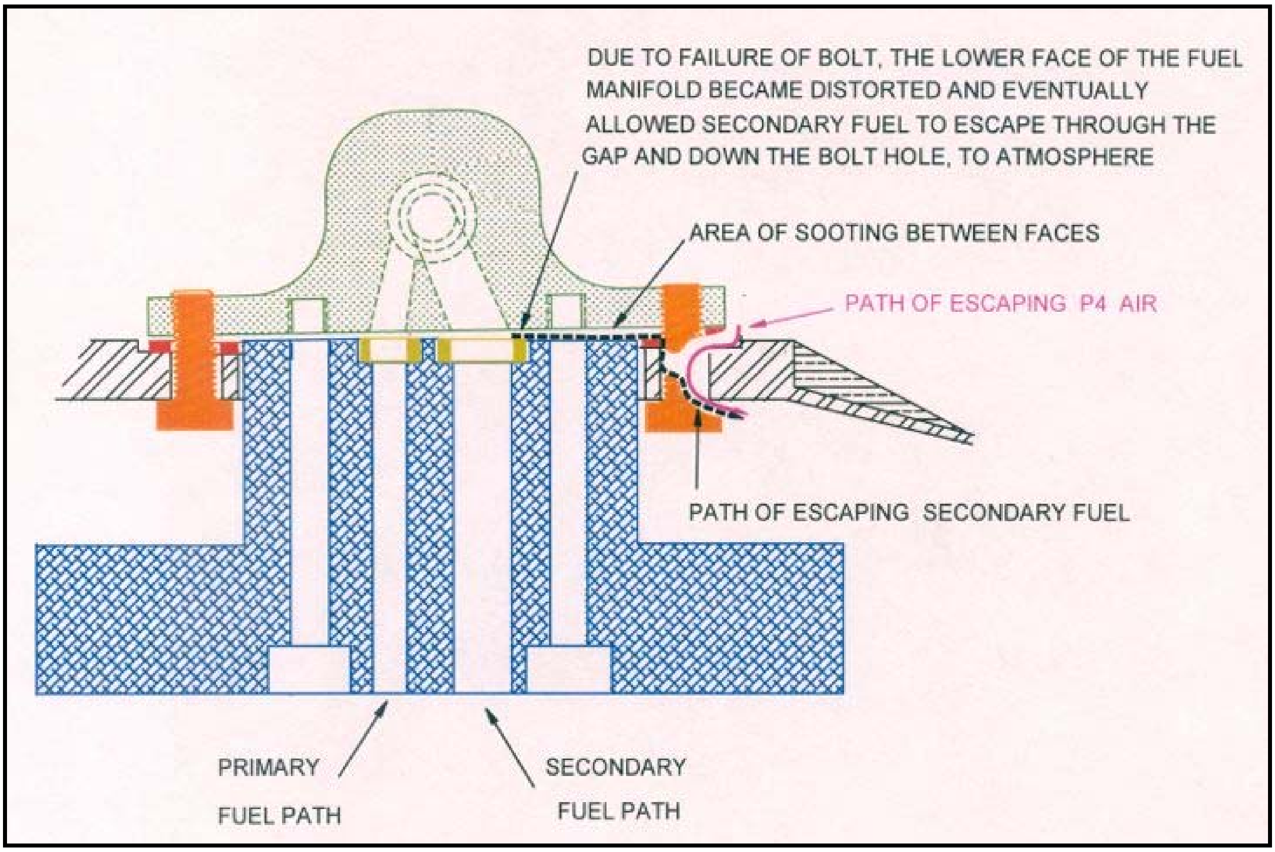
ENLARGED VIEW OF THE BOLT AREA
SHOWING THE PROBABLE PATH OF
THE INITIAL LEAK

Appendix D



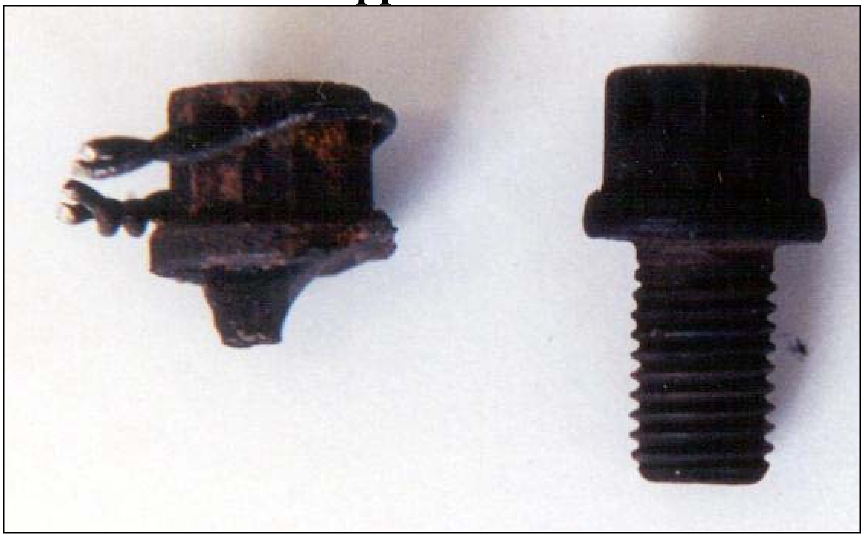
ENLARGED VIEW OF THE BOLT AREA
SHOWING THE EROSION OF THE BOLT
CAUSED BY THE LEAK

Appendix E



ENLARGED VIEW OF THE P&D VALVE ASSEMBLY
SHOWING THE SITUATION
AFTER THE FAILURE OF THE BOLT

Appendix F



VIEW OF THE ERODED BOLT (LEFT)
AND AN UNDAMAGED BOLT (RIGHT)

PHOTO 1

PHOTOGRAPH OF THE INTERIOR OF THE DIFFUSER CASE SHOWING THE P&D VALVE MOUNTING-BOSS& DETAILING THE EROSION DAMAGE TO THE FUEL MANIFOLD AND THE DEFECTIVE WELD REPAIR

PHOTO 2