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AIRCRAFT

SYSTEMS AND EQUIPMENT

CARBON MONOXIDE CONTAMINATION

1 INTRODUCTION This Leaflet describes the nature and effects of carbon monoxide (CO), and outlines the main causes of this type of contamination. It gives only general guidance on the inspections, tests and repairs which should be carried out in order to minimise the dangers of such contamination to crew and passengers, and must, therefore, be read in conjunction with the relevant aircraft Maintenance Manuals.

1.1 The harmful effects of contaminants in the air breathed by crew and passengers are recognised in British Civil Airworthiness Requirements. It is stipulated in the Requirements that CO should not be present in occupied compartments in quantities exceeding 50 parts/million by volume, for any period exceeding five minutes: maximum allowable concentrations are also prescribed for other noxious substances such as fuel, oil, de-icing and hydraulic fluids, fire extinguishing agents, and the fumes given off by other materials when they are heated. Airworthiness Notices Nos. 40 and 41 deal specifically with CO contamination.

2 THE NATURE AND EFFECTS OF CARBON MONOXIDE Carbon monoxide is a gas which is colourless, odourless, and tasteless, and is therefore impossible to detect by the senses. It is a product of the incomplete combustion of carbonaceous materials, and is found in varying amounts in the smoke and fumes emanating from the exhaust systems of aircraft engines and combustion heaters.

2.1 If a person breathes air contaminated by CO, the CO will combine with the haemoglobin in the blood and cause oxygen starvation in the body and brain, thus reducing the person's normal ability to reason and make decisions. Exposure to even small amounts of CO over a period of several hours can be as dangerous as a short exposure to much larger amounts. At altitude, with a smaller quantity of oxygen in the atmosphere, the susceptibility to CO poisoning is correspondingly increased.

2.2 The presence of CO in the air may often be assumed from the smell of exhaust fumes, and from the onset of symptoms such as mild tiredness, a feeling of warmth, and tightness across the forehead. These symptoms cannot, however, be relied upon to give adequate warning of CO contamination, and a person's judgement may become impaired by levels of CO in the blood lower than that at which the symptoms normally appear.

3 CAUSES OF CARBON MONOXIDE CONTAMINATION Carbon monoxide may enter the interior of an aircraft in a number of ways. Defective cabin heating systems of the type which use the engine exhaust pipe as the heat source, and combustion heaters which are independent of the aircraft engines, may introduce CO directly into the fuselage through the cabin heater outlets, while the engine and heater exhaust gases may enter from the outside, either on the ground or during flight. Exhaust gas leaking from any part of the engine exhaust system through cracks, or faulty slip joints, gaskets or muffs, can find its way into the aircraft through ineffectively sealed bulkheads, access panels or skin joints, and in some cases, particularly during starting, ground-running and taxying, the gas discharged from the engine exhaust pipes may enter through open windows or cabin fresh-air intakes. During flight, any poorly sealed doors or windows can result in reduced cabin pressure, encouraging exhaust gas to be drawn into the cabin through the lower fuselage or wing roots.

4 ROUTINE INSPECTIONS The physical inspection of all exhaust system and cabin heating components, of bulkheads and of access panels in the fuselage, should be carried out at the intervals prescribed in the Maintenance Schedule.

4.1 All parts of the engine exhaust system should be inspected for security, warping, dents, cracks, and evidence of gas leakage (i.e. overheating or smoke traces) particularly at clips, slip-joints, clamps, expansion joints and heater jackets. Repair or replacement should be carried out in accordance with the manufacturer's instructions.

4.2 Exhaust pipes under heater jackets should be inspected very carefully at the prescribed intervals, and whenever CO contamination is suspected. In some cases the heater jacket is detachable, and can be completely removed to enable a thorough visual inspection of the exhaust pipe for signs of gas leakage. In cases where the jacket is integral with the exhaust pipe, it is recommended that a pressure test should be carried out by blanking the outlet from the heater jacket and applying air pressure, via a suitable non-return valve, through the inlet; there should be no leakage when the air supply is turned off.

NOTE: The maximum test pressure prescribed in the appropriate Maintenance Manual should not be exceeded, since excessive pressure may damage the jacket and increase the likelihood of crack propagation.

4.3 The procedures for ensuring the serviceability of combustion heaters are outlined in Airworthiness Notice No. 41, and detailed in the appropriate manufacturer's and aircraft manuals. The heater exhaust system should be inspected for the defects listed in paragraph 4.1 and the ducting carrying the heated fresh air from the combustion heater to the cabin should be examined for signs of exhaust contamination. Overhauls of heaters should normally be carried out at the prescribed intervals (normally not exceeding two years). In some instances the combustion chambers are required to be pressure-tested at half the overhaul life.

4.4 Engine bulkheads and the bulkheads isolating combustion heaters, are designed to prevent the transmission of flame, heat or gas to the airframe structure or cabin. Any joins or openings for controls, pipes, or fittings, are sealed with heat-resistant material. All bulkheads should be examined for cracks, damage, ineffective sealing, and signs of smoke or overheating.

4.5 Access panels, particularly those fitted in the underside of the fuselage or giving direct access to the cabin, are generally sealed with a rubber or elastomeric gasket between the panel and the fuselage skin. These gaskets prevent the entry of exhaust gases into the fuselage and are thus important in preventing CO contamination. The fasteners and gaskets of access panels should be examined for security and effectiveness whenever the panels are removed.

4.6 Lap joints and butt joints in the exterior skin of an aircraft are often sealed by the use of a liquid sealant when the skins are riveted during manufacture. When modifications or skin repairs are carried out the same methods should be used to prevent the entry of exhaust gas, and an inspection should be made to ensure that the sealing is effective.

4.7 Cabin windows and windscreens are usually secured to the metallic structure of the aircraft by means of rubber sealing channels or strips. Poor sealing of these glazed panels could allow exhaust gas into the fuselage, and the seals should be examined for security, condition and fit.

4.8 On twin-engined aircraft, exhaust gas may enter the wheel wells or flap shrouds and flow along the leading and trailing edges of the wings into the fuselage. The sealing in these areas, and the landing gear doors, should be checked for effectiveness.

5 TESTS FOR CO CONTAMINATION When doubt exists as to the extent of contamination of the air in the crew or passenger compartments, a test should be carried out to determine the CO concentration. This test is usually carried out by a sampling process, detection being based on the colour reaction of CO with iodine pentoxide, selenium dioxide and fuming sulphuric acid. A typical apparatus and test are described in paragraph 5.1.

5.1 The apparatus usually consists of a hand-operated bellows, which is used to draw a specified volume of air through a sampling tube, the presence of CO being indicated by the staining of crystals in the indicating portion of the tube.

5.1.1 The sampling tube is a sealed glass capsule containing crystals which are white on one side of a datum line and pigmented with the reagent on the other side of the datum line. The white (indicating) part of the tube has two scales marked on the outside of the glass, one graduated for small CO concentrations and the other graduated for large CO concentrations, the units used generally being parts per million (ppm).

5.1.2 When carrying out a test the ends of a sampling tube should be broken to expose the chemicals, and the indicating end of the tube should be inserted in the air intake opening of the bellows assembly. The bellows should then be fully compressed, and when released will expand under internal spring pressure to draw a specified quantity of air through the sampling tube. The number of times the bellows is operated depends on which scale is being used, and this information should be obtained from the manufacturer's published literature. The presence of CO in the air drawn through the sampling tube will result in a green-brown staining of the indicator crystals, the extent of staining depending on the quantity of CO in the sample. The CO concentration can then be read directly from the appropriate scale, at the dividing line between the white and stained crystals.

5.2 Tests should be carried out with the engine(s) running and the cabin heater turned on, both on the ground and during flight, to take account of varying conditions of airflow around the aircraft.

6 REPAIR OR REPLACEMENT OF PARTS The repair or replacement of parts may have to be carried out if it is discovered that CO is entering the crew or passenger compartments in quantities sufficient to cause concern. The procedures relevant to particular components are outlined in paragraphs 6.1 to 6.5.

6.1 **Exhaust Pipes and Heater Jackets.** Renewal of damaged parts is generally preferable to repair, and new gaskets or seals should always be fitted when replacing a component. Damage may often be repaired by welding, but when making such repairs it is important to comply with any specific instructions which may be contained in the relevant Maintenance Manual. Extreme care should be taken to maintain the original contour, since any disruption to the smooth flow of exhaust gas will result in a hot spot and lead to early failure at that point. It is also important to ensure that the materials used in a repair are the same as, or compatible with, the original material. Pre-heating may be necessary in some cases to prevent cracking, and it may be recommended that, after welding, parts are heat-treated in accordance with a prescribed procedure or normalised to reduce grain size in the weld area. Pressure tests are generally required after welding operations. Advice on gas and arc welding is contained in Leaflets **BL/6-4** and **BL/6-5** respectively.

6.2 **Combustion Heaters.** Combustion heaters should be maintained in accordance with an approved Maintenance Schedule, using only those procedures detailed in the relevant manuals produced by the aircraft constructor or the equipment manufacturer; any repairs or replacements which become necessary should be carried out in accordance with these instructions. If burning or traces of smoke are found in the cabin heater ducting the cause should be ascertained and the defective parts repaired or renewed as necessary. Damage to the cabin heater ducting, which is generally made from glass-cloth, nylon or silicone rubber, and supported by a steel coil, is generally not repairable, and the affected parts should be renewed.

6.3 **Bulkheads.** Cracked or otherwise damaged bulkheads should be repaired in accordance with the procedures laid down in the relevant Repair Manual, and using only those materials specified for the particular repair. At the same time that repairs are carried out, all sealing material applied to the bulkhead should be examined for condition and effectiveness, and renewed as necessary.

6.4 **Access Panels.** Access panels may become distorted with use and allow contaminated air to enter the aircraft. If a panel is found to be in this condition it may sometimes be repaired by, for example, adding a stiffener, or by adjustment or replacement of the fasteners, but replacement with a new panel may often be necessary. Damaged or incorrectly fitted rubbing strips or seals in an access panel aperture may also result in air leakage, and should be repaired or renewed in accordance with the relevant manuals.

6.5 **Doors and Windows.** Poorly fitting or ineffectively sealed cabin doors and windows on aircraft can allow the entry of contaminated air. Although hinges and locks are adjusted during installation to provide a good aerodynamic fit and to ensure the safety of the locking mechanisms, the effects of air loads and wear may result in the need for re-adjustment from time to time, and this should be carried out strictly in accordance with the manufacturer's instructions. Door seals may be of the solid or inflatable type, and are usually attached to the door surround with a suitable adhesive; if damaged or loose they may usually be repaired, but special procedures and materials are usually required. Information concerning the repair or replacement of door and window seals should be obtained from the relevant Maintenance Manual.

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AIRCRAFT

SYSTEMS AND EQUIPMENT

HYDRAULIC SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the operation and maintenance of hydraulic systems in aircraft. There are wide variations in the hydraulic installations of different aircraft, and no attempt is made, in this Leaflet, to describe any particular system in detail; it is important, therefore, that this Leaflet should be read in conjunction with the relevant manuals for the aircraft concerned.

1.1 Information on associated subjects will be found in Leaflets **BL/6-15**—Manufacture of Rigid Pipes, **BL/6-30**—Torque Loading, **AL/3-13**—Flexible Pipes, and **AL/3-14**—Installation of Rigid Pipes in Aircraft.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet AL/4-1, Issue 3, 15th February 1961.

2 GENERAL PRINCIPLES Hydraulics is a method of transmitting power through pipes and control devices, using liquid as the operating medium. For certain applications hydraulic systems are used in preference to mechanical or electrical systems for a number of reasons, among which are ease of application of force, ability to increase the applied force as necessary, ease of routeing of pipelines, and elimination of backlash between components.

2.1 Liquids are, for most practical purposes, incompressible, and this fact enables movement to be transmitted through pipelines, over great distances, without loss of time or motion. However, liquids will expand or contract as a result of temperature changes, and a relief valve is necessary, to prevent damage from excessive pressures, in any closed system which may be subjected to large changes of temperature.

NOTE: In systems using very high pressures, the compressibility of the liquid and the elastic yield of the system components may become important. In design calculations a value of 0·07%/MN/m² (0·05%/1000 lbf/in²) is often used for the combined effects of these factors, compressibility of the liquid amounting to approximately 0·05%/MN/m² (0·035%/1000 lbf/in²).

2.2 In a closed static system, pressure exerted on a liquid is transmitted equally in all directions. Figure 1 shows a simple arrangement of pistons, cylinders and pipes, which uses this principle to obtain mechanical advantage. The area of piston A is 10 mm², and the force applied to it is 10 N. The pressure in the liquid is, therefore, 1 N/mm², which is transmitted undiminished to piston B. The area of piston B is 100 mm², and the force exerted upon it is thus 100 N, representing a mechanical advantage of 10:1. This advantage is obtained at the expense of distance, however, because the area of piston B is 10 times that of piston A and piston B will move only one tenth the distance of piston A.

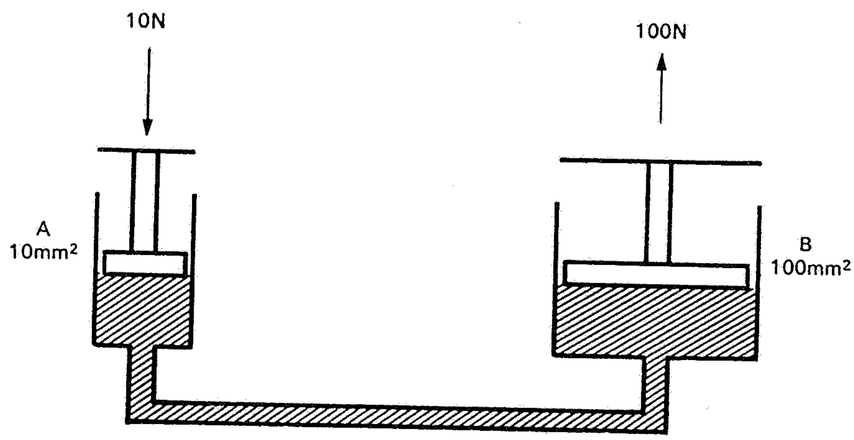

Figure 1 MECHANICAL ADVANTAGE BY HYDRAULIC MEANS

2.3 When liquid is in motion, its dynamic characteristics must also be taken into consideration. Friction exists between the molecules of a liquid, and between the liquid and the piping through which it flows; this friction increases with any increase in viscosity or velocity of the liquid. Friction results in some of the power available from a pump being transformed into heat, and in a reduction in pressure throughout the pipelines.

2.4 Any restriction in a pipeline will increase liquid velocity and produce turbulence, resulting in reduced pressure downstream of the restriction. This fact is often exploited in system design and a restrictor is also used to limit the rate of liquid flow, and thus the rate of movement of components such as the landing gear or flaps.

3 HYDRAULIC FLUIDS Almost any sort of liquid could be used in a hydraulic system, but the special requirements of aircraft systems have resulted in the use of vegetable, mineral and synthetic-based oils (known as hydraulic fluids) which have the following properties:—

(a) They provide good lubrication of components.

(b) Their viscosity is low enough to minimise friction in pipelines and to allow high-speed operation of motors and pumps, but high enough to prevent leakage from components.

(c) They prevent internal corrosion in the system.

(d) They have a wide operating-temperature range.

Fluids are coloured for recognition purposes, and fluids to different specifications must never be mixed; fluids to the same specification, but produced by different manufacturers, may be mixed when permitted by the appropriate Maintenance Manual. Use of a fluid which is not approved for a particular system may result in rapid deterioration of seals, hoses and other non-metallic parts, and may render the system inoperative.

3.1 Vegetable-based fluid is normally almost colourless, and must be used with pure rubber seals and hoses. It is used in some braking systems, but is not often found in hydraulic power systems.

3.2 Mineral-based fluid is normally coloured red, and must be used with synthetic rubber seals and hoses. It is widely used in light aircraft braking systems, hydraulic power systems, and shock-absorber struts.

3.3 Phosphate ester based fluid is widely used on modern aircraft, mainly because of its fire-resistance and extended operating-temperature range. It may be coloured green, purple or amber, and must only be used with butyl rubber, ethylene propylene or teflon seals and hoses.

3.3.1 This fluid requires extreme care in handling as it is irritant to the skin and eyes. A barrier cream should be applied to the hands and arms, and fluid resistant gloves should be worn, whenever servicing operations on the hydraulic system are carried out. In addition, goggles should be worn whenever there is the possibility of fluid being splashed into the eyes, such as when pressure-testing or bleeding components.

3.3.2 Spillage of fluid should be avoided, but, if it does occur, the area affected should immediately be wiped with a dry rag, and thoroughly washed with soap and hot water.

3.4 In view of the incompatibility of different fluids, it is important that any containers, or test rigs, used for servicing aircraft, are clearly marked with the type of fluid they contain.

4 PUMPS Most modern aircraft are fitted with either fixed volume or variable volume, multi-piston type hydraulic pumps, driven from the engines. Other types of pumps, such as gear or vane positive displacement pumps, may be found in some installations, but these are generally used for powering emergency systems. Hand pumps, where fitted, are often of the double-acting type.

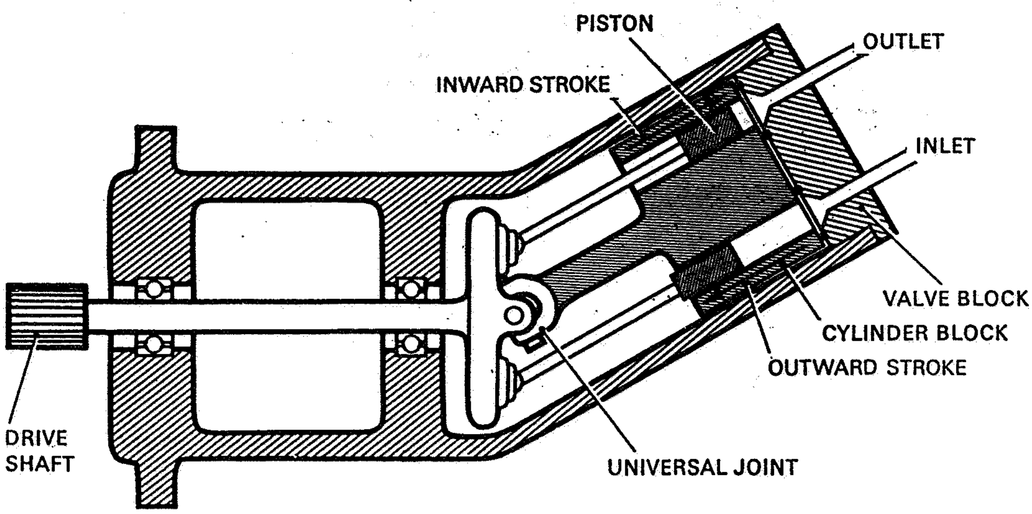

Figure 2 AXIAL PISTON PUMP

4.1 **Fixed Volume Pumps.** These pumps deliver a fixed quantity of fluid into the system at a particular speed of rotation, regardless of system requirements, and means must be provided for diverting pump output when it is not required in the system. These means are discussed in paragraphs 5 and 6.

4.1.1 One type of fixed volume multi-piston pump is illustrated in Figure 2. The cylinder block and drive shaft rotate together, and because of the angle between the cylinder block and shaft axes, each piston moves into and out of its cylinder once each revolution. The stationary valve block has two circumferential slots leading to the top of the cylinder block, which are connected to the fluid inlet and outlet ports, and are arranged so that the pistons draw fluid into the cylinders on the outward stroke, and expel fluid into the system on the inward stroke.

4.1.2 Another type of fixed volume pump is illustrated in Figure 3. In this pump the cylinders are arranged radially around an eccentric crankshaft, so that when the crankshaft is rotated, a piston moves up and down in each cylinder once per revolution. Fluid is drawn into the pump body, and enters each cylinder, through ducting in the cylinder block, whenever the associated piston is at the bottom of its stroke. As a piston moves outwards into its cylinder, it covers the inlet port, and forces fluid out of the top of the cylinder, past a delivery valve, to the pump outlet connection.

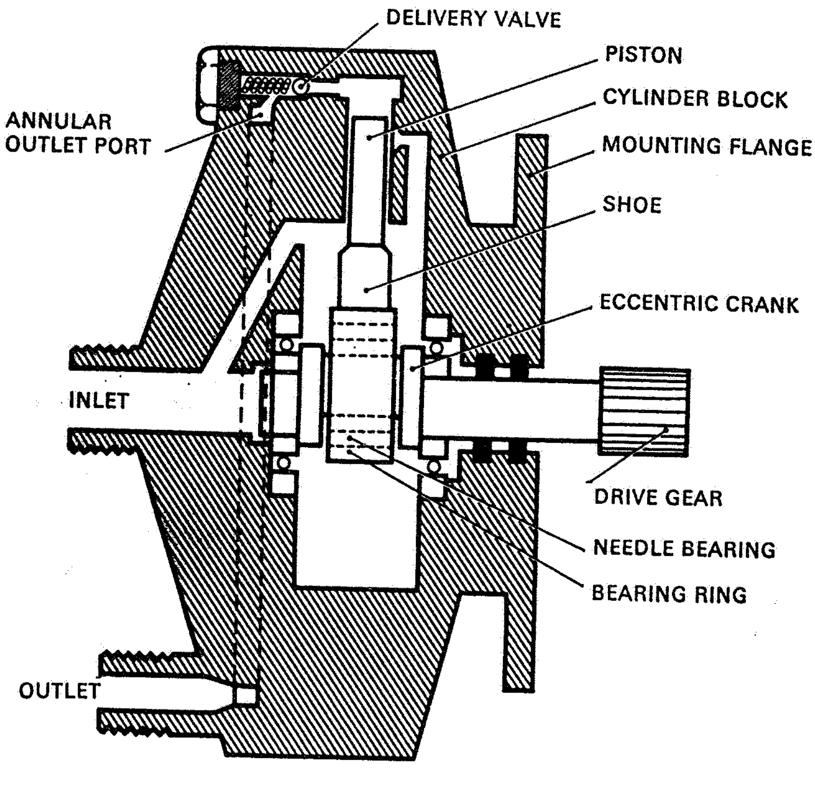

Figure 3 RADIAL PISTON PUMP

4.2 **Variable Volume Pump.** This type of pump is similar in construction to the fixed volume pump described in paragraph 4.1.1, but the cylinder block and drive shaft are co-axial. The pistons are attached to shoes which rotate against a stationary yoke, and the angle between the yoke and cylinder block is varied to increase or decrease pump stroke to suit system requirements. Figure 4 shows the operation of the pump. When pressure in the system is low, as would be the case following selection of a service, spring pressure on the control piston turns the yoke to its maximum angle, and the pistons are at full stroke, delivering maximum output to the system. When the actuator has completed its stroke, pressure builds up until the control piston moves the yoke to the minimum stroke position; in this position a small flow through the pump is maintained, to lubricate the working parts, overcome internal leakage and dissipate heat. On some pumps a solenoid-operated depressurising valve is used to block delivery to the system, and to off-load the pump.

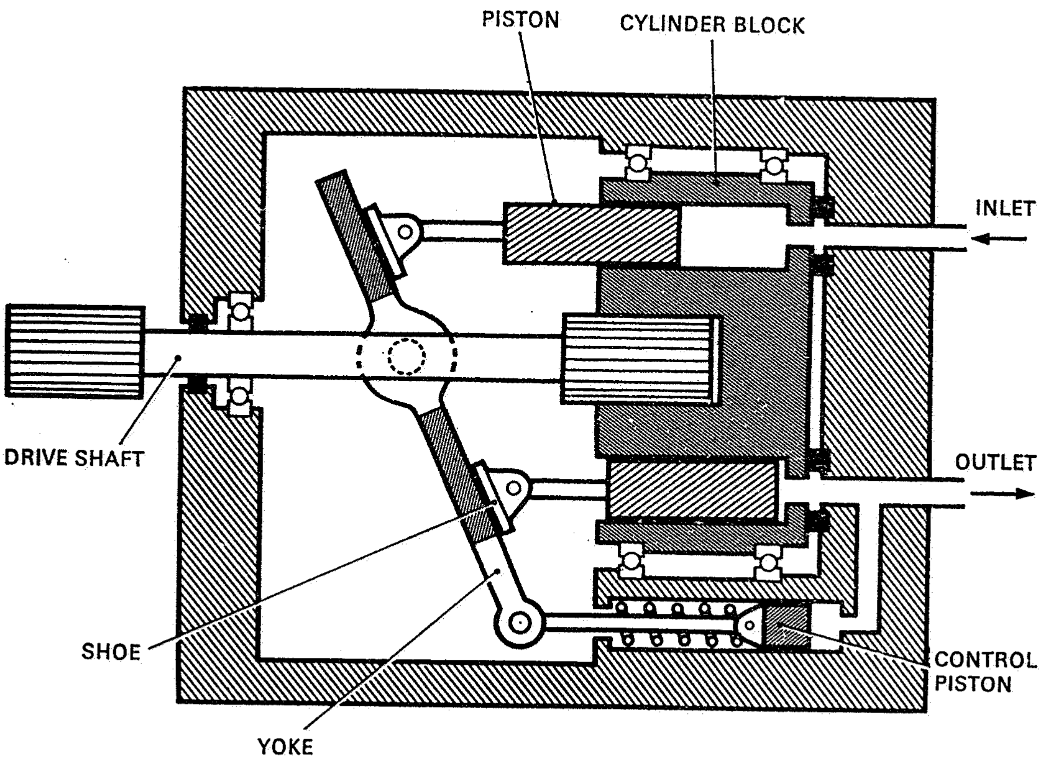

Figure 4 VARIABLE VOLUME PUMP

4.3 **Hand Pumps.** A hand pump is included in some aircraft installations, for emergency use and for ground servicing operations. Figure 5 illustrates a double-acting hand pump (i.e. a pump which delivers fluid on each stroke). As the piston moves upward in the cylinder, fluid is drawn in through a non-return valve (NRV) at the inlet connection into the cylinder; at the same time fluid above the piston is discharged through a non-return valve in the outlet connection. As the piston moves downwards, the inlet NRV closes and the transfer NRV opens, allowing fluid to flow through the piston; since the area below the piston is larger than the area above the piston, part of this fluid is discharged through the outlet port. When pressure in the outlet line exceeds the relief valve setting, discharged fluid is by-passed back to the pump inlet.

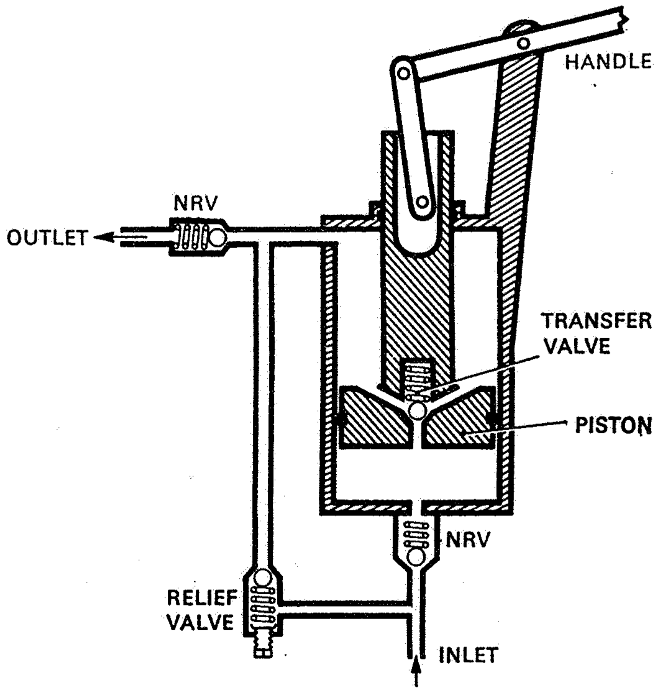

Figure 5 DOUBLE-ACTING HAND PUMP

5 PRESSURE CONTROL Maximum system pressure is often controlled by adjustment of the main engine-driven pump, but a number of other components are used to maintain or limit fluid pressures in various parts of a hydraulic system, and these sometimes have additional functions.

5.1 **Relief Valves.** A relief valve is the simplest form of pressure limiting device, and may be used by itself, or within larger components. A relief valve is frequently used as a safety device, e.g. a thermal relief valve, in which case it is adjusted to blow-off at a pressure slightly higher than normal system pressure, and is normally designed to relieve only a small quantity of fluid. In some systems a full-flow relief valve is fitted downstream of the pump, to by-pass full pump output to the reservoir in the event of failure of the cut-out valve, or of blockage elsewhere in the system. A simple ball-type relief valve and full-flow relief valve are shown in Figure 6.

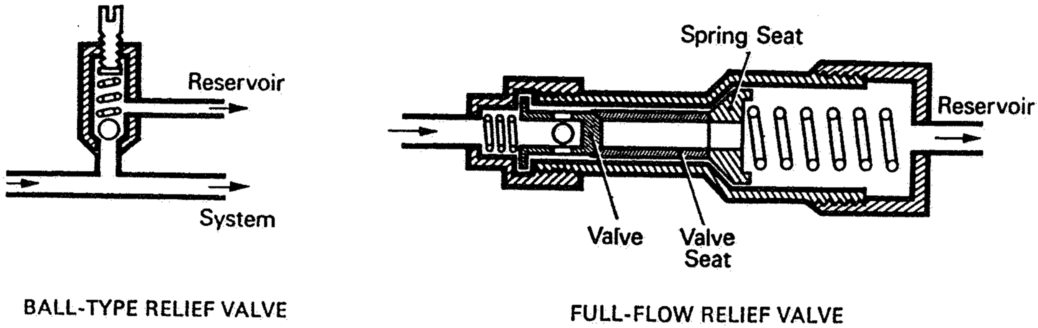

Figure 6 RELIEF VALVES

5.2 **Cut-out Valves.** A cut-out valve is fitted to a system employing a fixed volume pump, to provide the pump with an idling circuit when no services have been selected. An accumulator is essential when a cut-out is fitted, since any slight leakage through components, or from the system, would result in operation of the cut-out, and in frequent loading and unloading of the pump.

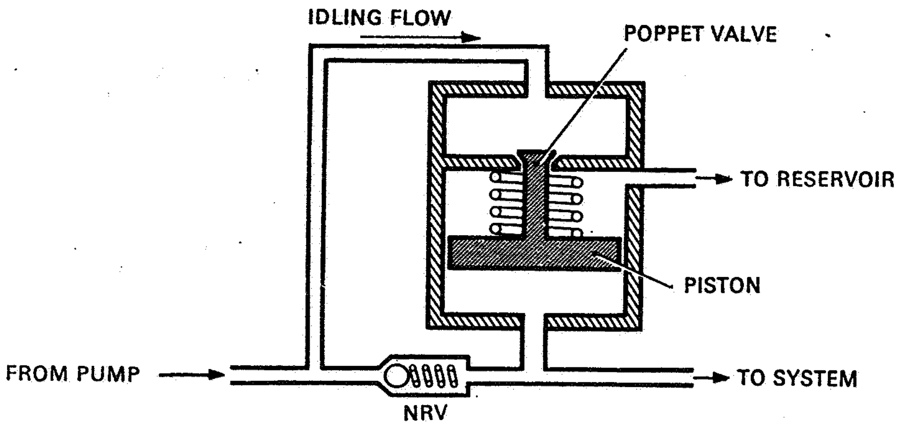

Figure 7 CUT-OUT VALVE

5.2.1 Figure 7 shows the operation of a cut-out valve. When a service has been selected and the pump is delivering fluid to the system, the NRV is open and equal pressure is applied to the poppet valve and piston; the force of the spring combined with the pressure on the poppet valve, is greater than the force on the piston, so the valve is closed and the return line to reservoir is blocked. When the service selected has completed its travel, pressure builds up in the delivery line to the system until the force applied to the piston is sufficient to lift the poppet valve off its seat; this results in a sudden drop in pressure on the pump side of the poppet valve which snaps the poppet valve open and the NRV closed. Pressure in the return line drops to a low value and the load on the pump is removed. Pressure in the system is maintained by the accumulator until a further selection is made; when pressure drops, and the force on the cut-out piston becomes less than the spring force, the poppet valve closes and pump output is again directed into the system.

5.3 **Pressure Maintaining Valves.** A pressure maintaining valve, or priority valve, is basically a relief valve which maintains the pressure in a primary service at a value suitable for operation of that service, regardless of secondary service requirements. When main system pressure exceeds this pre-determined value, the spring load is overcome, and the valve opens to allow main system pressure to reach the secondary service. A pressure maintaining valve is generally used to safeguard operation of important services such as flying controls and wheel brakes. Figure 8 shows a valve in the open position, pressure being sufficient to move the piston against spring pressure and connect the main supply to the sub-system.

5.4 **Pressure Reducing Valves.** A pressure reducing valve is often used to reduce main system pressure to a value suitable for operation of a service such as the wheel brakes. Figure 9 illustrates a pressure reducing valve, which also acts as a relief valve for the service operating at reduced pressure. Fluid enters the inlet port, and flows through the valve to the sub-system; when the fluid pressure exceeds the spring-loading on the valve, the valve is lifted and gradually covers the inlet port until sub-system pressure reaches the specified value. If sub-system pressure increases for any reason, the valve is lifted further and uncovers the return port to relieve excess pressure.

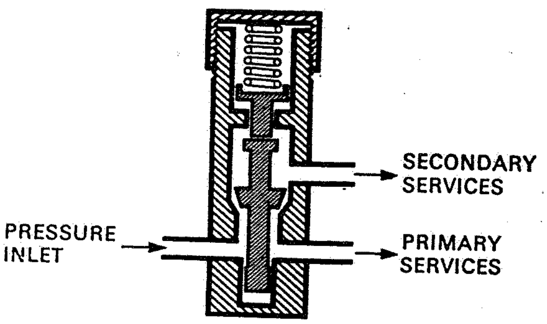

Figure 8
PRESSURE MAINTAINING VALVE

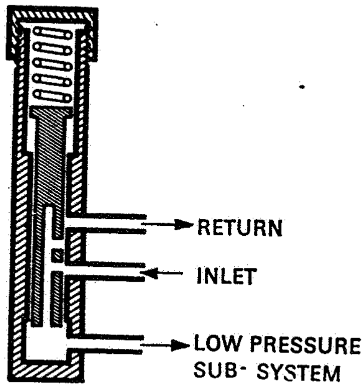

Figure 9
PRESSURE REDUCING VALVE

5.5 **Brake Control Valves.** A brake control valve is essentially a variable pressure reducing valve, which controls pressure in the brake system according to the position of the pilots' brake pedals. The valve usually contains four elements, one pair for the brakes on each side of the aircraft, to provide duplicated control. Figure 10 illustrates a single element, in this case operated by a slave servo from the brake pedal.

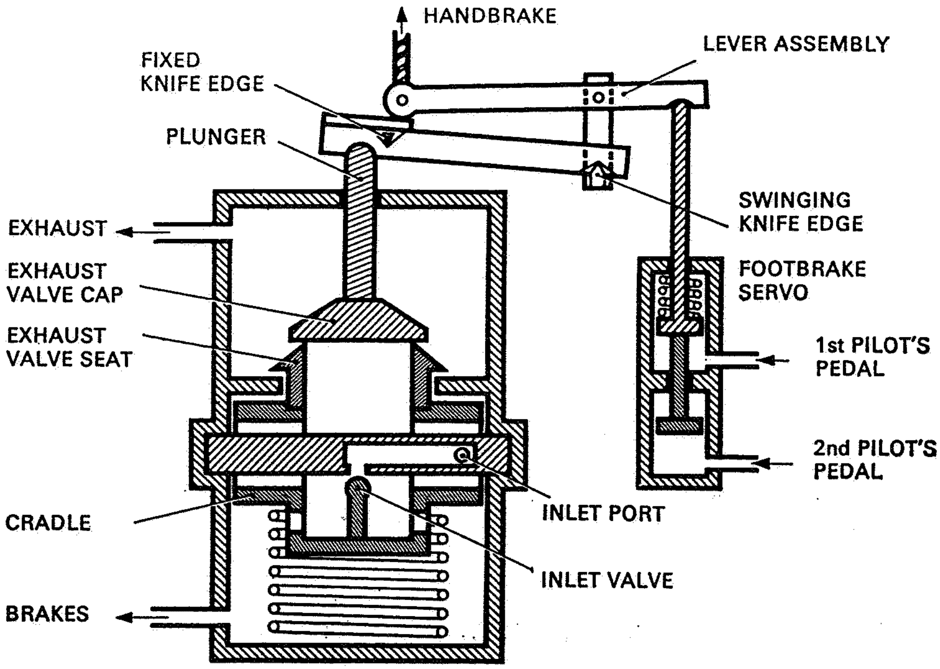

Figure 10 BRAKE CONTROL VALVE

5.5.1 When either pilot's brake pedal on the appropriate side is depressed, or the hand brake is operated, the servo piston applies load to the linkage on the control valve, which, via the lever assembly and plunger, presses down the exhaust valve cap. This action initially closes the gap between the exhaust valve cap and the exhaust valve seat, then moves the cradle down to open the inlet valve, and to direct fluid to the brakes. Pressure builds up in the brakes and valve, until it is sufficient, assisted by the spring, to overcome the inlet pressure, to force the cradle and exhaust valve seat against the exhaust valve cap, and to close the inlet valve. An increase in the load applied to the valve linkage will be balanced by increased delivery pressure, and a decrease in the load applied will be balanced by relief of delivery pressure past the exhaust valve. When the brake pedals are released, the exhaust valve cap lifts, and exhausts pressure from the brakes to the reservoir.

6 FLOW CONTROL The components described in this paragraph are used to control the flow of fluid to the various services operated by the hydraulic system.

6.1 **Non-return Valves.** The most common device used to control the flow of fluid is the non-return valve, which permits full flow in one direction, but blocks flow in the opposite direction. Simple ball-type non-return valves are included in Figure 5, but design may vary considerably. When a non-return valve is used as a separate component, the direction of flow is indicated by an arrow moulded on the casing, in order to prevent incorrect installation.

6.2 **Restrictor Valves.** A restrictor valve may be similar in construction to a non-return valve, but a restrictor valve is designed to permit limited flow in one direction and full flow in the other direction; the restriction is usually of fixed size, as shown in Figure 11. A restrictor valve is used in a number of locations, in order to limit the speed of operation of an actuator in one direction only. It may, for instance, be used to slow down flap retraction or landing gear extension.

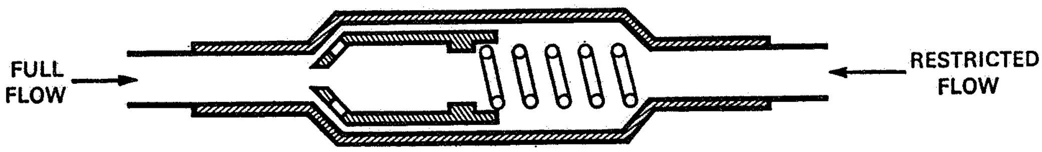

Figure 11 RESTRICTOR VALVE

6.3 **Selectors.** The purpose of a selector is to direct fluid to the appropriate side of an actuator, and to provide a return path for fluid displaced from the opposite side of that actuator. Many selectors are simple four-way valves, connecting the pressure and return lines to alternate sides of the actuator, without a neutral position, but selectors in open-centre systems (see Figure 22) often lock fluid in the actuators while providing an idling circuit for the pump. Selector valves are generally manually operated, and some typical examples are illustrated in Figure 12.

6.3.1 It is sometimes necessary to be able to hold the actuator in an intermediate position. On some aircraft this is achieved by using a selector which blocks both lines to the actuator when it is in the neutral position, the selector being manually returned when the desired actuator position is reached. However, as this could be distracting for the pilot at a critical stage of flight, a feed-back mechanism is often used, which automatically returns the selector to neutral whenever a selected position is reached. Figure 13 shows, diagrammatically, a method which is used in a flap circuit to enable any intermediate position to be held; the selector would normally operate in a gated quadrant.

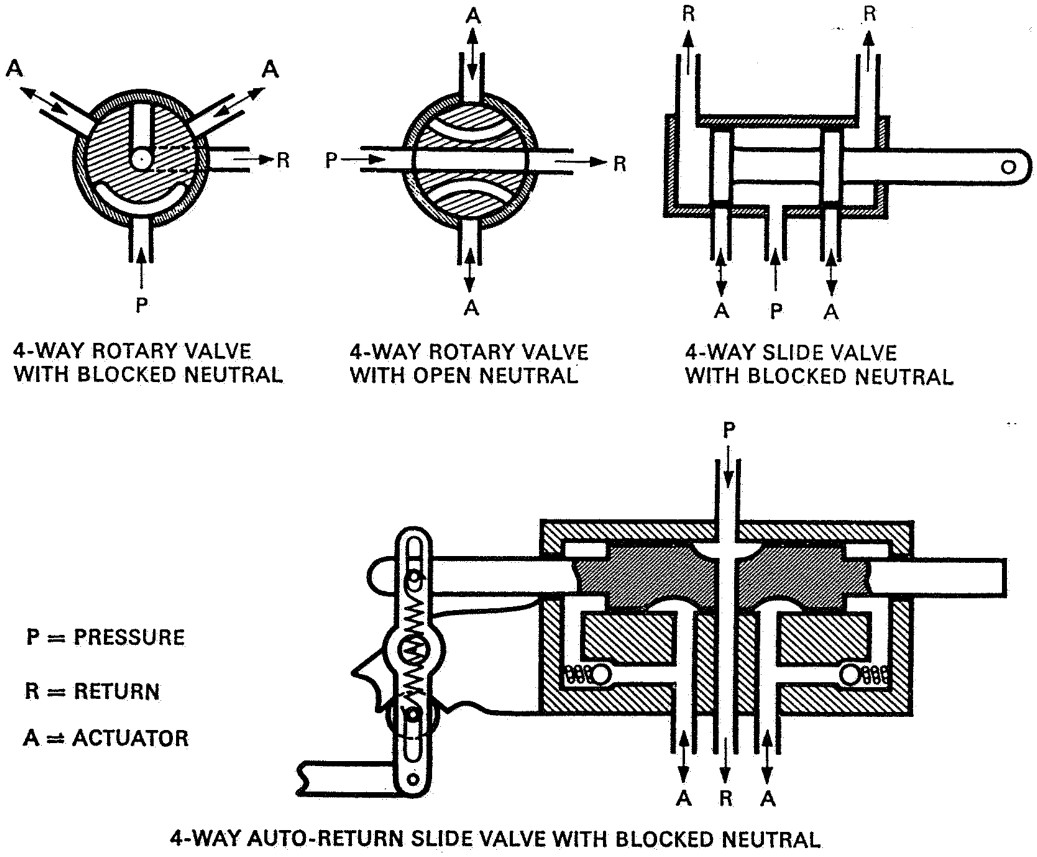

Figure 12 MANUAL SELECTOR VALVES

6.3.2 **Electrically-operated Selectors.** It is sometimes convenient to locate a selector valve at a position remote from the crew compartment, and to eliminate the need for extensive mechanical linkage the selector is normally operated electrically. The selector shown in Figure 14 is a typical electrically-operated two-way valve, which may be used, for example, for emergency operation of the flaps or landing gear. With the solenoid de-energised, the pilot valve is spring-loaded against the return seat, and fluid from the emergency system passes to both sides of the slide valve. Since the right hand end of the valve is of larger diameter than the left, the valve moves to the left and fluid passes to the actuator to extend its ram; fluid from the opposite side of the actuator passes through the selector to the return line. With the solenoid energised, the pilot valve is held against the pressure seat, and supply pressure acts on the left hand side of the slide valve only, the right-hand side being open to return; the slide valve moves to the right, and directs fluid to retract the actuator ram, the opposite side of the actuator being open to return.

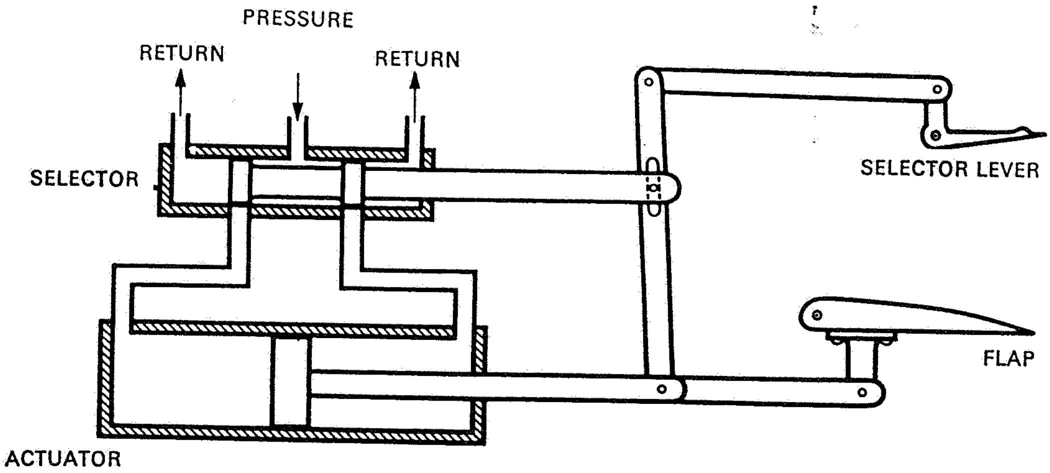

Figure 13 FOLLOW-UP LINKAGE

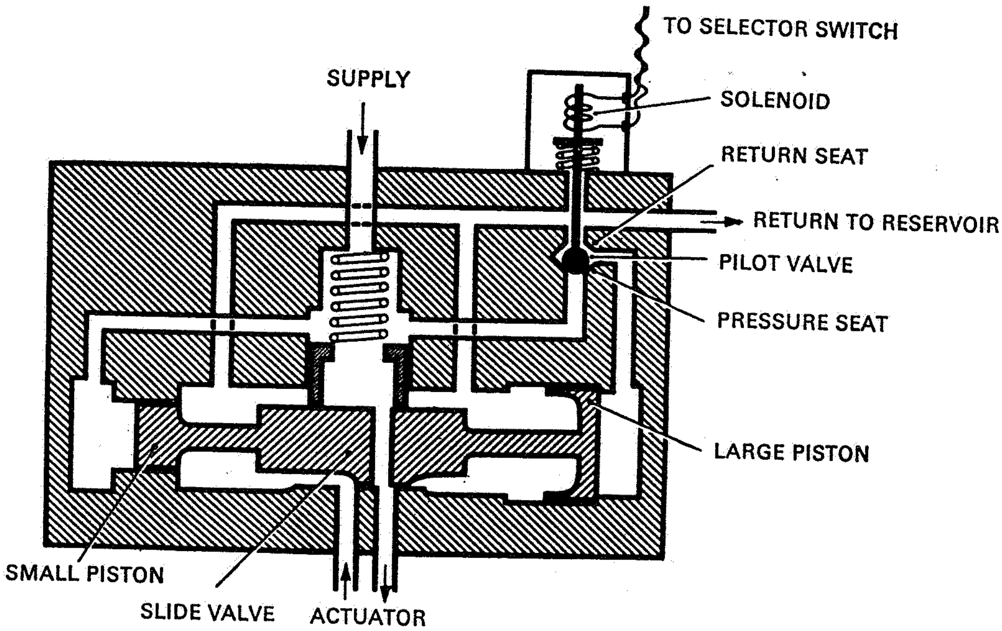

Figure 14 ELECTRICAL SELECTOR VALVE (2-way)

6.4 **Shuttle Valves.** These are often used in landing gear and brake systems, to enable an emergency system to operate the same actuators as the normal system. During normal operation, free flow is provided from the normal system to the service and the emergency line is blocked. When normal system pressure is lost and the emergency system is selected, the shuttle valve moves across because of the pressure difference, blocking the normal line and allowing emergency pressure to the actuator. A typical shuttle valve is shown in Figure 15.

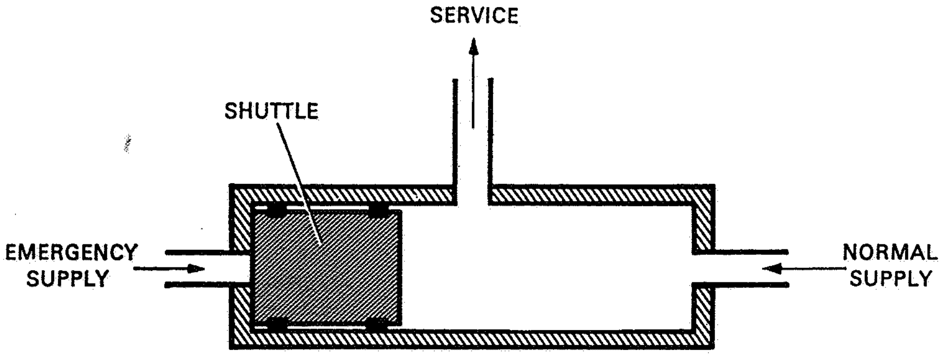

Figure 15 SHUTTLE VALVE

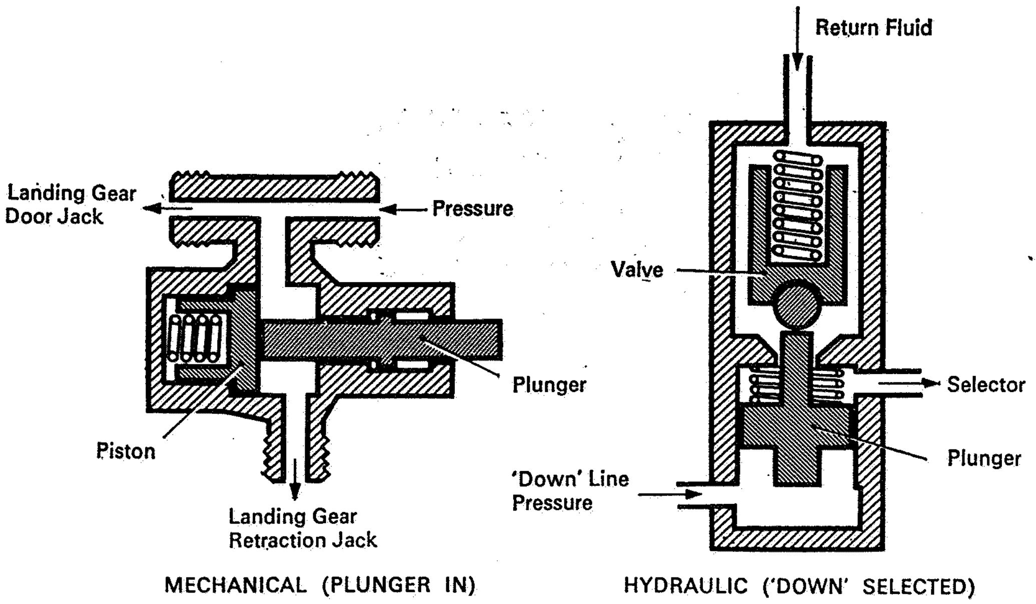

Figure 16 SEQUENCE VALVES

6.5 **Sequence Valves.** Sequence valves are often fitted in a landing gear circuit to ensure correct operation of the landing gear doors and jacks. Examples of mechanically operated and hydraulically operated sequence valves are illustrated in Figure 16.

6.5.1 Mechanically operated sequence valves ensure that the landing gear does not extend until the doors are open, and that the landing gear is retracted before the doors close. Completion of the initial movement in the sequence results in part of the mechanism operating the plunger of the sequence valve, and allowing fluid to flow to the next actuator.

6.5.2 During extension of the landing gear, pressure in the 'up' lines could exceed pressure in the 'down' lines, because of the force of gravity acting on the landing gear, and thus result in partial closing of the doors. This is prevented by fitting a hydraulically operated sequence valve in the 'up' line, which blocks return flow until down line pressure, acting on the plunger, is sufficient to overcome the spring and open the valve. The ball valve is virtually a non-return valve, which does not significantly restrict flow when the landing gear is selected up.

6.6 **Modulators.** A modulator is used in conjunction with the anti-skid unit in a brake system. It allows full flow to the brake units on initial brake application, and thereafter a restricted flow. Figure 17 shows a modulator, the swept volume of which would be equal to the operating volume of the brake cylinders. During initial operation of the brake control valve, the piston is forced down the cylinder against spring pressure, and the brakes are applied. Subsequent fluid feed to the brakes, necessitated by anti-skid unit operation, is through the restricting orifice, and is very limited. This limited flow allows the anti-skid unit to completely release the brakes when necessary, and conserves main system pressure. When the control valve is released, the piston returns to its original position under the influence of the spring and the return fluid.

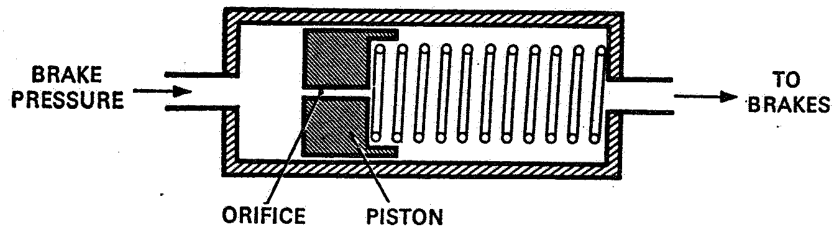

Figure 17 MODULATOR

6.7 **Flow Control Valves.** A flow control valve may be fitted in a hydraulic system to maintain a constant flow of fluid to a particular component; it is frequently found upstream of a hydraulic motor which is required to operate at a constant speed. A typical flow control valve is shown in Figure 18, and consists of a body and a floating valve. Flow through the valve head is restricted by an orifice, which creates a pressure drop across the valve head. At normal supply pressure and constant demand, the pressure drop is balanced by the spring and the valve is held in an intermediate position, the tapered land on the valve partially restricting flow through the valve seat, and maintaining a constant flow through the outlet. If inlet pressure rises, or demand increases, the pressure differential across the valve head also increases, and moves the valve to the left to reduce the size of the aperture and maintain constant flow. The spring loading is increased by the valve movement, and again balances the pressure drop. Similarly, if inlet pressure drops or demand decreases, the valve takes up a new position, slightly further to the right, so as to maintain a constant flow.

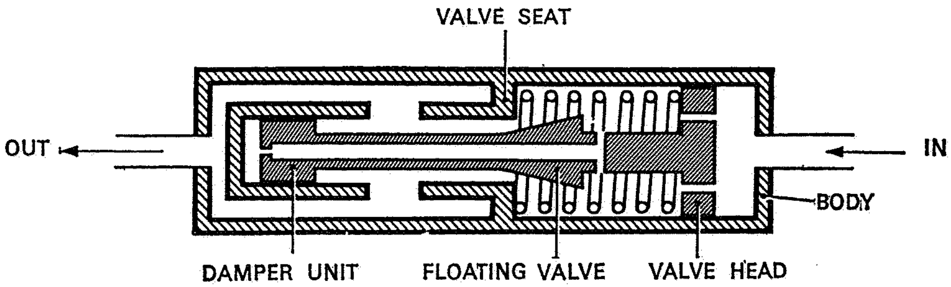

Figure 18 FLOW CONTROL VALVE

7 ACCUMULATORS An accumulator is fitted to store hydraulic fluid under pressure, to dampen pressure fluctuations, to allow for thermal expansion, and to provide an emergency supply of fluid to the system in the event of pump failure. A non-return valve fitted upstream of an accumulator, prevents fluid from being discharged back to the reservoir.

7.1 Three different types of accumulator are illustrated in Figure 19, but many other types are used. Accumulators of the type shown in (a), in which the gas is in contact with the fluid, are seldom used on modern high-pressure systems, as there is a possibility that the gas may be dissolved into the fluid, and thus introduced into the system. For this reason the accumulators shown in (b) and (c) are most commonly used.

7.2 The gas side of the accumulator is charged to a predetermined pressure with air or nitrogen. As hydraulic pressure builds up in the system, the gas is compressed until fluid and gas pressures equalise at normal system pressure. At this point the pump commences to idle, and system pressure is maintained by the accumulator. If a service is selected, a supply of fluid under pressure is available until pressure drops sufficiently to bring the pump on line.

7.3 The initial gas charge of the accumulator is greater than the pressure required to operate any service, and the fluid volume is usually sufficiently large to operate any service once; except that brake accumulators permit a number of brake applications.

7.4 The gas side of an accumulator is normally inflated through a charging valve, which may be attached directly to the accumulator, or installed on a remote ground servicing panel and connected to the accumulator by means of a pipeline. The charging valve usually takes the form of a non-return valve, which may be depressed by means of a plunger in order to relieve excessive pressure.

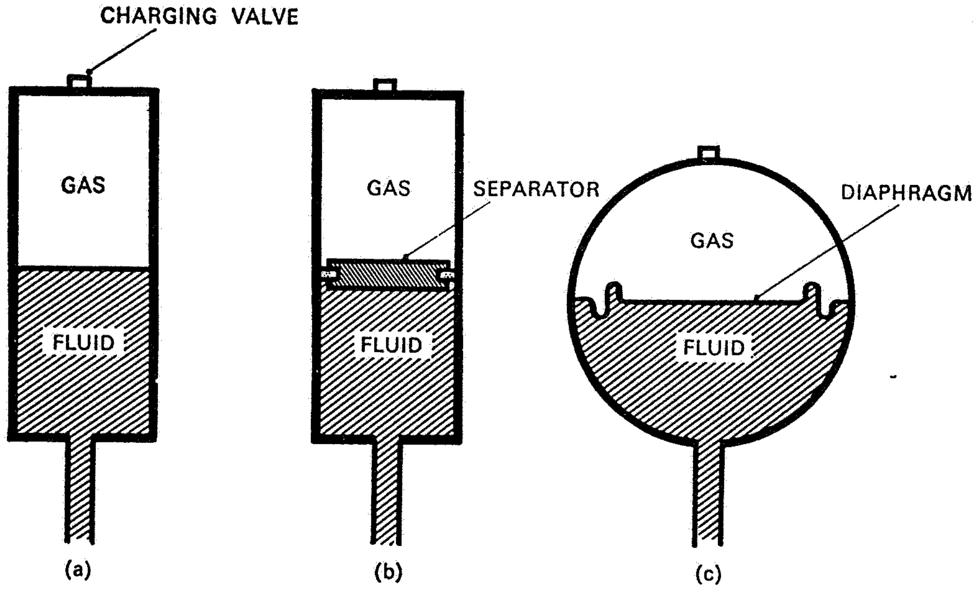

Figure 19 ACCUMULATORS

8 RESERVOIRS A reservoir provides both storage space for the system fluid, and sufficient air space to allow for any variations in the volume of fluid in the system which may be caused by thermal expansion and actuator operation. Most reservoirs are pressurised, to provide a positive fluid pressure at the pump inlet, and to prevent air bubbles from forming in the fluid at high altitude. On modern jet aircraft, air pressure is normally supplied from the compressor section of an engine, but it may be supplied from the cabin pressurisation system. Air entering the reservoir is filtered, and, in some cases, provision is also made for the removal of moisture.

8.1 A reservoir also contains a relief valve, to prevent over-pressurisation; connections for suction pipes to the pumps, and return pipes from the system; a contents transmitter unit and a filler cap; and, in some cases, a temperature sensing probe. In systems which are fitted with a hand pump, the main pumps draw fluid through a stack pipe in the reservoir. This ensures that, if fluid is lost from that part of the system supplying the main pumps, or supplied solely by the main pumps, a reserve of fluid for the hand pump would still be available.

9 ACTUATORS The purpose of an actuator is to transform fluid flow into linear or rotary motion. Figure 20 illustrates three types of simple linear actuator, which are used for different purposes in an aircraft hydraulic system. Numerous refinements to the simple actuator will be found in use, and these may include such features as internal locking devices, auxiliary pistons and restrictors, each designed to fulfil a particular requirement. Details of a particular actuator should be obtained from the appropriate Maintenance Manual.

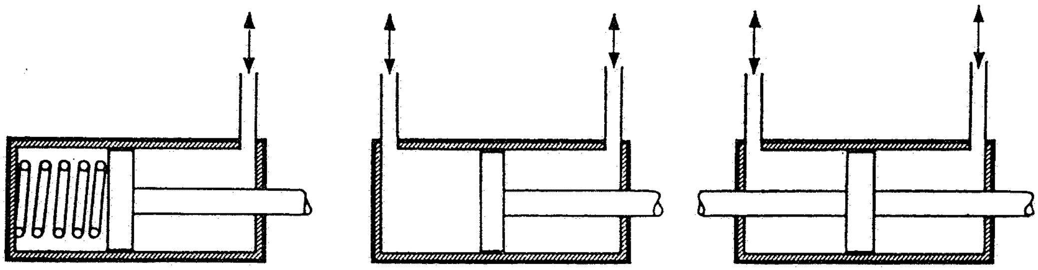

Figure 20 ACTUATORS

9.1 The single acting actuator is normally used as a locking device, the lock being engaged by spring pressure and released by hydraulic pressure. A typical application is a landing gear up-lock.

9.2 The double-acting actuator is used in most aircraft systems. Because of the presence of the piston rod the area of the top of the piston is greater than the area under it. Consequently, more force can be applied during extension of the piston rod. Therefore, the operation which offers the greater resistance is carried out in the direction in which the piston rod extends; for example, in raising the landing gear.

9.3 A balanced actuator, in which equal force can be applied to both sides of the piston, is often used in applications such as nose-wheel steering and flying control boost systems. Either one or both sides of the piston rod may be connected to a mechanism.

9.4 Hydraulic motors are a form of rotary actuator, and are sometimes connected through gearing to operate a screw jack, or to drive generators or pumps. In some aircraft they are used for driving a hydraulic pump unit, thus enabling power to be transferred from one hydraulic system to another without transferring fluid. The construction of a hydraulic motor is generally similar to the construction of a variable volume multi-piston pump. Hydraulic pressure directed through the inlet port forces the pistons against the angled yoke, causing rotation of the cylinder block and drive shaft. A starter valve is used to initiate rotation in the correct direction, and a governor, driven from the cylinder block, meters fluid to a control piston, altering the angle of the yoke according to the load placed upon the motor.

10 FILTERS Main filters are fitted in both suction and pressure lines in a hydraulic system, in order to remove foreign particles from the fluid, and to protect the seals and working surfaces in the components. In addition, individual components often have a small filter fitted to the inlet connection. Main filters usually comprise a filter head containing inlet and exhaust valves, and a sump which houses the filter element. Installation of the sump normally opens the valves, and removal of the sump normally closes them, so that the filter element can be removed without the need for draining the complete system.

10.1 Some filters are fitted with a device which senses the pressure differential across the filter element, and releases a visual indicator, in the form of a button, when the pressure differential increases as a result of the filter becoming clogged. False indication of element clogging, as a result of high fluid viscosity at low temperature, is prevented by a bi-metal spring which inhibits indicator button movement at low temperatures. Other filters are fitted with a relief valve, which allows unfiltered fluid to pass to the system when the element becomes clogged; this type of filter element must be changed at regular intervals.

10.2 Paper filter elements are usually discarded when removed, but elements of wire cloth may usually be cleaned. Cleaning by an ultrasonic process is normally recommended, but if a new or cleaned element is not available when the element becomes due for check, the old element may be cleaned in trichloroethylene as a temporary measure.

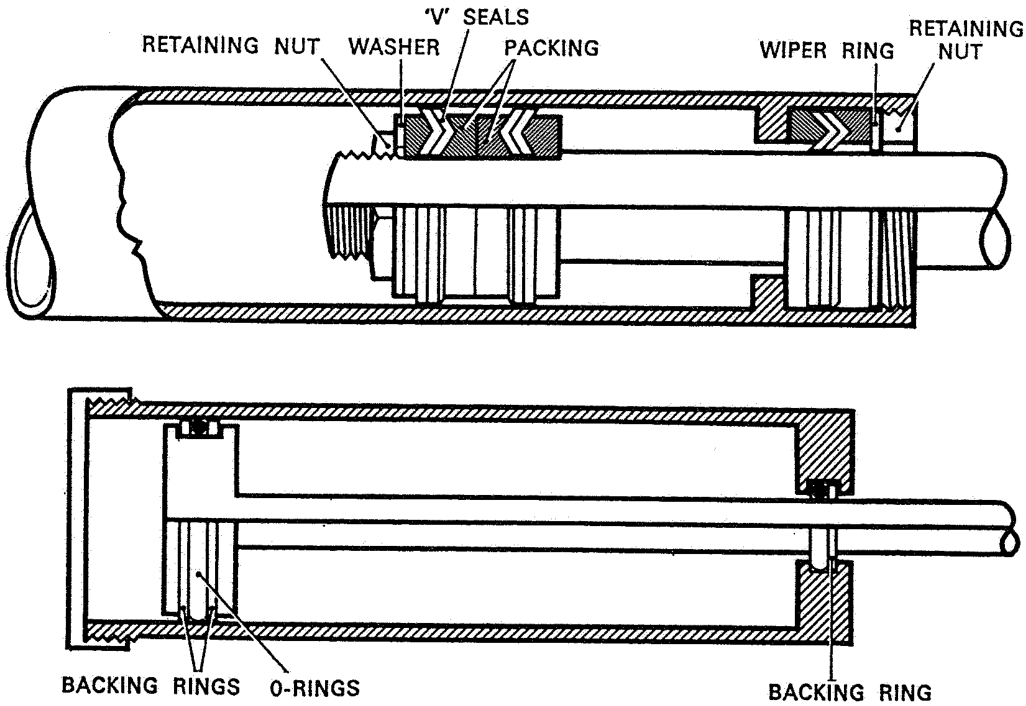

Figure 21 TYPICAL INSTALLATION OF SEALS

11 SEALS Seals perform a very important function in a hydraulic system, in preventing leakage of fluid. Static seals, gaskets and packing are used in many locations, and these effect a seal by being squeezed between two surfaces. Dynamic seals, fitted between sliding surfaces, may be of many different shapes, depending on their use and on the fluid pressures involved. 'U' and 'V' ring seals are effective in one direction only, but 'O' rings and square section seals are often used where pressure is applied in either direction.

Dynamic seals require lubrication to remain effective, and wetting of the bearing surface, or a slight seepage from the seals, is normally acceptable. Where high pressures are used, an 'O' ring is normally fitted with a stiff backing ring, which retains the shape of the seal and prevents it from being squeezed between the two moving surfaces. Seals are made in a variety of materials, depending on the type of fluid with which they are to be used; if a seal of an incorrect material is used in a system, the sealing quality will be seriously degraded, and this may lead to failure of the component. Typical seal installations are shown in Figure 21. Seals are easily damaged by grit, and a wiper ring is often installed on actuators to prevent any grit that may be deposited on the piston rod from contaminating the seals.

12 BASIC HYDRAULIC SYSTEMS There are two main types of system in use, the open-centre system and the closed system. The former is frequently found on light aircraft, and the latter, or a combination of the two, is found on most large aircraft.

12.1 **Open-centre System.** The main advantage of this system is its simplicity, and the main disadvantage is that only one service can be operated at a time. When no services are being operated, the pressure in the system is at a low value, pump output passing directly to the reservoir. Figure 22 shows a simple open-centre system which contains all the components necessary for operation. It should be noted, however, that when the actuator reaches the end of its travel, pressure will build up and remain at the relief valve setting until the selector is returned to neutral. This imposes a high load on the pump, which is normally overcome by fitting automatic-return selectors.

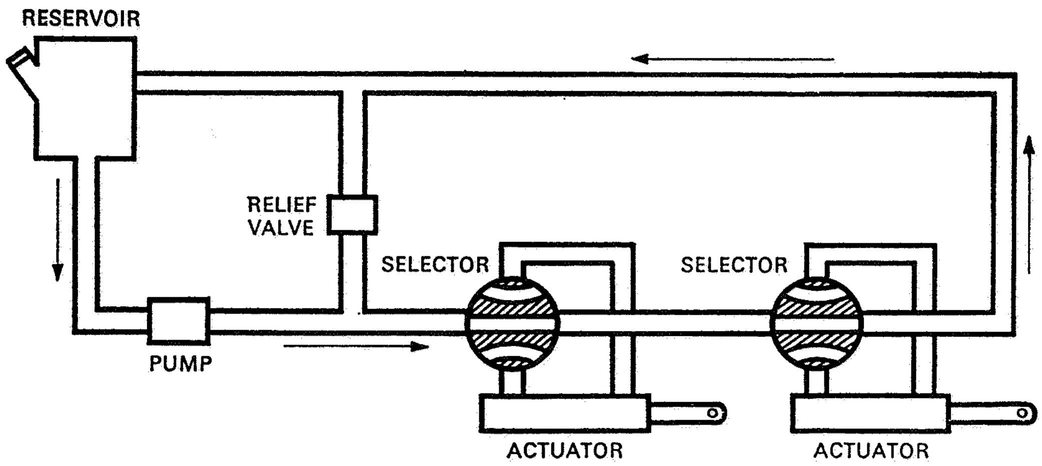

Figure 22 OPEN-CENTRE SYSTEM

12.2 **Closed System.** With this type of system, operating pressure is maintained in that part of the system which leads to the selector valves, and some method is used to prevent over-loading the pump. In systems which employ a fixed volume pump (Figures 2 or 3), an automatic cut-out valve is fitted, to divert pump output to the reservoir when pressure has built up to normal operating pressure. In other systems a variable volume pump (Figure 4) is used, delivery being reduced as pressure increases, whilst in some simple light aircraft systems, operation of an electrically-driven pump is controlled by a pressure-operated switch. A simple closed system is illustrated in Figure 23.

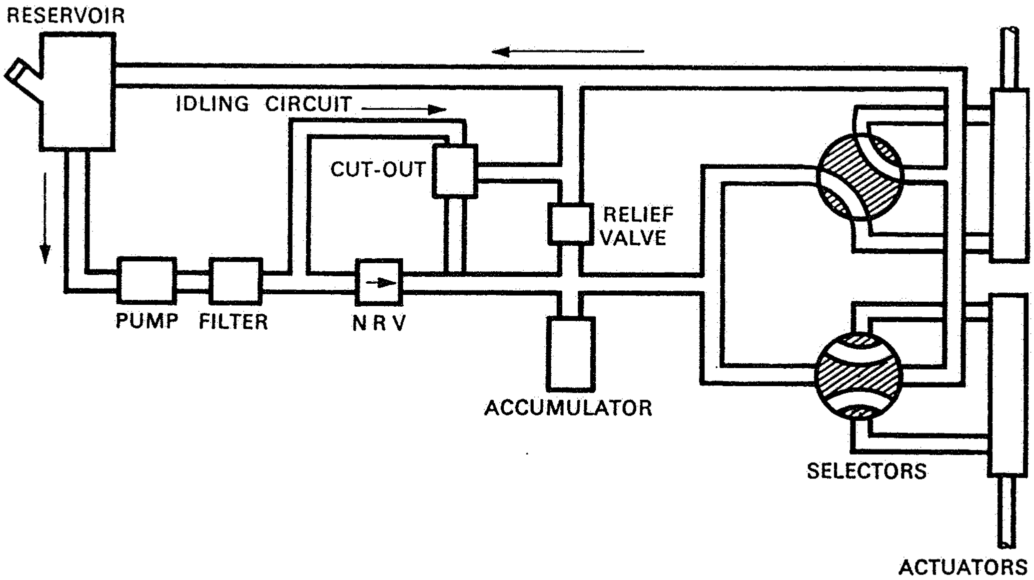

Figure 23 CLOSED SYSTEM

12.3 **Power Packs.** A power pack system is one in which most of the major components, with the exception of the actuators, and, with some systems, of the pumps, are included in a self-contained unit. The system may operate on either the open-centre or the closed system principle, and is widely used in light aircraft.

12.3.1 Figure 24 shows a simple power pack used for raising and lowering the landing gear. Power is provided by the accumulator, which is automatically re-charged by operation of the electrically-operated pump. When a selection is made, pressure in the accumulator drops and the plunger is raised until its collar contacts the trip switch arm, providing electrical power to the pump motor. As pressure builds up in the system, the accumulator plunger lowers until it contacts the switch arm and cuts off power to the pump motor. Pressure is constantly maintained between the pump cut-in and cut-out pressures, and power is constantly available for operation of the landing gear.

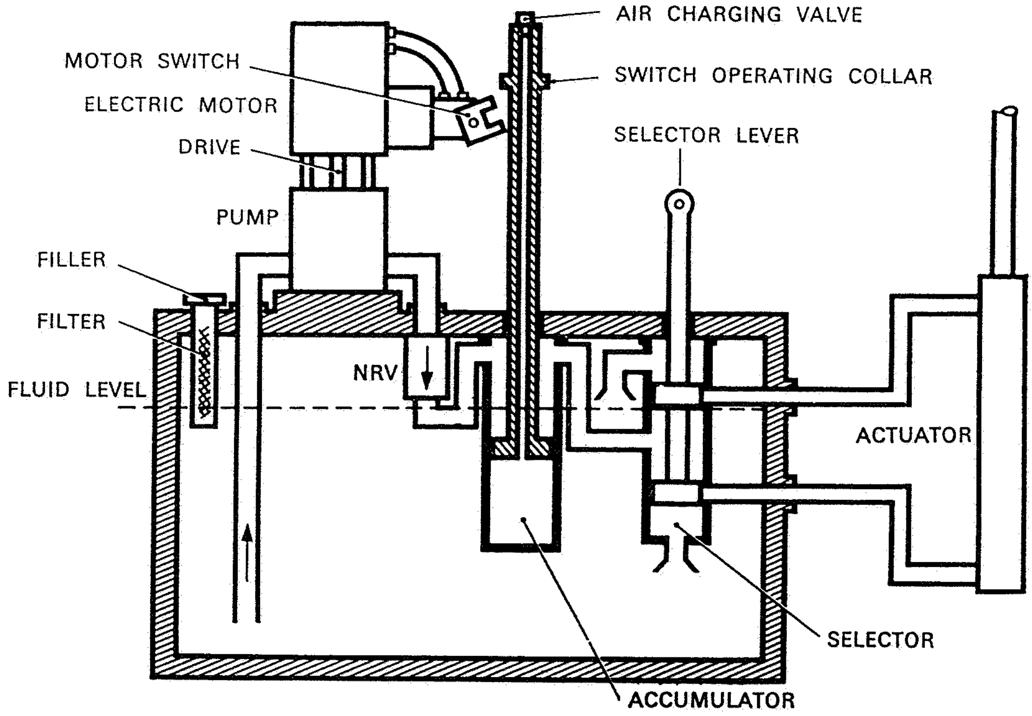

Figure 24 POWER PACK

13 AIRCRAFT INSTALLATIONS Light aircraft are often fitted with a power pack, or provided with a single hydraulic system of the open circuit type, which is powered by an engine-driven or electrically-driven pump. A hand pump is fitted to enable the flaps to be lowered in the event of main pump failure; landing gear up-locks are manually released to enable the landing gear to free-fall and lock down under its own weight. If a power-operated brake system is fitted, sufficient pressure is available in the accumulator to enable a landing to be made. Multi-engined transport aircraft usually have two or more self-contained hydraulic systems, each system providing power for the flying controls and some of the remaining services; in addition, facilities are provided for transferring power from one system to another following failure of a main pump. Alternative pumps, operated by a.c. or d.c. electrical power, or air turbines, are often provided for use in emergency. A cut-off valve is sometimes provided for each system, and this may be operated by use of the fire control handle.

13.1 Since weight is an important factor with aircraft, modern hydraulic systems tend to use very high pressures, thus enabling smaller diameter piping and jacks, and less fluid, to be used. Tubing in parts of the system containing fluid at maximum pressure is usually made from stainless steel, but tubing providing return flow only, or subjected solely to air pressure, is often made from aluminium alloy. Tubing used in the hydraulic system is labelled for recognition purposes in accordance with British Standard M23. This marking consists of a label with the word "HYDRAULIC" in black on a white, or blue and yellow, background, and a symbol in the form of a black circle on a white background. In addition, the sub-system, e.g. "LANDING GEAR", and the direction of flow may be added.

13.2 In most modern aircraft, a number of the major components such as accumulators, electrically-operated pumps, reservoirs, filters, drain valves, charging valves, and associated instruments, are grouped together in a hydraulic service bay, which is easily accessible for routine servicing operations.

13.3 **Instrumentation.** In many light aircraft, there is often no indication, in the cabin, of hydraulic system operation. Incorrect operation will, therefore, only become known to the pilot when a service is selected. However, an aircraft fitted with a power pack, as described in paragraph 12.3, will normally have a combined warning lamp/master switch on the instrument panel, which will indicate when the pump motor is operating, and will enable correct operation of the system to be determined. Larger aircraft normally have a hydraulic services panel in the crew compartment, which contains indicators covering parameters such as fluid quantity, pressure and temperature, and switches to control operation of emergency pumps and valves. The instruments and switches for each separate hydraulic system are normally grouped together, and the panel may be marked with a mimic diagram to assist the crew in transferring hydraulic power, or in overcoming an emergency situation. The components normally used are described in paragraphs 13.3.1 to 13.3.6.

13.3.1 **Quantity Indicators.** A clear window fitted in the reservoir provides a means of checking fluid level during servicing, but the reservoir may also be fitted with a float-type contents unit, which electrically signals fluid quantity to an instrument on the hydraulics panel in the crew compartment.

13.3.2 **Pressure Relays.** A pressure relay is a component which transmits fluid pressure to a direct reading pressure gauge, or to a pressure transmitter which electrically indicates pressure on an instrument on the hydraulics panel. In some cases both types of indication are provided, the direct reading gauge being fitted in the hydraulic equipment bay, adjacent to the relay. A typical pressure relay is shown in Figure 25. During normal operation the piston acts as a separator, transmitting fluid pressure to the gauge side. If a leak develops on the gauge side, the piston moves to the gauge end of the cylinder, and the valve seats in the cylinder head, thus preventing leakage from the system. The valve also permits bleeding when a new gauge, or gauge line, is fitted.

13.3.3 **Pressure Gauges.** Electrically operated pressure gauges are fitted on the hydraulics panel, to register main and emergency system pressures. Direct reading gauges are often fitted to the accumulators and reservoirs, to enable servicing operations to be carried out. Operation and maintenance of pressure gauges is dealt with in Leaflet **AL/10—3**, Engine Instruments.

13.3.4 **Pressure Switches.** Pressure switches are often used to illuminate a warning lamp, and to indicate loss of fluid pressure, or loss of air pressure in a reservoir. Such switches contain a diaphragm, which flexes under fluid or air pressure, this movement being transmitted to a micro switch, which, at the appropriate pressure, makes or breaks contact with the warning lamp.

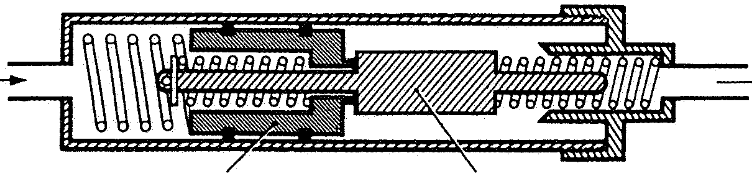

Figure 25 PRESSURE RELAY

13.3.5 **Flow Indication.** A flow indicator valve is often fitted in the outlet line from a pump, and is used to provide warning of pump failure. The valve comprises a body, a spring-loaded plunger connected to an actuator arm, and a micro-switch. During normal operation, fluid pressure overcomes spring pressure, and the plunger moves to allow full flow through the valve. If pump output decreases below a predetermined minimum, the spring loading overcomes fluid pressure, moving the plunger and actuator arm, and closing the micro-switch contact to illuminate the warning lamp.

13.3.6 **Temperature Indication.** Warning of fluid overheating is normally provided by a temperature sensing element in the reservoir. Warning of overheating of electrical motors which are used to operate emergency pumps, is normally provided by fitting a similar element in the motor casing. The sensing element takes the form of a bi-metal strip or rod arrangement, which operates a snap-action switch when the warning temperature is reached. Operation of the switch closes the contacts to an associated warning lamp.

13.4 **Components for Servicing Purposes.** A number of components are included in the hydraulic system specifically to facilitate servicing. These components are normally located in the hydraulic equipment bay.

13.4.1 **Quick-disconnect Couplings.** In positions where it is necessary to frequently disconnect a coupling for servicing purposes, a self-sealing, quick-disconnect coupling is fitted. The coupling enables the line to be disconnected without loss of fluid, and without the need for subsequent bleeding.

13.4.2 **Pressure Release Valves.** Pressure release valves are fitted to enable pressure to be released from the system for servicing purposes. The valves are manually operated, and consist of a valve body with an inlet and outlet port, the passage between the two being blocked by a spring-loaded valve. Operation of an external lever opens the valve against spring pressure, and allows fluid to flow from the accumulator to the reservoir.

13.4.3 **Drain Cocks.** Drain cocks are generally simple manually operated spherical valves, and are located in the hydraulics bay at the lowest point in the system. They are marked to indicate direction of flow, and are used to drain the system, when it is necessary to do so, in order to replace the fluid, or, in some systems, to change certain components.

13.4.4 **Fluid Sampling Points.** Fluid sampling points are suitably positioned in the suction and pressure lines, to enable samples of fluid to be removed for analysis. The component is usually a T-piece adaptor, the two main connections being connected in the system pipeline, and the third connection being fitted with a bleed screw.

13.4.5 **Ground Servicing Couplings.** These components are included in most hydraulic systems, and enable the system to be tested using a ground test rig. The coupling is self-sealing, and is similar to the quick-disconnect coupling, one half being located in the aircraft and the other on the test rig. When not in use the coupling is sealed by a dust cap.

14 POWERED FLYING CONTROLS Because of the high loads imposed on the flying control surfaces, modern transport aircraft are provided with power-operated or power-assisted controls. Because of the importance of the flying control system, hydraulic power to each control surface is provided by at least two independent hydraulic systems (sometimes using separate actuators) plus an emergency system operated by electrical power or by ram air turbines. In addition, some systems allow for reversion to manual operation of the control surfaces, or tabs, in the event of all hydraulic systems failing.

14.1 A hydraulic sub-system for the operation of the flying controls, is often fed through a priority valve, which ensures that fluid under pressure is always available; the sub-system may also have a separate accumulator.

14.1.1 The unit which moves a control surface is a combined selector valve and actuator, usually known as a servo-control unit, the selector being connected by cables and rods to the pilots' controls. A typical servo-control unit is illustrated in Figure 26. With hydraulic power available, operation of a pilot's control moves the spool in the selector, thus directing fluid to one side of the actuator and opening a return path from the other side. Movement of the actuator operates the control surface, and at the same time moves the selector back towards the neutral position. When control surface movement corresponds to the deflection of the pilots' control, the selector is in the neutral position, and fluid is locked in the actuator. When no hydraulic pressure is available, the interconnecting valve opens under spring pressure and the actuator is free to move. The control may then be operated by alternative servo-control units, or by manual linkage, depending on the particular installation.

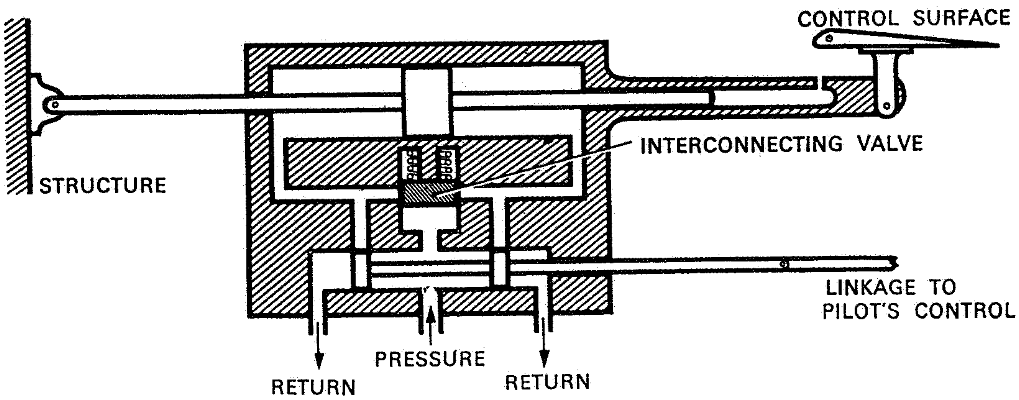

Figure 26 SERVO-CONTROL UNIT

14.2 An alternative method of operating the flying controls is by means of self-contained powered flying control units (PFCU's). Control surfaces are divided into sections, and each section is operated by a separate PFCU, thus providing duplication to guard against failure of a unit. Each unit is controlled by mechanical linkage from the pilots' controls, and some units also accept electrical inputs from the auto-pilot and auto-stabilizer. The mechanical input rod to each unit is telescopic and spring loaded, so that failure of one PFCU will not prevent operation of the associated control system. In the event of failure, or when a unit is inoperative, the actuating ram is mechanically locked in the neutral position, thus preventing movement of the associated section of the control surface. Actual operation is basically similar to that of the servo-control unit described previously, but each PFCU is a self-contained hydraulic system, and is not connected with the main hydraulic system, or with other PFCU's. The main body of each PFCU acts as a reservoir, and houses all the components necessary for operation of the unit, including electrically driven pumps and hydraulic actuator.

15 INSTALLATION AND MAINTENANCE Aircraft installations vary considerably, and the appropriate Maintenance Manual should be consulted before any work is carried out on the hydraulic system of any particular aircraft. Failure to observe the precautions detailed by the manufacturer could lead to damage to the aircraft, and, possibly, to physical injury. Even when the aircraft pumps are stationary, high pressures are maintained in parts of the system by the accumulators, and no disconnections should be made while the system is pressurised. Any specific instructions regarding the isolation of electrical circuits, or the fitting of hydraulic safety locks during servicing, should be carefully followed.

15.1 **Cleanliness.** With a modern hydraulic system cleanliness is of the utmost importance. The filters fitted in the aircraft system will normally protect the components from the effects of particle contamination, but it is important that any ground equipment used for servicing purposes is kept scrupulously clean, and that the fluid is filtered to a similar standard. Contamination from other fluids must also be avoided, and provision is usually made for taking fluid samples. Whenever a connection is broken, or a component is removed, precautions must immediately be taken to prevent the ingress of foreign matter or moisture. If it is necessary to top-up the system, fluid should be poured directly from a new fluid container into the reservoir, or a sealed dispensing rig should be used. When the system is topped-up from a can, any unused fluid should be discarded.

15.2 **Sampling.** Samples of the system fluid should be taken at the periods specified in the approved Maintenance Schedule, and whenever contamination is suspected. If a fluid sampling kit is available it should be used strictly in accordance with the manufacturers' instructions, but, if such a kit is not available, the sample should be sent to a laboratory for examination.

15.2.1 The bottle into which the fluid is drained must be scrupulously clean, to avoid adding to any contamination that may already be present in the sample. The bottle should be washed with soap and water to give a clean, bright finish, rinsed in clean water, then in filtered alcohol, and dried with clean dry air. It is usually recommended that plastic sheet is interposed between the bottle and the cap, to prevent the formation of loose particles when the cap is screwed on.

15.2.2 When taking a sample, a suitable service should be operated to circulate the fluid, and a small quantity should be drained from the sampling point before filling the sample bottle. Every precaution should be taken to prevent contamination of the sample, and any instructions contained in the Maintenance Manual, or in the test kit, should be carefully followed.

15.2.3 The action which it is necessary to take following the testing of a sample of fluid, will depend on the degree of contamination found. The parameters to be tested are—acidity, specific gravity, viscosity, water content, and particle contamination, and acceptable values are specified in the appropriate Maintenance Manual. If slight contamination is present, the fluid should be circulated by operation of the services, and a further sample taken. If heavy contamination is found, the affected system should be flushed or drained, and re-filled with clean fluid.

15.3 **Flushing.** Flushing is normally required after extensive removal and replacement of pipelines or components, and is carried out by operating the particular service a number of times, so that any particle contamination may be trapped by the filters. When it is necessary to flush the main system, the filters should be changed and the fluid should be circulated by operating the largest hydraulic jacks a number of times. Either an auxiliary pump, or an external hydraulic test rig, may be used for flushing, but, if an auxiliary pump is used, it is normally recommended that it is subsequently removed and inspected for possible damage.

15.4 **Draining the System.** The hydraulic system should be drained whenever components which are not provided with self-sealing couplings have to be removed, and also when overheating or mechanical failure of a pump, or the introduction of extraneous fluids or foreign matter, has resulted in contamination of the system.

15.4.1 It is common practice to disconnect the engine-driven pump from the system before commencing draining, so as to prevent the formation of air locks in the pump and to maintain lubrication when the pump is rotated.

15.4.2 The hydraulic system should be made electrically safe (by the tripping of circuit-breakers or the removal of fuses, as appropriate), the hydraulic pressure should be released by operating one of the services, and the air pressure should be released from the accumulators and reservoir. The reservoir filler cap should be removed, and fluid should be drained into a clean container of suitable capacity, by means of the system drain cock. Drained fluid should be returned, in appropriately identified containers, for reclamation by an approved process.

15.4.3 If fluid contamination is the reason for draining, it will also be necessary to remove the filters, and to clean or replace the filter elements as appropriate. Cleaning is usually by an ultrasonic cleaning process, but washing in trichloroethylene may also be permissible as a temporary measure.

15.5 **Filling the System.** Following initial installation, and whenever the fluid has been drained, the system should be filled and primed. Filling may be carried out through the reservoir filler neck, or through a priming connection in the ground servicing bay, using an external priming rig. The system is pressurised for priming purposes by using either an aircraft electrically-operated pump, or an external hydraulic test rig.

15.5.1 To ensure correct operation of the system, all air must be removed from the pipelines and components. Some components are bled by slackening the pipe connections, allowing fluid to escape, then retightening; some components are fitted with bleed valves, and others are purged by operating the service and forcing any trapped air to return to the reservoir.

15.5.2 The aircraft should be jacked in accordance with the relevant Maintenance Manual, and the accumulators should be charged with air or nitrogen, as appropriate. Ground electrical power should be connected, and the appropriate fluid and pump overheat warning lamps should be tested.

15.5.3 The reservoir filler cap should be removed, the system should be completely filled with fluid, and the quantity indicators should be checked. The system should be pressurised to normal system pressure, using the electrically operated pump or test rig as appropriate, and one of the services should be operated until the reservoir fluid level has stabilised. Trapped air should be released from the reservoir, and fluid added to keep the level at maximum. This process should be repeated for each service, bleeding being carried out where appropriate, and careful watch being kept on the pump and fluid temperatures. Fluid bled or drained from components must not be returned to the system.

15.5.4 After each service has been primed, the fluid level should again be checked. In some systems the fluid level depends on the positions of various actuators, and, before checking the fluid level, it is necessary to make the appropriate selections, and to ensure that all accumulators and reservoirs are fully charged.

15.5.5 When filling and priming are completed, all connections should be checked for tightness, and locked. Electrical power (and the hydraulic test rig, if used) should be disconnected, and the aircraft should be lowered to the ground. Engines should be run to check correct operation of the hydraulic services.

15.6 **Replacement of Components.** Before removing any components in the system, fluid pressure should be released by operating an appropriate service a number of times, and gas pressure should be released by means of the accumulator gas charging valve and the reservoir filler cap. Care should be taken to release gas pressure slowly. In addition, it may be necessary to electrically isolate some components by tripping the associated circuit-breaker, or by removing a fuse, making due note of the circuits disconnected, for reference when re-assembling. Electrical isolation is preferable, in order to avoid any possibility of inadvertent selection, whether or not power is available at that time. Some components, such as the engine-driven pumps, are connected into the system by quick-release couplings, so that they may be removed without disturbing the rest of the system, but it may be necessary to drain the system in order to remove other components. In instances where a component, such as a pump, has to be removed because of mechanical failure, the fluid may have been contaminated by metal particles, and it will be necessary to clean the filters, drain the old fluid, and flush the system with clean fluid.

15.6.1 Care should be taken not to spill any fluid drained from the system, and pipes should be blanked immediately they are disconnected. Blanks should not be removed until immediately prior to fitting the new component.

15.6.2 **Installation.** Replacement components must be checked to ensure that they have the correct part number, that they are to the correct modification standard, and that storage life has not been exceeded. The age of replacement seals is particularly important. If the components are filled with storage oil, they should be drained and flushed, then filled with system fluid before installation. Care should be taken, when fitting the pipes, to ensure that the connections meet properly; flexible pipes should not be allowed to twist when the end fittings are tightened, and the associated mechanism should be operated to ensure that the pipes are not stretched or kinked, and do not foul any adjacent structure. Any adjustments to sequence valves, micro-switches and linkage, should be carried out in accordance with the relevant Maintenance Manual, to ensure correct operation of the service and its associated signalling and warning systems. Where necessary, the system should be filled and primed, and all connections should be tightened to the specified torque, and locked, as appropriate.

15.6.3 Actuators usually have a range of movement slightly greater than that of the service they operate. This both ensures that the actuator piston will not bottom in its cylinder before operation of the service is complete, and allows for vibration and flexing of the structure. Adjustable actuators are often used to operate the over-centre linkage on a landing gear, and these are initally adjusted so that the attachment pins are an easy fit; they are then lengthened by one turn of the eye-end, to make sure that the actuator piston will not bottom and inadvertently release the over-centre lock. After adjustment, the eye-end should be checked to ensure that it is still in safety, i.e. that the thread can be seen in the hole provided in the piston rod for this purpose. Another example of an adjustable actuator, is the single acting actuator used as a locking device, although in this case, the actuator cylinder may be adjustable for length. These actuators are adjusted in a similar way, to ensure that the lock is always under spring pressure.

15.6.4 **Testing.** In order to carry out functional tests, the system must be full, accumulators must be charged with air or nitrogen to the correct pressure, and the electrical circuits must be re-connected. Power for operation of the system may be provided by an engine-driven pump, by an aircraft electrically-operated pump, or by an external hydraulic test rig. All hydraulic controls and switches should be set to their appropriate operating positions, and the system should be checked for correct operation, service operating times, and signs of fluid leakage. Both the normal and emergency systems should be operated, and all gauges, instruments and warning lights should be checked for correct operation, according to the particular aircraft system. Full normal functioning tests should be carried out after testing the emergency systems, to ensure that shuttle and emergency valves are returned to their normal positions.

15.7 **Routine Maintenance.** The procedures outlined below are applicable to most aircraft hydraulic systems, but the detailed requirements for a particular system should be obtained from the approved Maintenance Schedule.

15.7.1 Lubrication of pivots and linkages should be carried out at the specified intervals.

15.7.2 Filters and chip detectors should be removed for examination and cleaning, and fluid samples should be taken and sent for analysis whenever contamination is suspected. Filter sumps should be cleaned, and a new gasket or seal should be fitted when changing the filter element.

15.7.3 Exposed actuator rods should be cleaned, and wiped with a lint-free cloth moistened with system fluid.

15.7.4 The fluid level in the reservoirs should be checked and topped-up as necessary. A certain amount of fluid may be lost through heating and seepage past seals, but the amount lost should remain fairly constant. If the level is unusually low, the system should be checked for leakage.

15.7.5 The gas pressure in the accumulators should be checked, and the cause of any excessive loss of pressure should be investigated. Internal leakage past the separator or diaphragm, may introduce gas into the fluid, and external leakage would reduce the effectiveness of the accumulator.

15.7.6 All system components should be examined for damage, corrosion, leaks and security. Pipes should be examined for kinks, dents, chafing, leaks, and security.

15.8 **Checks for System Deterioration.** Sluggish or erratic operation of a hydraulic system may be caused by external leakage from components or joints, or by internal leakage resulting from erosion, or faulty seals. A small amount of external leakage may not seriously affect system operation, and some Maintenance Manuals specify acceptable limits. Temperature indicators installed in some aircraft hydraulic systems will, since flow produces heat, give some warning of incipient failure; but internal leakage tests are generally only conducted at specified intervals, or when faulty system operation is reported. Depending on the type of system installed, either flow rate or leak rate checks are carried out, an external hydraulic test rig usually being connected to the aircraft, and the hydraulic system usually being prepared for normal operation.

15.8.1 **Flow Rate Check.** This check is carried out with a flow indicator installed in line with the external test rig, the hydraulic services being systematically operated in the manner prescribed in the relevant Maintenance Manual, and the flow rates being recorded. Flow through a particular component may be checked by comparing the flow reading at various actuator positions, but some aircraft are fitted with a maintenance hydraulic power system, which uses separate pipelines and isolation cocks to facilitate flow rate checks. Components with internal leakage greater than the maximum permitted, should be removed for investigation.

15.8.2 **Leak Rate Check.** For this check, the system should be pressurised to normal operating pressure, then the test rig should be quickly turned off and the time taken for system pressure to decay by a prescribed amount, should be recorded. If the leakage rate is excessively high, parts of the system may be checked individually, by blanking appropriate connections and recording the leakage rate through particular components, or groups of components. In some cases, leakage through a component, such as an actuator, may be checked by disconnecting one pipeline, applying system pressure to the opposite connection, and measuring the quantity of fluid discharged through the open port over a specified time. Components showing excessive leakage should be removed for examination and possible replacement of seals.

15.9 **Seals.** When it becomes necessary to remove a component with a gasket or static seal fitted to the joint face, or to disassemble a component containing static or dynamic seals, the old gaskets or seals should be discarded, and new ones should be fitted. A new seal should be checked to ensure that it is the correct size, and of the correct material for the type of fluid in the system, and to ensure that the shelf-life, where applicable, has not been exceeded.

15.9.1 Extreme care must be exercised when handling and fitting a seal, and a suitable assembly tool or guide should be used where necessary; a tubular guide should be used when passing a seal over a thread. Scratches and nicks must be avoided, and the seal must not be stretched excessively; it is particularly important to check 'O' rings after assembly to ensure that they are not twisted. Seals should normally be lubricated with system fluid before assembly, and in some instances it is recommended that they should be soaked in fluid for a specified time.

15.9.2 In some cases a number of seals are used together, or in an assembly with backing rings or wiper rings. It must be ensured that these components are fitted facing in the correct direction, and in the correct sequence, otherwise leakage and failure of the component may result.

15.9.3 Backing rings of nylon or similar material may be supplied uncut. The join should be cut at 45°, and the ends should be trimmed to produce the gap specified in the appropriate Maintenance Manual.

15.9.4 Rings made from polytetrafluoroethylene (PTFE) require particular care during assembly, as undue stretching or kinking could result in permanent damage. A tapered mandrel should normally be used during assembly, to minimize stretch, with the larger diameter the same size as the land over which the ring must pass. It is recommended that the component to which the ring is fitted should not be assembled for 30 minutes, to enable the ring to relax.

16 STORAGE Hydraulic components are normally packed in sealed containers or plastic bags, and should not be unpacked until required for use. They should be stored in conditions which are dry and free from corrosive fumes.

16.1 Assemblies containing seals, or other non-metallic parts, are normally filled with system fluid or storage oil, and all connections are securely blanked to prevent leakage or ingress of dirt or moisture. Pipes are usually blanked and stored in a dry condition, and care must be taken to ensure that flexible pipes are stored in the shape in which they have been manufactured or which they have assumed during use. Particular care should be taken with pipes manufactured from PTFE, which has a low structural strength, and which may become permanently kinked if bent.

16.2 Storage life of assemblies is determined by the life of the non-metallic parts, and depends on the material from which those parts are made. The life of rubber components is dependent upon storage conditions, and may be limited, but the life of PTFE parts may be indefinite. The date of packing, and the storage life, should be marked on the container, but storage life may also be checked by reference to the appropriate Maintenance Manual.

16.3 Components removed from storage should be checked, before installation, for damage and corrosion. Components which have been stored dry, or have been filled with storage oil, should be flushed with system fluid, and every precaution should be taken to prevent the ingress of dirt or moisture.

AL/3-22

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AIRCRAFT
SYSTEMS AND EQUIPMENT
HIGH PRESSURE PNEUMATIC SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the operation and maintenance of high-pressure pneumatic systems in aircraft, and no attempt is made to describe any particular system in detail. Any maintenance work on an aircraft or system should be carried out in accordance with the procedures defined by the manufacturer, and the Leaflet should, therefore, be read in conjunction with the relevant manuals for the aircraft concerned.

1.1 Information on associated subjects will be found in Leaflets **BL/6-15**—Manufacture of Rigid Pipes, **BL/6-30**—Torque Loading, **AL/3-13**—Flexible Pipes, **AL/3-14**—Installation of Rigid Pipes in Aircraft, and **AL/3-19**—Wheels and Brakes.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet **AL/5-1**, Issue 2, 15th June, 1962.

2 GENERAL The use of a compressed-air system to operate an aircraft's services usually represents a saving in weight compared to a hydraulic system, since the operating medium is freely available, no return lines are necessary, and pipes can be of smaller diameter. Systems having operating pressures of up to 24 MN/m^2 (3,500 lbf/in^2) are in use, and provide for the rapid operation of services when this is required. However, compressed air is generally not suitable for the operation of large capacity components, leaks can be difficult to trace, and the results of pipeline or component failure can be very serious.

2.1 Extensive high-pressure pneumatic systems powered by engine-driven compressors are generally fitted on the older types of piston-engined aircraft and are used to operate services such as the landing gear, wing flaps, wheel brakes, radiator shutters and, at reduced pressure, de-icing shoes. There are some modern aircraft which also use a high-pressure pneumatic system, however, and there are many aircraft which use pneumatic power for the emergency operation of essential services; the latter type of system is usually designed for ground-charging only.

2.2 Low-pressure pneumatic systems such as are used on most turbine-engined aircraft for engine starting, de-icing, and cabin pressurization, are supplied with compressed air tapped from the engine compressor and are not dealt with in this Leaflet.

3 TYPICAL SYSTEM This paragraph describes both a typical high-pressure pneumatic system, and the types of components which could be used.

3.1 The system illustrated in Figure 1 contains two separate power circuits, each of which is supplied by a four-stage compressor driven from the gearbox of one main engine, and a common delivery pipe to the high-pressure storage bottles and system services. A multi-stage cooler attached to each compressor cools the air between each of the compression stages, and a means is provided for off-loading the compressor when the system is not being used.

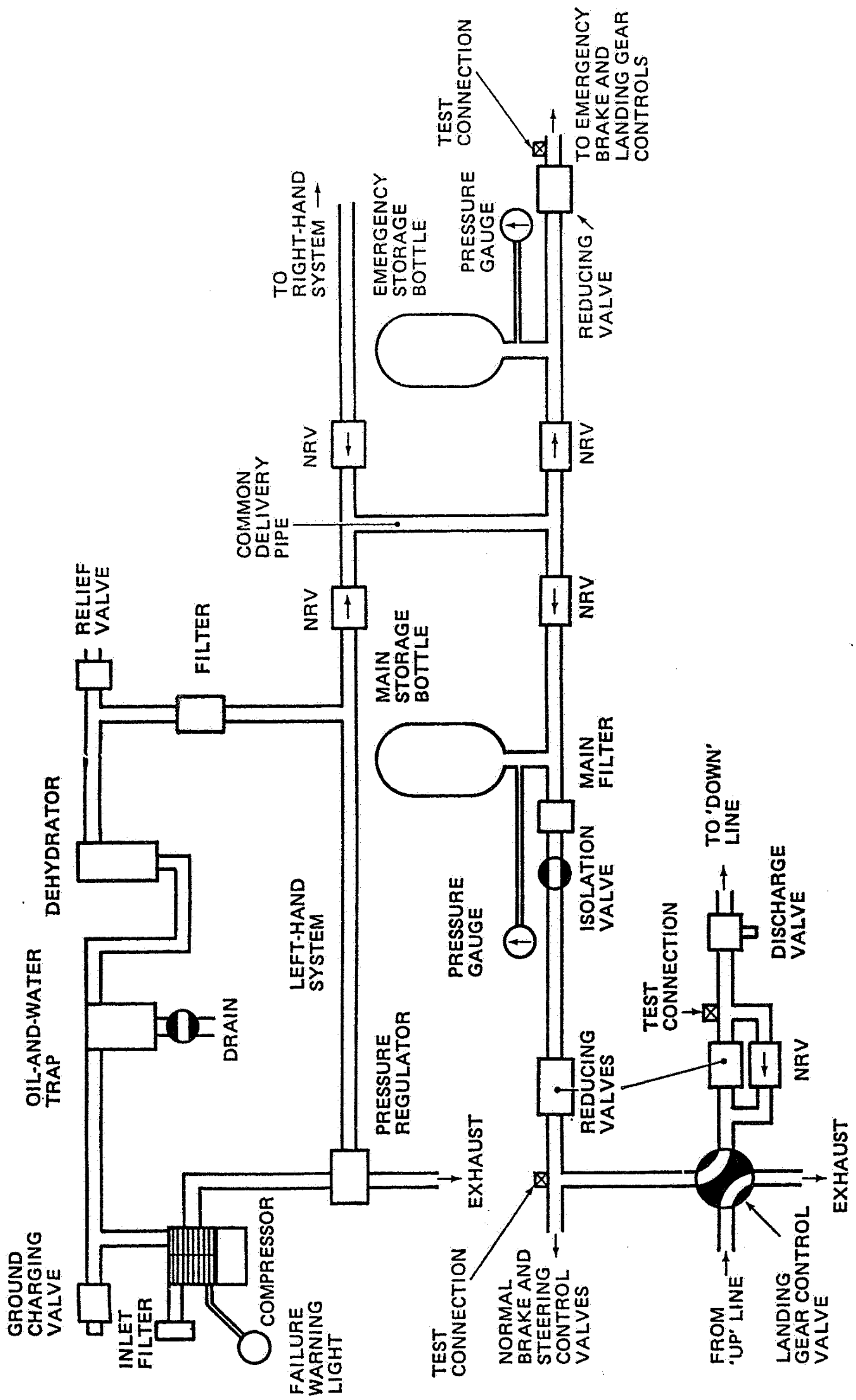


Figure 1 TYPICAL HIGH-PRESSURE PNEUMATIC SYSTEM

3.2 Air is drawn through an inlet filter into each compressor, and is discharged through an oil-and-water trap, a chemical dehydrator, a filter and a non-return valve, to the main storage bottle and system. Overall control of main system pressure is provided by means of a pressure regulator, but pressure relief valves are included to prevent excessive pressures in the system, which may be caused by regulator failure or by an increase in temperature in the pipelines and components. Pressure reducing valves are used to reduce the pressure supplied to some components.

3.3 A storage bottle for the emergency system is pressurized through a non-return valve from the main system supply, and maintains an adequate supply of compressed air to enable the landing gear and flaps to be lowered, and the brakes to be applied a sufficient number of times to ensure a safe landing.

3.4 Isolation valves are fitted to enable servicing and maintenance to be carried out without the need to release all air from the system, and pressure gauges are provided to indicate the air pressure in the main and emergency storage bottles.

4 COMPONENTS The types of components used in a high-pressure pneumatic system will vary considerably between aircraft, but the examples considered in this paragraph are typical of the components which may be found in current use.

4.1 **Compressors.** A positive-displacement pump is necessary to raise the air pressure sufficiently for the operation of a pneumatic system, and a piston-type pump is generally used. Some older types of aircraft are fitted with a single-cylinder piston pump, which provides two stages of compression and raises the working pressure to approximately 3 MN/m^2 (450 lbf/in^2). To obtain higher working pressures further compression stages are required. The compressor described in paragraphs 4.1.1 to 4.1.3 is capable of raising air pressure in four compression stages to 24 MN/m^2 (3,500 lbf/in^2).

4.1.1 The compressor illustrated in Figure 2 has two stepped cylinders, each of which houses a stepped piston; a plunger attached to the head of No. 2 piston operates in a small cylinder bored in the head of No. 2 cylinder. The reciprocating motion of the main pistons is provided by individual cranks and connecting rods, the cranks being rotated by a common drive gear, and rotating in the same direction. Air passing between each compression stage is routed through an integral cooler, and lubrication is provided by an oil feed connection from the main engine lubrication system.

4.1.2 Compression depends on the volume of each successive stroke being smaller than the stroke preceding it; the induction strokes for each cylinder and the four compression strokes are accomplished during each revolution of the cranks. Operation of the compressor is as follows:—

(a) On the downward stroke of No. 1 piston, air is drawn into the cylinder head through a filter and non-return valve (NRV).

(b) On the upward stroke of No. 1 piston, air is compressed in the cylinder, opens a NRV in the cylinder head, and passes to the annular space formed between the steps of the cylinder and piston.

(c) The next downward stroke of No. 1 piston compresses air in the annular space in this cylinder and forces it through a NRV into the annular space formed between the steps of No. 2 cylinder and piston. No. 2 piston is approximately 90° in advance of No. 1 piston, and is moving upwards as No. 1 piston approaches the bottom of its stroke.

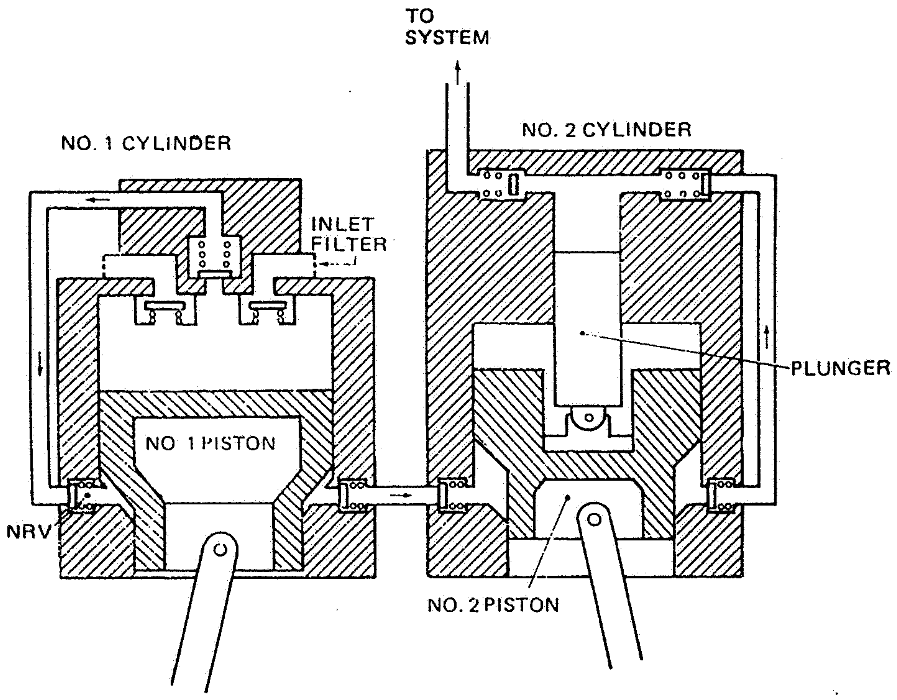


Figure 2 AIR COMPRESSOR

(d) On the downward stroke of No. 2 piston, air is compressed in the annular space at the bottom of the cylinder, and passes through a NRV into the small cylinder formed in No. 2 cylinder head.

(e) On the upward stroke of No. 2 piston, the plunger attached to it also moves upwards, further compressing the air in the small cylinder and passing it through a NRV to the system.

4.1.3 A pressure warning transmitter is fitted at the second-stage outlet, and third-stage pressure is connected to the pressure regulator (paragraph 4.2).

4.2 **Pressure Regulator.** The pressure regulator is fitted to control the maximum pressure in the system and to off-load the compressor when the system is idle. With the regulator illustrated in Figure 3, system pressure is fed to the top connection and acts on a piston, the lower end of which is in contact with the ball of a spring-loaded ball valve. At the predetermined maximum system pressure, the air pressure on the piston overcomes spring pressure and the ball valve is opened, releasing third-stage compressor pressure to atmosphere and allowing the pump to operate at second-stage pressure only. If any pneumatic services are operated, or a leak exists in the system, the air pressure trapped in the storage bottle and pipelines will drop, and the ball valve in the pressure regulator will close. The compressor will thus be brought back on line until the maximum system pressure is restored.

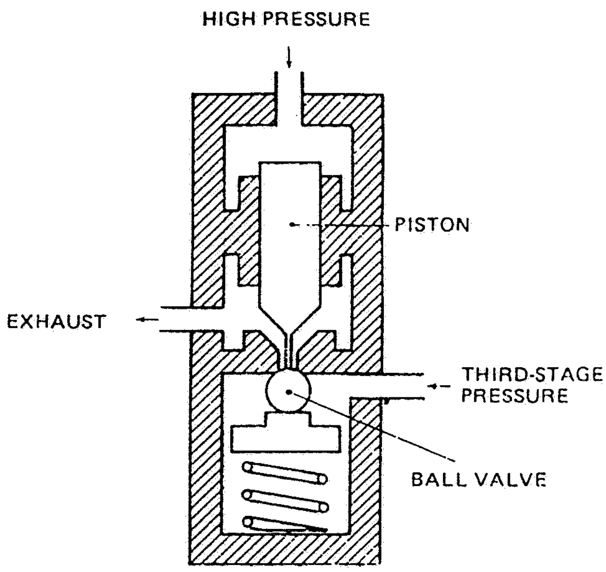


Figure 3 PRESSURE REGULATOR

4.3 **Oil-and-Water Trap.** The oil-and-water trap is designed to remove any oil or water which may be suspended in the air delivered by the compressor. It consists of a casing with inlet and outlet connections at the top and a drain valve in the bottom. Air entering the trap does so through a stack pipe, which includes a restriction and a baffle to prevent the air flow stirring up any liquid or sediment in the bottom of the container. Air leaving the trap also passes through a stack pipe, to prevent liquid or sediment entering the system during aircraft manoeuvres.

4.4 **Dehydrator.** To protect pneumatic systems from malfunctioning due to moisture freezing in the components and pipelines, the compressed air may be dehydrated by a substance such as activated alumina, or it may be inhibited by a small quantity of methanol vapour. The handling of methanol presents some difficulties, however, and because of its corrosive nature systems must be specially designed for its use; activated alumina is, therefore, more generally used.

4.4.1 Activated alumina is housed in a container through which the compressed air passes after leaving the oil-and-water trap, and which generally contains a filter at the outlet end. The charge of alumina in the container will gradually become saturated with moisture, and should be changed at the specified intervals. The number of flying hours at which the alumina charge is changed is normally determined by the aircraft manufacturer through practical experience.

4.5 **Storage Bottles.** In a pneumatic system the storage bottles provide the reservoir of compressed air which operates all services, the compressors being used to build up system pressure when it falls below the normal level. The volume of the actuators and pipelines determines the size of the bottles required for the normal and emergency operation of the pneumatic services.

4.5.1 Storage bottles are generally made of steel, and may be of wire-wound construction for maximum strength. Bottles are generally mounted in an upright position, and a fitting screwed into the bottom end contains the supply connection and, usually, a connection to an associated pressure gauge, together with a drain valve by means of which any moisture or sediment may be removed. Stack pipes are provided at the supply and gauge connections in the fitting, to prevent contamination passing to the system or pressure gauge. Pressure testing of high-pressure storage bottles is required at specified periods, and the date of testing is usually stamped on the neck of the bottle.

4.6 **Pressure Reducing Valves.** Some services operate at pressures lower than the pressure available in the air bottle, and are supplied through a pressure reducing valve. This low pressure is, in some instances, further reduced for the operation of, for example, the wheel brakes, by the fitting of a second pressure reducing valve.

4.6.1 Figure 4 illustrates the operation of a pressure reducing valve. When pressure in the low-pressure system is below the valve setting, the compression spring extends and, by the action of the bell-crank mechanism, moves the inlet valve plunger to admit air from the high-pressure system. As pressure in the low-pressure system increases, the bellows compresses the spring and returns the inlet valve plunger to the closed position. The inside of the bellows is vented to atmosphere, and the valve thus maintains a constant difference in pressure between the low-pressure system and atmospheric pressure.

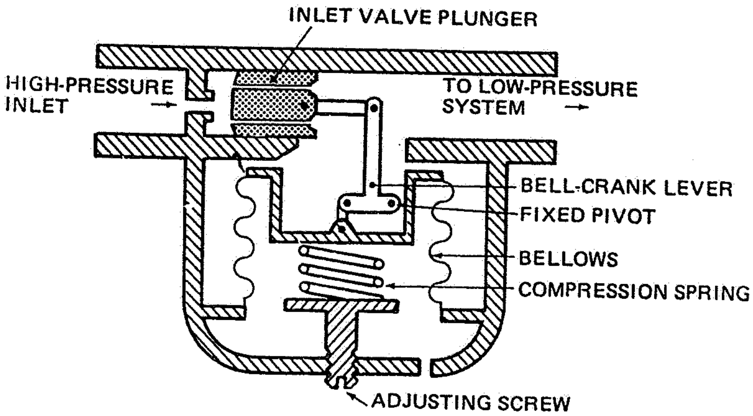


Figure 4 PRESSURE REDUCING VALVE

4.7 **Pressure Maintaining Valve.** A pressure maintaining valve is designed to conserve air pressure for the operation of essential services (e.g. landing gear extension and wheel brake operation), in the event of the pneumatic system pressure falling below a pre-determined value.

4.7.1 Figure 5 illustrates the operation of a typical pressure maintaining valve. Under normal circumstances air pressure is sufficient to open the valve against spring pressure and allow air to flow to the non-essential services. Should the pressure in the storage bottle fall below a value pre-set by the valve spring, however, the valve will close (as shown) and prevent air passing to the non-essential services.

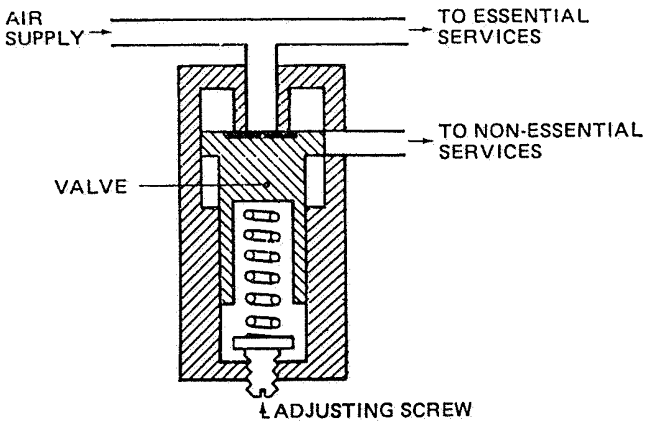


Figure 5 PRESSURE MAINTAINING VALVE

4.8 **Control Valves.** Compressed air stored in the bottle is distributed to the various pneumatic services, and directed to the various types of actuators by means of control valves, which may be manually or electrically operated. Examples of several types of control valves are described in paragraphs 4.8.1 to 4.8.3.

4.8.1 **Electrically-operated Control Valve.** The electrically-operated control valve for a pneumatic landing gear retraction system is illustrated in Figure 6. Selection of the landing gear position is made by either of two push-buttons (marked 'up' and 'down') which are mechanically interconnected to prevent operation of both buttons at the same time. These buttons, when depressed, supply electrical power to the 'up' or 'down' solenoid as appropriate. Actuation of this solenoid lifts an attached pilot valve, supplying compressed air to the cylinder at the bottom of the associated valve; the piston moves downwards, and the valve guide attached to it opens the inlet valve, admitting compressed air to the appropriate side of the landing gear actuators. At the same time the beam attached to the extension of this piston transfers movement to the valve guide in the opposite valve, allowing air from the opposite side of the actuators to exhaust to atmosphere.

4.8.2 **Manually-operated Control Valve.** The valve illustrated in Figure 7 is a simple two-position valve, and may be used as an isolation valve in some systems. The sleeve valve is operated by a cam, and is spring-loaded to the 'off' position; linkage from the cam spindle connects the valve to an operating lever. When used as an isolation valve the operating lever would normally be wire-locked in the 'on' position, and would only be used to permit servicing operations to be carried out.

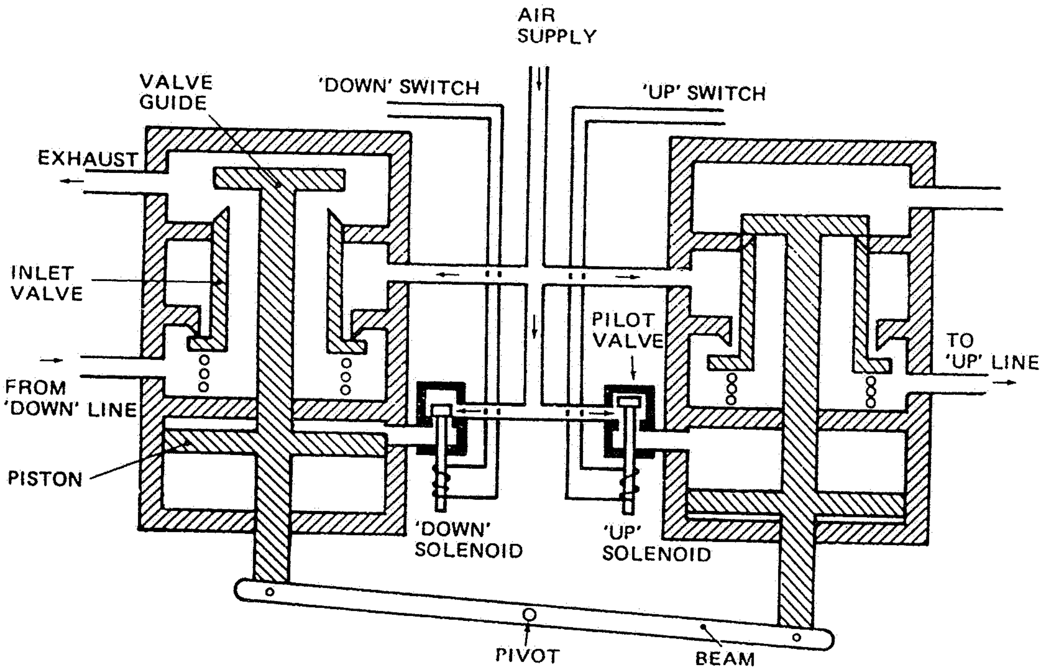


Figure 6 ELECTRICALLY-OPERATED CONTROL VALVE

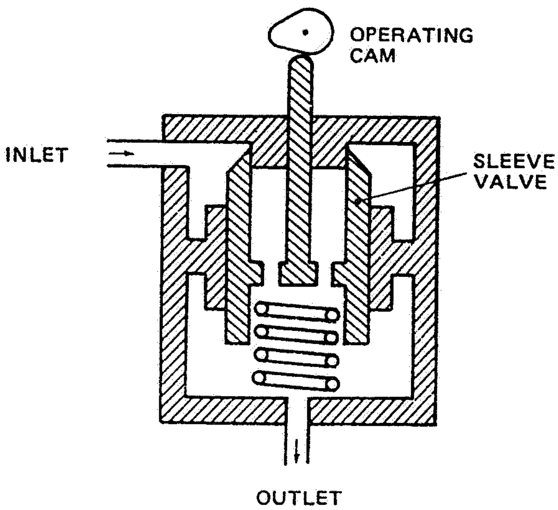


Figure 7 MANUALLY-OPERATED CONTROL VALVE

4.8.3 **Brake Control Valve.** Some older types of aircraft may be fitted with a type of brake control valve (known as a dual-relay valve) by means of which total brake pressure is applied by the operation of a single hand-control, and distribution to either or both brakes is effected by means of a mechanical connection to the rudder bar. The type of brake control valve illustrated in Figure 8 is used on some modern aircraft, and is operated by linkage from brake pedals attached to the rudder bar; separate valves supply compressed air to the brake units on each wheel. Operation of the valve is as follows:—

(a) In the 'off' position (as illustrated) the inlet valve is closed and pressure in the brake line is connected to the exhaust port.

(b) Pressure applied to the associated brake pedal is transmitted via the brake linkage to the valve sleeve, which moves up to close the exhaust valve. Further pressure applied through the valve sleeve and lower spring tends to open the inlet valve, and air pressure in the brake line combined with the force exerted by the upper and centre springs tends to close it. This produces a balanced condition in which any increase in the force applied to the valve sleeve results in a higher air pressure in the brake line, and a decrease in the force applied to the valve sleeve results in opening of the exhaust valve and a reduction in the air pressure in the brake line.

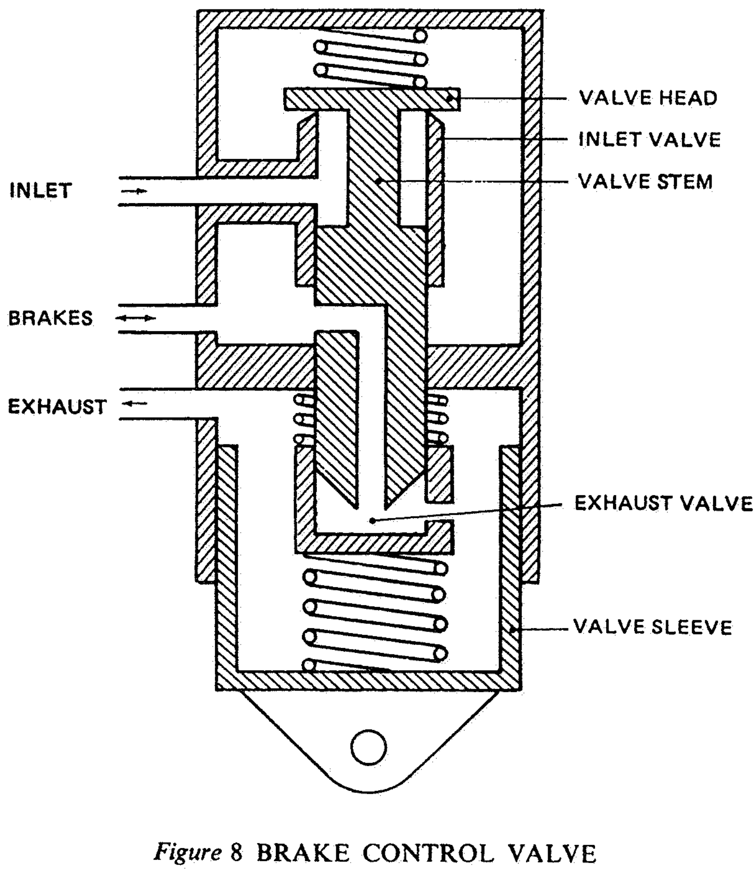


Figure 8 BRAKE CONTROL VALVE

4.9 **Actuators.** The purpose of an actuator is to transform the energy of the compressed air into linear or rotary motion. Actuators in pneumatic systems are normally of the linear type, and are similar in construction and operation to those described in Leaflet **AL/3-21** for hydraulic systems. Because of the nature of the operating medium, however, actuators in pneumatic systems are often damped to prevent violent operation of the services. A typical damped actuator is illustrated in Figure 9, the damping in this case being obtained by forcing grease through the annular space between the inner wall of the piston rod and a stationary damper piston; an orifice and plate valve in the damper piston provide less damping action when the piston rod retracts than when it extends. This type of actuator could be used, for example, to operate the landing gear and to restrict the rate of extension.

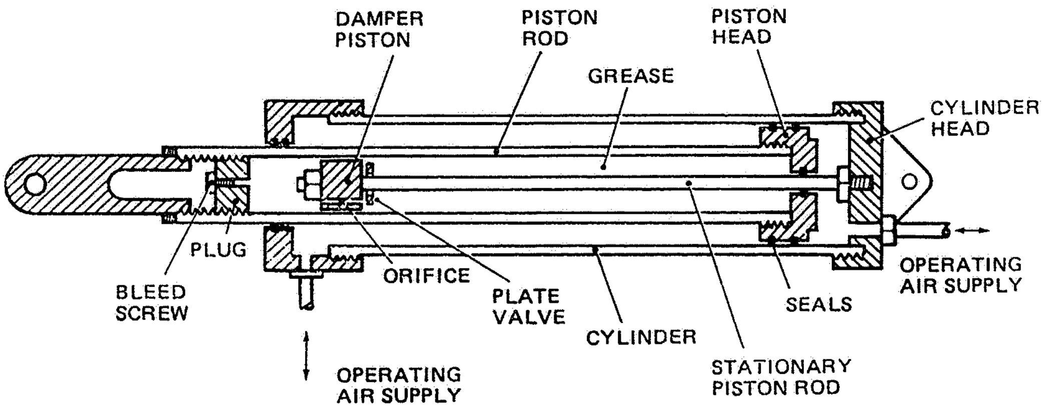


Figure 9 DAMPED ACTUATOR

5 REMOVAL AND INSTALLATION Aircraft pneumatic installations vary considerably, and reference should be made to the relevant Maintenance Manual before any work is carried out on a particular aircraft. Failure to observe any precautions detailed by the manufacturer could result in damage to the aircraft and, possibly, in physical injury. High pressures exist in parts of the system even when the aircraft engines are not running, and this pressure must be released before attempting to disconnect or remove any components or pipelines. Rapid operation of the system services is also a feature of pneumatic systems, and care must be taken during any tests to ensure that the services have complete freedom of movement and that the area is clear of personnel.

5.1 **Cleanliness.** The cleanliness of a pneumatic system is of the utmost importance to its correct operation. The filters fitted in the system will, if serviced at the appropriate intervals, protect the system components from contamination during normal use, but whenever a connection is broken or components are removed, the open pipes should be blanked immediately to prevent the entry of dirt and moisture; blanks should be left in position until the component is re-installed or the connection is re-made. Proper blanking caps should be fitted wherever possible, and on no account should rags or masking tape be used. Any external rig which is likely to be used to charge an aircraft system must be kept to the same standards of cleanliness, and the supply line should be blown through before being connected to the aircraft charging point.

5.2 **Removal of Components.** Before removing any components or disconnecting any pipelines, all pressure should be released from that part of the system. In some cases release of all pressure from the storage bottle will be specified by the manufacturer as being necessary; in the typical system shown in Figure 1 this is done by operating the discharge valve, but in other systems it may be necessary to unscrew a connection a quarter turn to release the air. Even those parts of the system protected from storage bottle pressure by a non-return valve or isolation valve may retain sufficient residual pressure to cause damage, and pipe connections should, therefore, be unscrewed slowly, pausing after the first quarter turn of the union nut to ensure that air pressure escapes slowly.

5.2.1 On aircraft which have a pneumatically-operated landing gear retraction system, ground locks should be fitted before releasing air from the 'down' lines in the system, and the landing gear control lever and emergency landing gear selector should be labelled to ensure that they are not operated.

5.2.2 On systems which have electrically-operated control valves it will usually be necessary to electrically isolate the part of the system being worked on, and this may be done by tripping the associated circuit-breakers or removing the associated fuses. Electrical isolation and placarding of controls is advisable in order to avoid any possible inadvertent selection, whether or not power is available at the time. Note should be taken of the disconnected circuits for reference when re-assembling.

5.2.3 Where a component, such as the compressor, has to be removed because of mechanical failure, other parts of the system may have become contaminated by metal particles. Filters downstream of the component which has failed should be checked for contamination, and if this is found, all components and pipes which may have been affected should be removed and cleaned or renewed as necessary.

5.2.4 Immediately after removing a component all openings should be blanked; flexible pipes should be secured to adjacent structure to prevent them from becoming damaged.

5.3 **Installation.** Before installing a new component, it should be inspected for any damage which may have occurred during storage, the part number and modification state should be checked, and it should be ensured that the storage life (paragraph 7) has not been exceeded. The thorough testing of components drawn from stores is not normally required (paragraph 5.4), but it should be ascertained that external moving parts function without binding, and operate in the correct sense. Components which have been removed from an aircraft and are to be re-installed must be thoroughly examined for cleanliness; pipes should be blown through with clean, dry air.

5.3.1 New gaskets should be fitted to all components which require their use, and other protective material such as may be used under straps or clamps, should be inspected for condition before being refitted.

5.3.2 Some components, such as non-return valves, must be fitted the correct way for the system to operate as intended, and are usually designed with different types of fittings at each connection to prevent incorrect installation. In some cases, however, the fittings may be identical, and the direction of flow marked on the component, should be checked.

5.3.3 The male threads on connections should be sparingly lubricated before assembly, as recommended by the manufacturer, and union nuts should be fitted by hand so as to check that the threads are not binding and to ensure that the connections are correctly aligned. All union nuts should be tightened to the torque values specified in the relevant Maintenance Manual, and should be locked in the appropriate manner.

5.3.4 All blanks should be removed from pipes before installation, and it should be ensured that the pipes are correctly installed and free from acute bends and kinks or damaged protective covering, are correctly aligned with mating connections, have adequate clearance between adjacent pipes and structure, and have been correctly identified, locked and supported. Flexible pipes should be checked to ensure that they are not bent, twisted or stretched at the limits of movement of the component to which they are attached, and are adequately supported.

5.3.5 After the installation of a component, any mechanical or electrical connections should be made, and a full functioning test should be carried out.

(a) Mechanical controls should be connected and adjusted so that control lever movement and valve operation are synchronized, and if stops are fitted to the valve the control should be adjusted to ensure that these stops are contacted; full details concerning the rigging and adjustment of the controls for a particular system should be obtained from the relevant Maintenance Manual. Controls should be free from binding over their full range of movement, and should have at least the minimum specified clearance from adjacent structure. After adjustment and checking, all linkage should be locked and lubricated as appropriate.

(b) The circuits to electrically-operated control valves should be checked for correct installation and functioning as described in Leaflet **EEL/1-6.** Micro-switches should be adjusted carefully to ensure that they operate positively without the plunger bottoming, and their mountings should be checked for rigidity and security.

(c) Unless otherwise stated, an actuator should be adjusted so that its piston does not bottom in its cylinder at the ends of its travel, and it should be checked for smooth and correct operation. When required by the relevant Maintenance Manual, actuators should be filled with grease or other specified damping fluid before carrying out a functional check.

5.4 **Testing.** The overhaul and testing of individual components must be carried out in accordance with the manufacturer's Overhaul Manual and requires the use of specially designed test rigs to ensure their correct operation. Dismantling of components should not be undertaken unless suitable test facilities are available, and the aircraft system should not be considered to be an acceptable alternative. Once tested after manufacture or overhaul, components do not normally require further tests to be carried out prior to installation, provided that their storage life has not been exceeded and that there is no superficial damage. System tests should, however, be carried out on new installations, after any part of a system has been adjusted, dismantled, or renewed, and at the periods specified in the relevant Maintenance Schedule. The method of carrying out a test of the pneumatic system is detailed in the aircraft Maintenance Manual, and will normally include the operations outlined in paragraphs 5.4.1 to 5.4.5.

5.4.1 After a system has been exhausted of air pressure, or parts of a system have been isolated from the storage bottles to permit removal and installation of components, certain precautions must be taken to prevent damage to the aircraft or injury to personnel when the system is re-pressurized prior to testing. The electrical circuits to electrically-operated controls should be reinstated by resetting the appropriate circuit breakers or refitting the fuses, and the positions of all controls, including emergency controls, should be checked as corresponding to the positions of the actuators in the pneumatic services. Ground locks should be fitted to the landing gear (unless the aircraft is on jacks), and air pressure should be built up slowly in the relevant parts of the system, either through the charging connection or by opening the isolation valves, as appropriate.

5.4.2 When a compressor has been changed, or whenever a slow build-up in system pressure has been reported, the output of the compressors should be checked; this check is usually carried out by running the appropriate engine(s) on the ground. The engine power setting, initial pressure, and maximum time permitted to build up pressure by a specific amount, are usually quoted in tables provided in the relevant Maintenance Manual; separate tables are often provided for checking new and in-service compressors.

5.4.3 When checking the operation of the various control valves in the system, care should be taken to ensure that the associated services are free to function and that adequate clearance is provided between any moving part and adjacent structure, trestles, etc. The air exhausted from some large components may be capable of causing damage, and warning notices should be positioned before operating these particular services.

5.4.4 The adjustment and correct operation of all locks, actuators, selectors, control mechanisms and indicators should be checked, using the appropriate test connections where necessary, and the operating pressures of the regulators, pressure reducing valves, pressure maintaining valves, brake valves and relief valves should be verified. It should also be ascertained that there is no internal or external air leakage from the valves or connections.

5.4.5 All services should be checked for correct operation, smoothness, and, when specified, speed of operation and system pressure drop. These tests should be carried out using both the normal and the emergency systems, and should be repeated a sufficient number of times to ensure consistency.

6 MAINTENANCE Maintenance of the pneumatic system should be carried out in accordance with the relevant Maintenance Manual and Schedule, and should include replenishment from an external source as necessary, routine inspections for condition, cleaning of filters, replacement of desiccants and checking for leaks.

6.1 **Charging.** A pneumatic system is fitted with one or more charging valves, by means of which the system may be fully pressurized from an external source. These valves also act as, or include, a non-return valve, and are fitted with a dust cap which must be removed when connecting an external supply. Any external supply, whether from high-pressure storage bottles or a mobile compressor, must be fitted with oil-and-water traps, and, preferably, a dehydrator, to ensure that the air supplied is clean and dry. The supply hose should be capped when not in use, and should be blown through with compressed air before being connected to the charging valve, to prevent the introduction of moisture or dirt into the aircraft system. Care should be taken to turn off the external supply and to release air pressure from the supply hose before disconnecting it from the aircraft.

6.2 **Routine Inspection.** The scheduled routine servicing of the pneumatic system should include the following operations:—

6.2.1 **Filters.** Wire-gauze air and oil filters such as may be fitted to a compressor, should be removed for cleaning and inspection at frequent intervals; cleaning in solvent is usually recommended, and the filters should be dried thoroughly before being refitted. The main air filter usually has a paper or felt element, and this should be renewed at the specified periods. This filter should also be drained periodically in order to check for the presence of water or oil, and this is best carried out by unscrewing the drain plug a quarter turn and releasing the trapped air; if moisture is found, the filter housing should be thoroughly dried and the element renewed, and if oil is found the compressor and the oil-and-water trap should be examined. A porous metal filter may also be fitted in some systems, and this is usually cleaned by reverse-flushing with methylated spirits; the filter must be thoroughly dried before replacing it in the system.

6.2.2 **Physical Condition.** All components and pipelines in the system should be examined periodically, for corrosion, cracks, dents and other superficial damage. Minor damage may often be removed and the area re-protected, but some components (e.g. storage bottles) must be considered unserviceable if the damage extends beyond the protective treatments. The components should also be checked for security and locking, and the pipelines for satisfactory clamping, protection and identification. Any leaks found should be treated as outlined in paragraph 6.3.

6.2.3 **Storage Bottles.** Storage bottles should be drained periodically to remove any sediment or moisture which may have accumulated. Draining is best carried out with pressure in the system, but the drain plug should not be unscrewed more than a quarter turn; without pressure in the bottle the drain plug may be completely removed, and it may be necessary to use a thin rod to clear any congealed sediment. After draining, the drain plug should be tightened to the specified torque and re-locked. The pressure testing of storage bottles should be carried out in accordance with, and at the times specified in, the relevant manuals.

6.2.4 **Oil-and-Water Trap.** The oil-and-water trap should be drained daily, or after each flight if freezing conditions exist, to prevent the freezing of water in the pipe from the compressor. Draining should be carried out as soon as possible after flight, and the procedures outlined in paragraph 6.2.3 for storage bottles should be used.

6.2.5 **Dehydrator.** The periods at which the alumina charge or other desiccant should be changed, depend on the weather conditions in general, and may vary considerably; the actual periods should be determined by experience, and should be such that the dehydrating agent never becomes saturated with moisture. In many cases it will be necessary to remove the dehydrator in order to recharge it, and the following procedure should be used:—

(a) Remove residual pressure from the container by means of the drain plug on the oil-and-water trap.

(b) Disconnect the pipe connection on the container, release the securing strap, and remove the container from the aircraft.

(c) Unscrew the end cap from the container and remove the dehydrating agent.

(d) Remove any moisture from the container by passing warm, dry air through it, and clean the outlet filter in methylated spirit. Check the container for corrosion.

(e) Examine any seals for damage or deterioration, and renew as necessary.

(f) Fill the container with a fresh charge of dehydrating agent, then refit and lock the end cap.

(g) Refit the container in the aircraft, and tighten and lock the connections and securing strap.

NOTE: The dehydrating agent is normally delivered in air-tight tins, but if permitted by the manufacturer the old charge may be re-activated, in emergency, by heating to 250°C to 300°C for 4 to 5 hours.

6.2.6 **Lubrication.** Any linkage associated with the control levers and valves in the pneumatic system, should be lubricated in accordance with the relevant Maintenance Manual, at the periods specified in the Maintenance Schedule. Engine oil is generally satisfactory for use on the threads of fasteners and components, but silicone grease may be recommended for use on some components (e.g. the dehydrator end cap), where it may come into contact with rubber seals.

6.2.7 **System Operation.** The operation of the complete system should be checked at the intervals specified in the Maintenance Schedule, whenever components are changed, and whenever faulty operation is reported. The method of testing a system is specified in the relevant Maintenance Manual, and the operations which are usually included are outlined in paragraph 5.4.

6.3 **Leakage.** In high-pressure pneumatic systems some leakage will inevitably occur, and manufacturers usually lay down a maximum permissible leakage rate for a particular aircraft system. Leakage will sometimes become apparent through the slow or incorrect operation of a service, or failure to maintain system pressure, but a small leakage may only be noticed by a drop in system pressure when the aircraft is out of use for a short period (e.g. overnight). The leakage rate is checked by fully pressurizing the system, then re-checking the pressure after a period of 12 hours (or other specified time). The initial and final pressures should be recorded, taking into account the ambient temperature at the time; if this drop exceeds the maximum permitted, a check for leaks should be carried out.

6.3.1 **Checking for Leaks.** Large external leaks can often be traced aurally or by the application of a non-corrosive soapy water solution (bubbles will appear at the position of a leak); all traces of soap solution must be removed after the test, using plenty of clean water, and the parts must be thoroughly dried. Smaller external leaks may not be detectable by these methods, but several types of electronic leak detectors are available which can be used to detect even the smallest leak. These detectors usually operate on ultrasonic principles, or by measurement of the positive ions emitted from the leak after a small quantity of carbon tetrachloride has been introduced into the system; operation of these detectors should be in accordance with the manufacturer's instructions. Internal leakage may be difficult to trace, and a knowledge of the particular system is essential. Leakage past seals and valves may often be found by checking the exhaust pipes, or by removing a connection and substituting a length of hose, the other end of which is held below the surface in a bucket of water; bubbles will indicate leakage from the component upstream of the disconnected pipe.

6.3.2 **Curing Leaks.** Leakage may be caused by a number of faults, such as deterioration of seals, loosening of nuts, splits in pipes, scoring of cylinder walls, or worn valve seats. Leakage from a pipe connection may sometimes be cured by tightening the union nut, but excessive force must not be used; if the leak persists after tightening, new parts should be fitted. Internal leakage from components will often require their removal for overhaul, but the replacement of seals and gaskets is sometimes permitted. Extreme care is necessary when refitting seals, and special tools may be required; any damage to the seal or component caused by careless handling could result in further leaks. When re-assembling components, absolute cleanliness is essential, and the tests specified in the relevant manual should be carried out before installing them in an aircraft.

7 STORAGE Pneumatic components are normally packed in sealed containers or plastic bags, and should not be unpacked until required for use. They should be stored in conditions which are dry, and free from corrosive fumes (see also Leaflet **BL/1-7**). The storage life of assemblies is determined by the non-metallic parts, such as seals, that they contain, and upon storage conditions. The date of packing, record of tests carried out, and storage life of a component should be marked on the container, but storage life may also be checked by reference to the Maintenance Manual.

7.1 Pipes are usually blanked and wrapped for storage, but flexible pipes should always be stored in the shape in which they were manufactured or have assumed during use.

7.2 Components removed from storage for installation on an aircraft should be examined for external damage and corrosion, and the condition of all threads should be checked. Where applicable the components should be blown through with clean, dry compressed air, and every precaution should be taken to prevent the ingress of dirt or moisture.

AL/3-23

Issue 2

September, 1988

AIRCRAFT

SYSTEMS AND EQUIPMENT

PRESSURISATION SYSTEMS

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide general guidance and advice on the installation, maintenance, and testing of equipment forming part of cabin pressurisation systems. These systems are designed to automatically maintain a selected altitude relationship between cabin and aircraft by controlling the pressure of the air normally derived from an associated air conditioning system (see Leaflet **AL/3-24**).

1.2 The information contained in this Leaflet is of a general nature and not of a particular aircraft type and should, therefore, be read in conjunction with the relevant Aircraft Manufacturers' Maintenance Manuals and Approved Maintenance Schedules.

1.3 Subject headings are as follows:—

1.4 Related CAIP Leaflets:—

AL/3-24 — Air Conditioning
AL/3-26 — Auxiliary Power Units
AL/7-14 — Repair of Metal Airframes
EL/1-3 — Turbochargers
EEL/1-6 — Bonding and Circuit Testing

2 GENERAL

2.1 In order to protect the occupants of transport aircraft from the effects of reduced atmospheric pressure at altitude, it is necessary to pressurise the cabin area. The purpose of pressurisation, is therefore, to maintain a safe cabin altitude relative to the aircraft altitude, and in association with an environmental air conditioning system, provide a comfortable environment when flying at the higher altitudes.

2.2 Cabin Altitude

2.2.1 With an increase in altitude there is a decrease in atmospheric pressure (see Figure 1).

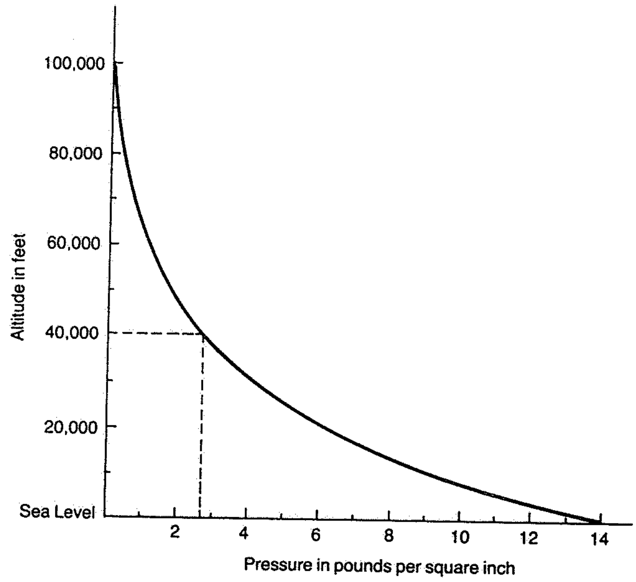


Figure 1 ATMOSPHERIC PRESSURE

2.2.2 From sea level to 7000 ft the oxygen content and pressure of the atmosphere is so sufficient as to maintain all mental and physical functions. At approximately 10,000 ft above sea level, oxygen saturation of the blood is lowered to approximately 90%, and any prolonged exposure to this level of cabin altitude could result in the occupants suffering headaches and fatigue. If the cabin altitude is allowed to rise further to approximately 15,000 ft, disorientation, impaired vision and physical changes may occur. Therefore, the purpose of the pressurisation system is to artificially create a lower altitude within the cabin (cabin altitude) relative to the aircraft altitude using pressurised air (see Figure 2). Design of the pressurisation system will, however, require certain devices to ensure the comfort and safety of the passengers and the structural integrity of the aircraft. These devices are described in the following paragraphs.

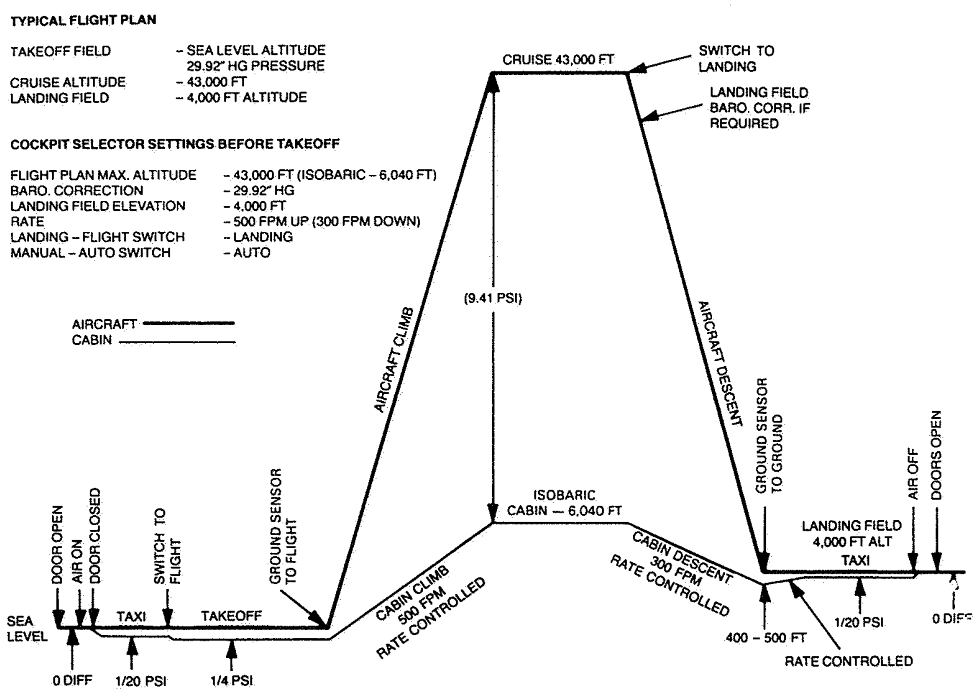


Figure 2 TYPICAL PRESSURISATION SCHEDULE

2.3 The cabin pressure (relative altitude) is controlled by regulating the rate at which air, normally supplied by the air conditioning system, is discharged to atmosphere by one or more discharge valves. In general this is achieved by the pressure controller passing a pneumatic or electrical command signal to the discharge valves (outflow valves) which respond by increasing or decreasing restriction to the flow of air from the cabin to atmosphere (see Figure 3).

2.4 In addition to the basic units which control cabin pressure, pressure limiting valves, inward relief valves, ground depressurisation valves, (of either automatic or manual control), and associated warning systems are provided as part of the pressurisation system to safeguard the occupants and airframe, in the event of a system or component failure.

2.5 Flight deck instrumentation systems and controls include indications of: cabin altitude, differential pressure, and cabin altitude rate of change. These indications can be of either, analogue or digital form, using instruments or cathode ray tube (CRT) displays.

2.6 Normally, visual warning systems also include additional simultaneous audible alarms to alert the crew members of any significant changes taking place, which may require immediate crew action.

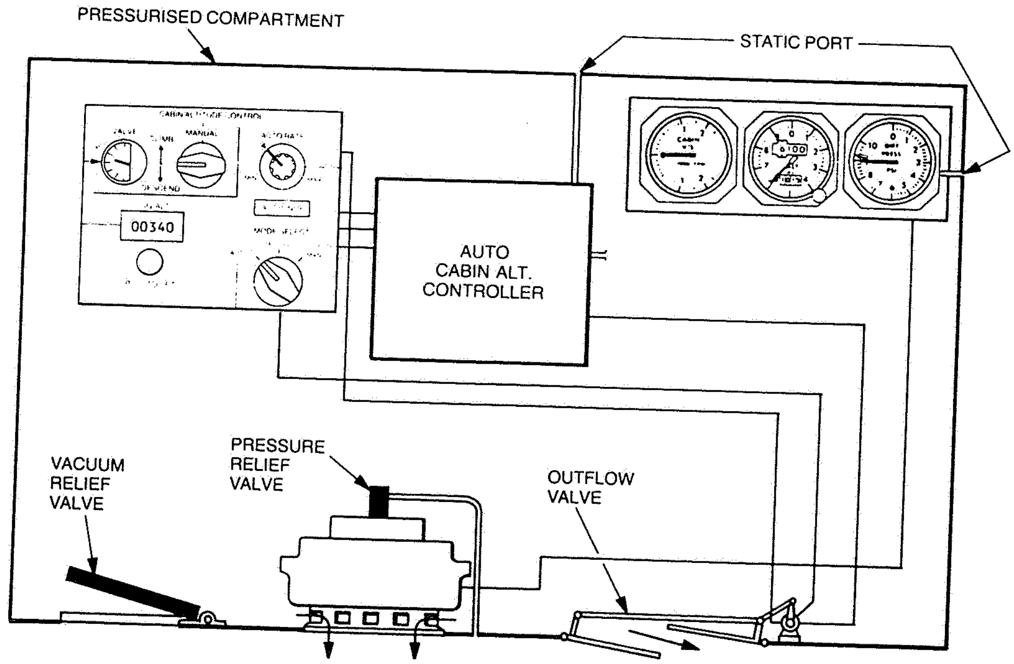


Figure 3 PRESSURISATION SYSTEM SCHEMATIC (ELECTRONIC)

2.7 Brief descriptions of some principal units, controls and instruments which form a typical pressurisation system are given in the relevant paragraphs of this Leaflet. For precise details of specific systems, reference should be made to the relevant Aircraft Maintenance Manual.

3 PRESSURISED AIR

3.1 The source of pressurised air is normally dependent upon the aircraft and engine type. Piston engine aircraft in general, use superchargers or turbochargers which may be part of the induction system or specifically incorporated for the purpose of pressurisation, for further information see Leaflet **EL/1-3**.

3.2 Where aircraft are powered by a turbo-jet engine(s), bleed(s) air from the compressor section of the main engine core is utilised (see Figure 4). However, on smaller aircraft, a system of ram air, supplemented by a small amount of high temperature bleed air for temperature control, may be adopted for air conditioning and pressurisation purposes.

3.3 Where fitted, the auxiliary power unit (APU) is another alternative source of pressurised air for the purpose of pressurisation. However operation is subject to certain operational limitations, for further information see Leaflet **AL/3-26**.

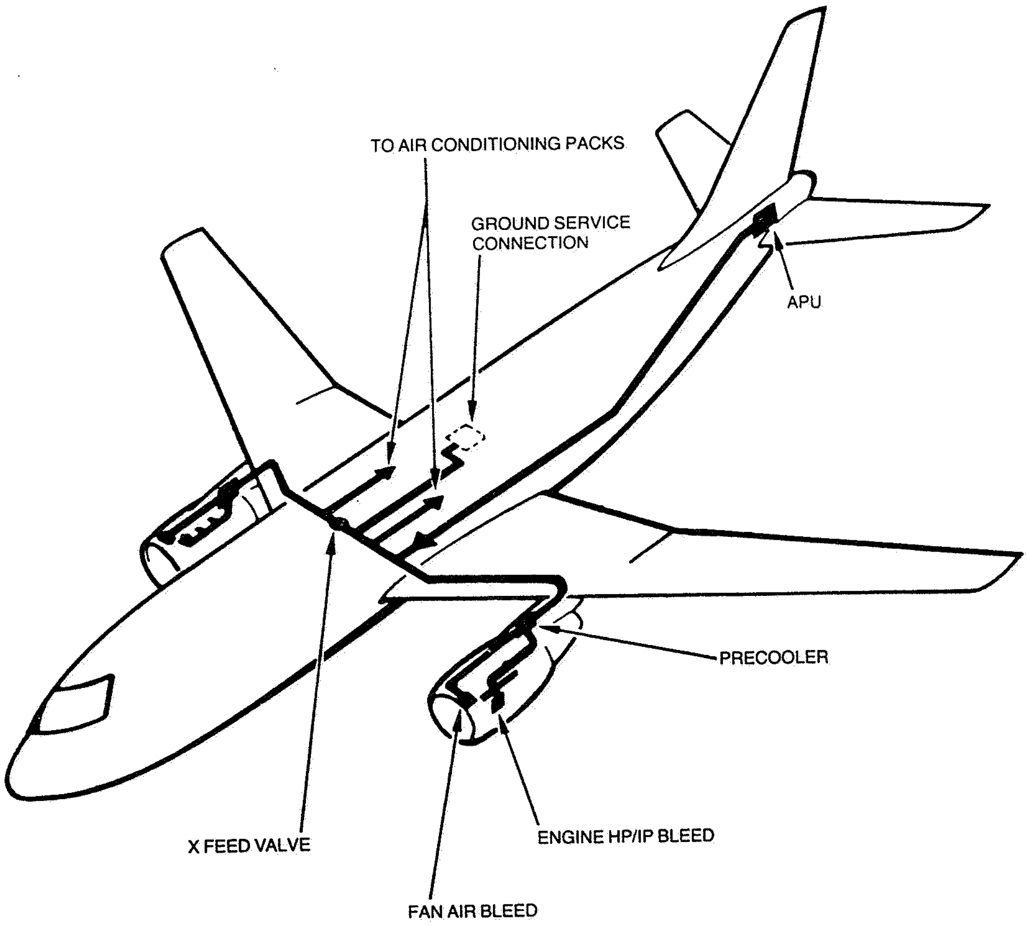


Figure 4 PRESSURISED AIR SCHEMATIC

4 THE PRESSURISATION CONTROL SYSTEM

4.1 **General.** The principal requirements of the pressurisation control system are:—

(a) To control, maintain and monitor the cabin altitude relative to the aircraft altitude within the specified parameters.

(b) To safeguard the occupants and airframe from 'pressure bumps' when ascending to or descending from altitude, by providing a controlled rate of altitude change.

(c) To provide safeguards against total system failure.

4.2 **Pressure Controllers.** Pressurisation control systems vary in their construction and mode of operation. Pneumatically controlled systems in general incorporate the pressure controller as an integral part of the instrumentation and pressurisation selector panel. Electrically controlled systems use remote cabin pressure controllers which amplify command signals from the selector panel to control and modulate the discharge valves (see Figures 5 and 6).

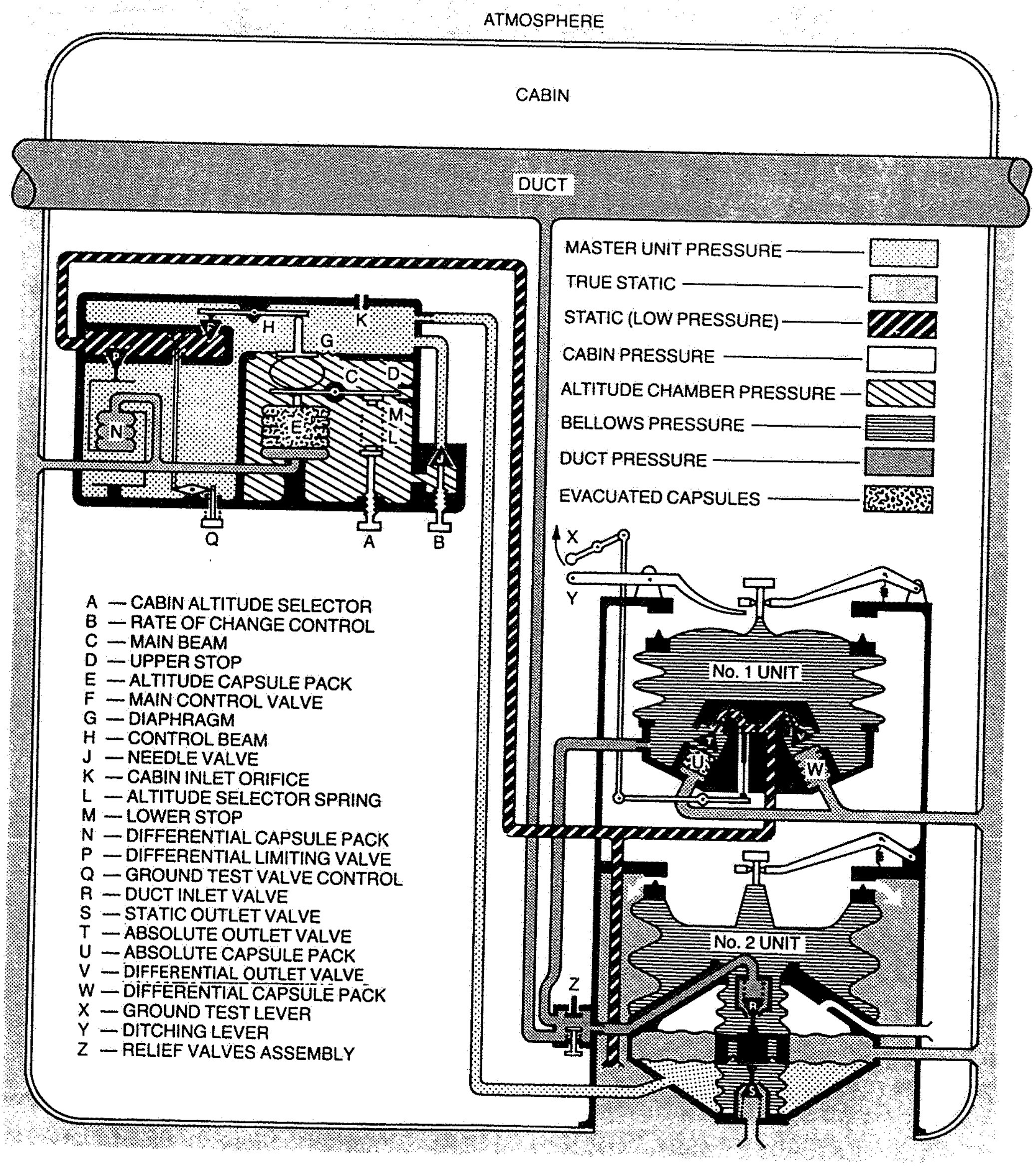


Figure 5 PRESSURISATION CONTROL (PNEUMATIC)

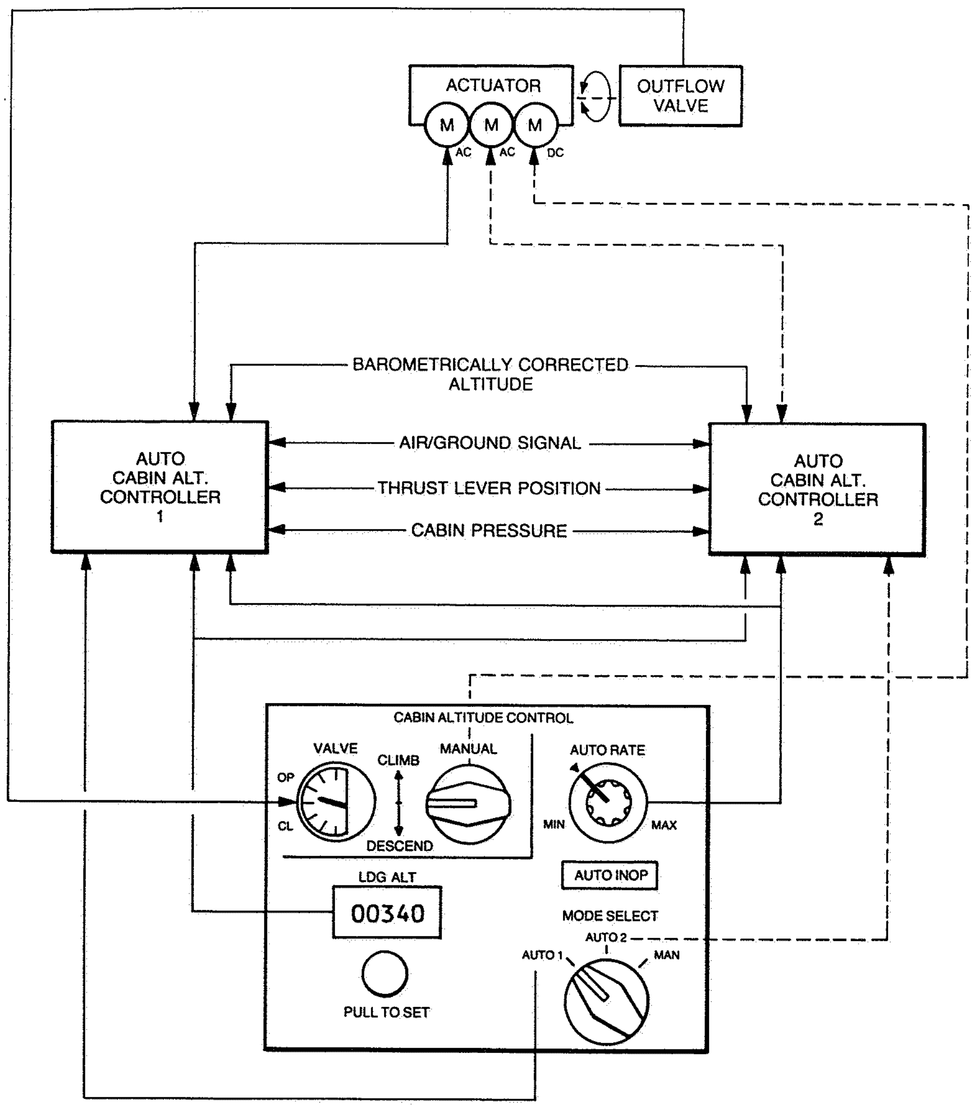


Figure 6 PRESSURISATION CONTROL (ELECTRONIC)

4.3 Pneumatic Pressure Controllers

4.3.1 Pneumatic pressure control systems comprise; pressure-sensing capsules and diaphragms which are subjected to both cabin and external pressures, metering valves, and controls for selecting the required cabin altitude and rate of change. With the controls preset prior to flight, the capsules, diaphragms and metering valves assume a datum position which will ultimately establish and maintain the appropriate cabin differential pressure. As the cabin pressure changes, the controller automatically senses the change relative to the external ambient pressure and transmits a pressure signal via a pressure sensing line connected to the discharge valves (outflow valves). The transmitted pressure signal will then open or close the valve to regulate the release of air from the cabin at the pre-selected rate of change, subject to the maximum differential pressure. The following paragraphs describe the function of a typical pressurisation controller and discharge valve of pneumatic operation (see Figure 5).

4.3.2 **Preflight Set-up.** Prior to take off, control knobs (A) and (B) respectively, are set for the required cabin altitude and rate of change. The effect of this, will impose a load on capsule (E) by the spring (L) through the beam (C). The combination of the spring and capsule will then position the main valve (F) through beam (H). The main valve (F) will now open to allow atmospheric pressure into the master unit control chamber and the lower chamber of the No. 2 unit of the discharge valve through the interconnecting pipework. Atmospheric pressure will also enter the altitude chamber through the rate of change needle valve (J), to equalise pressure either side of the diaphragm (G).

4.3.3 **Aircraft Climb.** As the aircraft continues to climb (with the main valve (F) open), the atmospheric pressure within the master unit control chamber will decrease. Pressure within the altitude chamber will also decrease but to a lesser degree because of the restriction imposed by the needle valve (J) on the rate of change control. As a result, pressure below the diaphragm (G) will be greater than the altitude chamber causing the diaphragm to move upwards to close the main control valve (F). As a consequence of the rising cabin pressure entering inlet orifice (K) and the closing of the main control valve (F), pressure within the master unit control chamber will rise. This rise in cabin pressure is also communicated through pipework to the lower chamber of the No. 2 unit. The upper chamber of the No. 2 unit is also subjected to cabin pressure, and between it, and the lower chamber is an additional chamber subject to atmospheric pressure. However, with the greater effective area of the lower chamber diaphragm and the increase in cabin pressure, the diaphragm assembly moves upwards. As a result of this upward movement, duct inlet valve (R) will open to allow duct air from the air conditioning system to enter the interior of the bellows, which expand and consequentially restrict the outflow of cabin air and pressurisation of the fuselage will commence.

4.3.4 **Cruise.** Once the aircraft achieves level flight, any pressure difference on either side of diaphragm (G) will soon equalise. Any further change in cabin pressure, will be sensed by the capsule pack (E), which is sensitive to both static and altitude chamber pressure. The resultant movement of the capsule pack (E) will be transposed through the control beam (H) to open or close the main control valve (F). Movement of the control valve will again create pressure changes within the master control chamber which will be transmitted to the lower surge chamber of the No. 2 unit. These pressure movements will then act upon the diaphragms within the No. 2 unit to either open the duct inlet valve (R), allowing duct pressure into the inner bellows and closing the discharge valve or to open the static outlet valve (S) which will vent duct pressure to atmosphere and subsequently open the bellows of the discharge valve.

4.3.5 Should the aircraft climb to the maximum differential pressure, the differential capsule pack (N) will contract to open the differential limiting valve (P). This will reduce pressure within the master control unit chamber and lower the surge diaphragm of No. 2 unit, subsequently closing the duct inlet valve (R) and opening the static outlet valve (S) allowing the discharge valve to contract and reducing cabin pressure to a safe level. With a reducing cabin pressure the differential capsule pack (N) will expand closing the differential limiting valve (P) returning the control chamber to the conditions of normal operation.

4.3.6 **Aircraft Descent.** Prior to descent, selection of a suitable rate of change, and cabin altitude equal to a landing field height, is required. These selections will reduce the compression load on the altitude capsule pack (E), the result of which, closes the main control valve (F). Therefore, assuming the aircraft cabin is now at the maximum differential pressure because of the low cabin altitude selection, the differential capsule (N) will be in control, as described in paragraph 4.3.5.

4.3.7 As the aircraft descends, the increasing atmospheric pressure, will expand the differential capsule (N) and progressively close the limiting valve (P). This produces a stronger pressure signal to the close discharge valve, subsequently lowering the cabin altitude. When the limiting valve finally closes, the pressure within the altitude chamber rises sharply creating a pressure differential across the diaphragm (G), causing it to deflect and, through the control beam (H), opening the main control valve (F) thus preventing a pressure surge on the lower surge control chamber. The rate of change mechanism will now take control, progressively closing the main control valve (F) and increasing the pressure signal to the discharge valve, at the selected rate of change until the point of cabin altitude and aircraft altitude are of the same value.

NOTE: If in practice the rate of descent of the aircraft is such that it attains the selected altitude before the cabin altitude has reached the same value, the landing of the aircraft must be delayed.

4.3.8 **Emergency Operation.** Under the circumstances of normal operation, the discharge valve No. 1 unit is non-effective in respect of pressurisation control, except to provide a free passage for air to flow into the No. 2 unit.

4.3.9 Whilst the No. 2 unit is in control, the absolute outlet valve (T) vents air from within the bellows of the No. 1 unit to atmosphere. As a consequence, the bellows collapse due to the impingement of cabin pressure on the outer surfaces.

4.3.10 However, should the No. 2 unit fail (open), the consequential decrease in cabin pressure allows the bellows to extend, thereby restricting the flow of air to atmosphere through the failed No. 2 unit.

4.3.11 Pressurisation control is now the responsibility of the absolute capsule pack (U); which is in two parts, and the differential capsule pack (W) with their respective valves, absolute outlet valve (T) and differential outlet valve (V).

4.3.12 As the aircraft altitude climbs or descends, the differential capsule of absolute capsule pack (U) reacts correspondingly, opening or closing absolute outlet valve (T). This results in changing the bellows pressure and the position of the bellows thereby modulating the flow of air and cabin pressure. The changing bellows pressure also effects the absolute portion of the capsule pack (U), which expands or contracts whereby the outlet valve (T) returns to a controlling position.

4.3.13 If there is any tendency for the cabin pressure altitude to exceed that of the preset calibration of absolute capsule pack (U), the resultant increase in bellows pressure will compress capsule pack (W) to open differential outlet valve (V). As a consequence the bellows will compress, discharging the overpressure condition of the bellows and the cabin to atmosphere.

NOTE: With the No. 1 unit in control it is not possible to control the rate of cabin altitude change. However, under normal operational conditions, the change in cabin altitude relative to aircraft altitude should be satisfactory.

4.4 Electronic Pressurisation Control

4.4.1 The operational parameters and requirements of the electronic pressure controller are identical to those of the Pneumatic Controller as described in paragraph 4.3.

4.4.2 The basic differences between, pneumatic and electronic pressurisation control (with reference to Figures 5 and 6), are as follows:—

(a) The automatic cabin altitude controllers are duplicated (Auto 1 and Auto 2), with additional inputs from the landing gear (air/ground signal) and thrust lever positions.

(b) The signal between the automatic cabin altitude controller and the outflow valve (discharge valve) is electrical as opposed to a pneumatic signal.

(c) The cabin altitude control panel is remote from the cabin altitude controller (normally located within the avionics equipment bay) and not an integral part of the controller.

(d) The outflow valve (discharge valve in this description) can be actuated by: either of the two A.C. motors, or for manual or emergency control the D.C. motor.

4.4.3 The electronic pressurisation controller (the cabin altitude controller in Figure 6) is, in basic terms, a shaping and summing network. With information derived from the air data computer, cabin altitude control and various systems within the aircraft, a reference signal is produced by the controller. This reference signal will then be compared by the cabin altitude controller, to the signal produced by the cabin altitude monitor. If a disagreement exists between the two signals, a correcting error signal is produced, which when applied, modulates the outflow valve(s) (see paragraph 5).

4.4.4 As a safeguard against the cabin altitude or rate of change exceeding defined limits within the pressurisation schedule, override circuits constantly monitor the performance of the system in control. If any deviation from the schedule exists, the override circuits will either: automaticallly transfer control to the standby system, (Auto 1 to Auto 2) or de-activate the system completely with the appropriate flight deck indications and aural warnings. The following paragraphs describe the operation of a typical electronic controller.

4.4.5 **Preflight Set-Up.** Automatic electronically controlled cabin pressurisation systems in general terms require the following action prior to take-off:—

(a) Provision of pressurised air from the air conditioning system.

(b) The setting of landing field height (QFE).

(c) Rate of cabin altitude change.

4.4.6 **Prepressurisation.** Where prepressurisation of the cabin prior to take-off is part of the pressurisation schedule, control inputs will be required of the: landing gear (air/ground signal), engine oil pressure, forward throttle position, and the door warning system. The cabin pressure within this part of the schedule is normally only marginally above the ambient atmospheric pressure (i.e. a cabin altitude just below airfield altitude).

4.4.7 **Climb.** Prepressurisation ceases when the aircraft leaves the ground and the landing gear and oleo fully extends (air/ground signal). The cabin altitude climb sequence of the pressurisation schedule will now commence with the cabin altitude rate of change limited to approximately 500 ft per minute.

4.4.8 **Cruise.** With the aircraft maintaining a constant height, the cruise sequence of the pressurisation schedule will commence. Simultaneously, the cabin altitude controller will, for the purpose of originating a datum point for a scheduled descent, and any correction of the cabin cruise altitude, compare the theoretical cabin altitude to that of the selected landing altitude. Any variation to aircraft altitude, in climb, or descent of less than 500 ft, the corresponding cabin altitude will remain unchanged. If, however, the aircraft altitude climbs or descends by more than 500 ft, the cabin altitude controller will enter into an appropriate auto schedule subject to the various controlling parameters i.e. take-off height, landing field height and selected auto rate of change.

4.4.9 **Descent.** The descent sequence of the pressurisation schedule is normally initiated by a descending aircraft altitude of approximately 500 ft and subject to the following criteria:—

(a) The relative aircraft altitude.

(b) The auto rate selected.

(c) The landing field height (QFE).

(d) The maximum cabin to ambient differential pressure limit.

4.4.10 **Landing.** For those aircraft which are designed to land in a pressurised condition, the cabin altitude controller will normally automatically lower the selected landing field by approximately 100 ft height. As a result the cabin will remain pressurised marginally above atmospheric pressure until touch down, where the landing gear air/ground signal takes precedence for controlled depressurisation of the aircraft (see paragraph 7).

4.4.11 **Emergency Operation.** Protection against system failure is provided for by duplication of the control system (see paragraph 4.4.2(a) and (d)). In the event of a system or power failure, control will be automatically transferred to the standby system which is electrically supplied from an alternate source. If total system failure does occur, a reversion to manual control will be required.

5 OUTFLOW VALVES (DISCHARGE VALVES)

5.1 The primary function of the outflow valves is to regulate the discharge of cabin air in response to the pressure signals received from the controller. They vary in design and construction but, in general, there are two main types: those operated by diaphragms, and those by electrical actuation (see Figure 7).

5.2 The size and number of valves required for a particular type of aircraft is governed by the amount of air necessary for pressurisation, and air conditioning. Some types of outflow valve, incorporate safety valves (see paragraph 6.1) and inward (negative) relief valves (see paragraph 6.2) and a means of locking the valve to the closed position in the event of a forced descent on water (ditching).

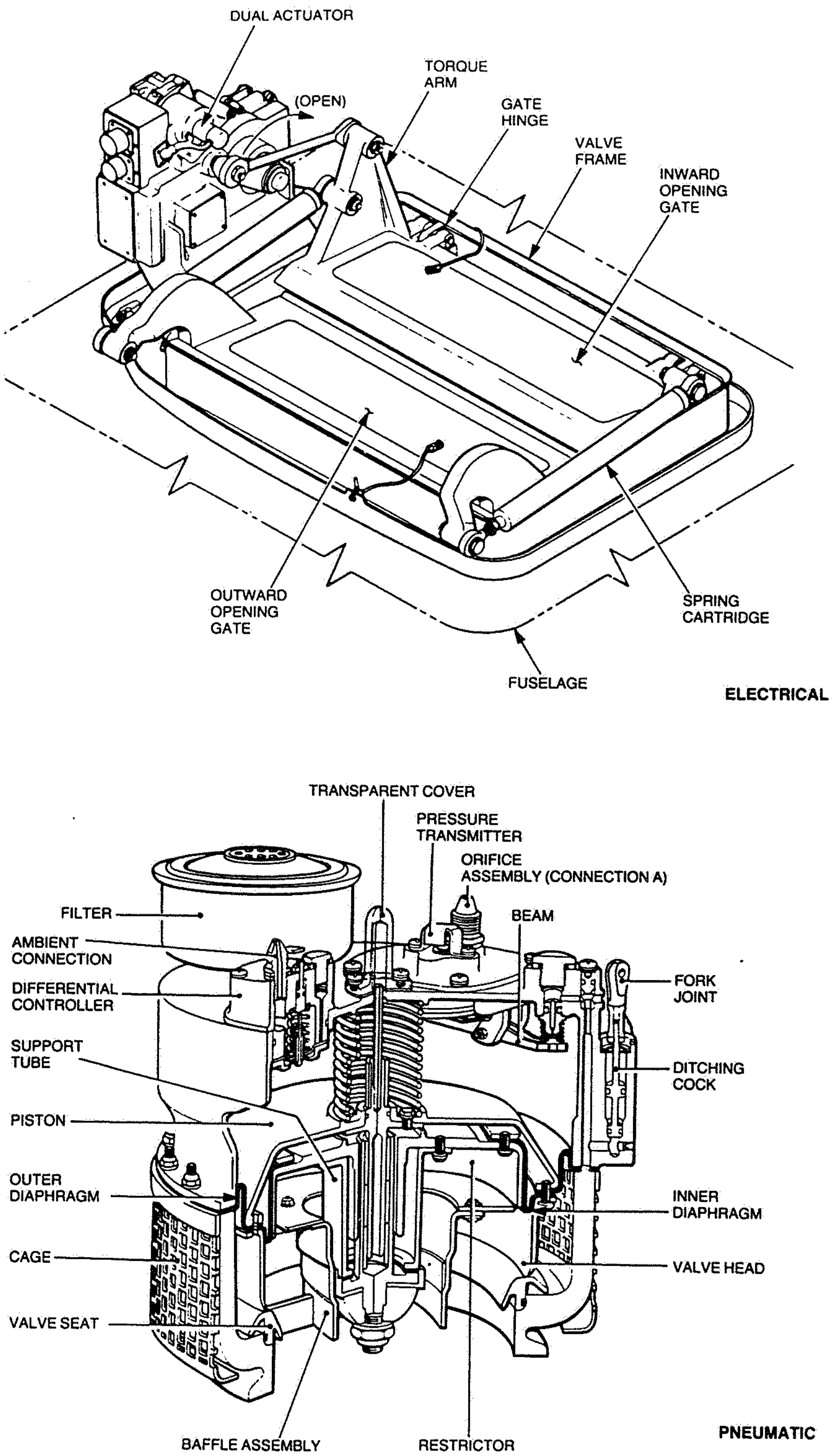
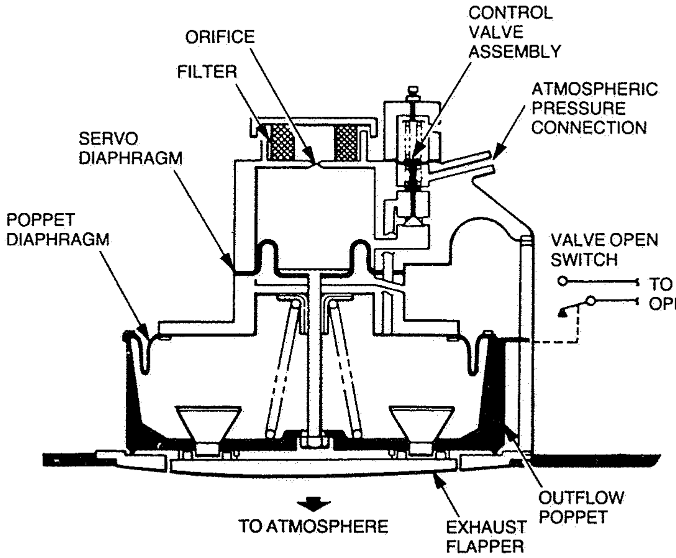


Figure 7 OUTFLOW VALVES (DISCHARGE VALVES)

6 SAFETY VALVES AND INWARD RELIEF VALVES

6.1 **Safety Valves.** Safety valves are provided to relieve excess cabin pressure in the event of a failure of either the pressure controller or discharge valves.



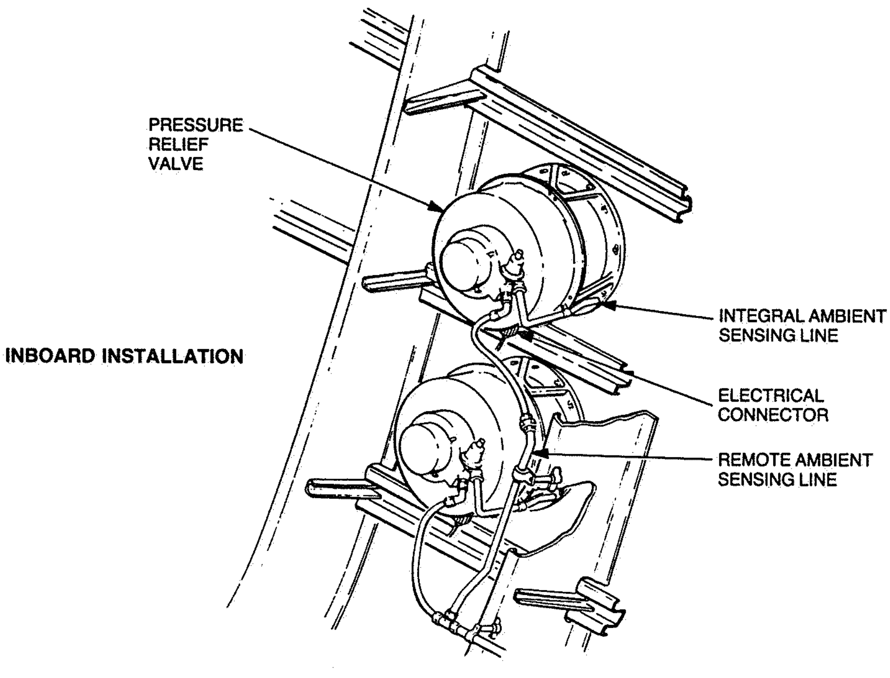


Figure 8 TYPICAL PRESSURE RELIEF SAFETY VALVES

6.2 **Inward Relief Valves.** Inward relief valves are provided to limit any possible negative differential pressure to a safe value. Depending on the system adopted for the particular aircraft type, the valves installed may either be in the form of separate units, single integrated units, or combined with the discharge valves. The valves vary in construction and operation but those most commonly used are of the type utilising diaphragm control (similar to a discharge valve).

7 GROUND AUTOMATIC RELIEF VALVES The ground automatic relief valve is a form of discharge valve used on some aircraft types which is additional to those discharge valves which form part of the pressurisation system. The valve as its title implies, is effectual whilst the aircraft is in a ground mode (i.e. ground/air signal) with the following primary functions:—

(a) To maintain a free flow of ventilating air within the aircraft when parked.

(b) To prevent cabin pressurisation and pressure surges whilst the aircraft is taxiing.

(c) To transmit ground/air signals derived from the landing gear and engine thrust levers, to the cabin altitude controller for controlled prepressurisation and depressurisation of the cabin when respectively the aircraft is taking off or landing (see paragraphs 4.4.5 and 4.4.10).

8 INSTRUMENTS AND INDICATORS

8.1 **General.** The presentation of instrumentation forming part of the pressurisation control system, is largely dependent upon the method of pressurisation control. Pneumatic pressure controllers; as described in paragraph 4.3, have the principal instruments as an integral part of the control panel. Electronic pressure controllers; as described in paragraph 4.4, have instruments which are remote from the controller and generally form part of the cabin altitude control panel.

8.2 **Instruments.** The principal instruments in respect of pressurisation control are, Cabin altitude, Differential pressure, and Rate of Change (vertical speed). These are generally positioned as described in paragraph 8.1, or as a cathode ray tube (CRT) generated display in either digital or analogue (dial and pointer) form in the main instrument panel. Instruments may also be provided to indicate the position of certain valves, e.g. discharge valves.

8.3 **Indicators.** Crew compartment indications, are in general, presented in visual and audio form, i.e. warning light or CRT image with an accompanying sound (bell, chime or horn etc). The factors which will activate those indications, in respect of the cabin altitude control are:—

(a) Excessive cabin altitude.

(b) Discharge valve failure or disagreement.

(c) Inward relief valve operation.

(d) An automatic system changeover.

(e) Excessive differential pressure.

(f) Positive pressure relief valve operation.

9 EMERGENCY CONTROLS In addition to the normal devices which control pressure to the required values, provision is made for the normal operating cabin pressure to be reduced rapidly in the event of, emergency landings, clearing the cabin of smoke or other contaminations, and the rapid reduction of cabin pressure. In all such cases cabin pressure is reduced by the 'dumping' of air. This may be achieved in a number of ways and the methods most commonly adopted include, separate manually operated dump valves, manual override control of a discharge valve or a safety valve, and in some cases manual control of a pressure controller.

10 FILTERS AND AIR DRIERS

10.1 Filters are connected in the cabin air pressure sensing lines to the pressure controllers and discharge valves and normally consist of a casing, housing a replaceable filter cartridge, and fitted with appropriate inlet and outlet connections. In some aircraft installations, air driers are provided to eliminate the possibility of ice forming in the pressure control system and are connected in the cabin air pressure sensing lines to discharge valves, safety valves and inward relief valves.

10.2 There are two types of driers in common use: one utilising the properties of a silica gel drying agent, and the other consisting of a baffle box mounted on the inside of the fuselage skin utilising skin temperature to condense any water vapour present in the cabin air. The moisture deposited in the box eventually drains away through an outlet in the box and aircraft skin.

11 COMPONENT INSTALLATION

11.1 General

11.1.1 Before installing any component of a cabin pressure control system, an inspection should be made to ensure that no deterioration of rubber components, corrosion of metal parts or other damage has occurred during storage or transit. The security of pipe connections, electrical connections, actuators, etc., should also be checked and, where specified, pre-installation functioning tests carried out.

11.1.2 Some aircraft pressure controllers' discharge valves and safety valves operate as preset units and must only be used in specific combinations. When renewing or replacing such units it is therefore essential to ensure that their part numbers are correct for the installation.

11.2 Pressure Controllers

11.2.1 It is recommended that where facilities are available, controllers should be bench tested before installation to ensure that the controlling mechanism has not been disturbed during storage or transit. Details of tests peculiar to particular types of controller should be obtained from the relevant Aircraft Maintenance Manual.

11.2.2 When assembling static pressure and reference pressure sensing pipelines, care is necessary to ensure that no obstruction or leakage can occur. Particular care is necessary to ensure that all pipes are correctly assembled. Cabin pressure must not leak into low pressure pipes or chambers as this would unbalance the control characteristics of the system. Where vents to cabin pressure form part of the system, they should not be obstructed by loose trimming or soundproofing materials.

11.2.3 After the installation is completed, functioning tests should be made to prove the correct connection or adjustment of electrical circuits, micro-switches, altitude selectors, rate of change control mechanisms and the pipeline system. Details of tests applicable to particular aircraft installations should be obtained from the relevant Aircraft Maintenance Manual. General guidance on the testing of pressurisation systems is provided in paragraph 12.

11.3 Discharge Valves and Ground Automatic Relief Valves

11.3.1 Before installation the valve faces and seating surfaces of discharge valves should be cleaned with a soft lint-free cloth. High pressure air blasts should not be used on discharge valves of the diaphragm-controlled type as damage may be caused to the diaphragms.

11.3.2 To ensure that the joint between discharge valves and appropriate adaptors on the pressure bulkhead or fuselage skin is pressure tight, new mounting gaskets or O-rings should be fitted. Where specified, mounting surfaces should be lightly smeared with the appropriate lubricant as specified in the relevant Aircraft Maintenance Manual.

11.3.3 Pipelines and valve unions should be checked to ensure that they are in correct alignment. Plug and socket connections to electrically actuated discharge valves should be secure.

11.3.4 If ditching cocks are fitted, the ditching control run in the aircraft should be checked before making the connections and locking the cocks to the appropriate discharge valve. Some discharge valves may be closed for ditching purposes by a directly mounted hand control wheel. In such cases the opening and closing of a valve should be checked by rotating the wheel through the requisite number of turns.

11.3.5 After installation of a discharge valve, functioning tests should be carried out to prove the correct connection of pressure sensing pipelines and, where appropriate, the connection of electrical cables to valve actuators. Details of the tests applicable to particular aircraft installations should be obtained from the relevant Aircraft Maintenance Manual.

11.4 Safety Valves and Inward Relief Valves

11.4.1 Valves should be cleaned and installed in a similar manner to discharge valves (see paragraph 11.3). Where facilities allow, bellows-type safety valves should be subjected to a leak test before installation in the manner described in the Aircraft or Component Manufacturers's Maintenance Manuals.

11.4.2 In some installations, safety valves are provided with electrical and manual override controls, in such cases functioning checks on the controls must be made after installation (e.g. limit switches of electrical actuators which may need to be adjusted to cut off the power supply when the valve is at the fully open and fully closed positions). Manual controls should be correctly rigged and checked to ensure that the controls and valve move in phase and operate freely over their full range of travel.

NOTES: (1) Limit Switch adjustment is normally carried out when the component is workshop tested.

(2) After carrying out override control system checks, the appropriate controls should be reset to their normal positions.

11.4.3 Some valves incorporate an electrically-operated position transmitter which signals the valve position to an indicator in the crew compartment; checks should therefore also be made to ensure that the indicated positions correspond.

11.5 Filters and Air Driers

11.5.1 Before installing a cartridge type of filter unit the cartridge and casing should be inspected for signs of damage and also to ensure freedom from dirt and other foreign matter.

11.5.2 In some unit designs the case is made of rubber and for this reason it may have been stored in French Chalk. Before fitting the cartridge into this type of case, all traces of chalk must be removed by lightly brushing the rubber with a suitable cleaning agent as recommended in the relevant Aircraft Maintenance Manual.

11.5.3 In some installations, air driers are of the type which utilises Silica Gel Crystals as drying media. Before installation, the units should be detached and charged with a fresh quantity of Silica Gel Crystals. After installation, a check should be made to ensure that the inspection windows, where provided, are readily visible.

11.5.4 When installing baffle-type air driers, it must be ensured that the sealant necessary for fixing is of the correct type and is correctly applied to the appropriate area of the fuselage skin and air drier casing.

11.5.5 After installation, the connections between the filters, air driers and all appropriate pressure sensing lines must be securely made and leak-tested in the manner described in the relevant Aircraft Maintenance Manual.

12 TESTING OF PRESSURISATION SYSTEMS

12.1 General

12.1.1 Pressurisation systems must be tested to ensure that there are no serious leaks and that pressure control equipment and pressure limiting devices function correctly to maintain the cabin differential pressure within the limits appropriate to the aircraft type. The periods at which functional tests and leak tests should be made are specified in the approved Aircraft Maintenance Schedules. Tests may also be necessary after repairs or modifications which affect the structural strength of a cabin (e.g. Proof Pressure Tests), or after suspected damage to the fuselage. The procedures for carrying out the proof pressure test and precautions to be observed, are also detailed in the relevant approved Structural Repair Manual.

NOTE: General guidance on the repair of metal aircraft is provided in Leaflet **AL/7-14** where attention is drawn to: the accuracy required in skin joints and seams, the necessity for the skin to be free from waves and buckles, and the importance of cleanliness when making airtight joints.

12.1.2 The precise method of carrying out the required tests depends on the type of aircraft and on the nature of its air conditioning and pressurisation system. It is, therefore, essential to make reference to the relevant Aircraft Maintenance Manuals for full details. There are however, certain recommendations, precautions to be observed, and aspects of testing procedures which are of a general nature, and these are summarised for guidance in the following paragraphs.

12.2 Test Preparation

12.2.1 The aircraft structure must be complete and fit for flight before attempting to carry out any ground test.

12.2.2 It is recommended that those personnel participating in a pressure test who are stationed within the pressurised area, be certified medically fit. This would include freedom from colds and sinus troubles.

NOTE: Where the pressure differential between the working environment and ambient exceeds 10 p.s.i (20·361 in Hg), medical supervision must be sought.

12.2.3 A minimum of two test operators should be inside the pressurised area during any pressure test where an external ground test unit is used as the air supply source. When using engines for the air supply a third operator to run the engines is required.

12.2.4 When using an external ground test unit as the supply source, intercommunication between test personnel inside the pressurised area and those operating the test unit must be established. (A socket for the connection of an interphone system is normally provided in aircraft for this purpose and is located in an area such as a nose-gear bay.)

NOTE: Warning placards should also be positioned around the aircraft indicating that such testing is being carried out, and only the test personnel should be within, or in the vicinity of the aircraft during testing.

12.2.5 It is necessary to ensure that static pressure and pitot pressure pipelines, within the pressurised area, are complete and connected to their relevant instruments and components such as autopilot coupling units and height lock units. Failure to observe this precaution will result in damage to instruments or units during a pressure test.

NOTES: (1) If it is not possible for a connection to be made, the relevant instrument or unit should be removed and the pipelines blanked off.

(2) Some pressure tests require certain instruments to be removed.

12.2.6 All doors, clear vision windows, emergency exits, etc., should be free to operate, after closing checked for security. If an unusual force is necessary to close any of these items, the cause should be investigated and rectified before the cabin is pressurised.

12.2.7 Where sandwich type windows are fitted, a check for security should be made and, where applicable, services for window de-misting purposes should also be checked to ensure freedom from leaks and obstructions, and for correct venting, i.e. to atmosphere or to the pressurised area dependent upon the design.

12.2.8 During testing, the maximum cabin differential rate of change must not exceed the values specified in the relevant Aircraft Maintenance Manual.

12.2.9 Manometers and other portable test indicators e.g. pressure gauges and vertical speed indicators, required for testing must be checked and calibrated at regular intervals.

12.2.10 Where any disturbance of cabin air ducting has occurred, checks should be made for correct alignment, security and freedom from foreign matter. As necessary, airtightness of the ducting should be checked by blanking local sections and subjecting them to pressure tests.

12.2.11 Any seals, glands or expansion joints should be checked for correct fitting, and where controls pass through the aforementioned they should be lubricated as necessary and in the manner specified in the relevant Aircraft Maintenance Manual.

NOTE: Detachable blanking plates used when testing should not be sealed with jointing compound.

12.2.12 Following the satisfactory completion of tests, the operation of all windows, doors and hatches (including those of galley units) should be checked.

NOTE: Following the conclusion of tests, it must be ensured that cabin pressure has been reduced to the prevailing ambient conditions before attempting to open any doors, windows or hatches.

12.3 **Functional Tests**

12.3.1 **General.** To perform a full or partial functional test of the pressurisation system reference should be made to the relevant Aircraft Maintenance Manual. Where it is required that the pressurisation system is pressurised, this can be achieved by one of the following methods:—

(a) Running the engines, utilising the bleed air or engine-driven compressors, as appropriate.

(b) Connecting a ground supply unit to the ground service connection point (where fitted) see Figure 4.

(c) Employing bleed air supplied from the auxiliary power unit (APU).

12.3.2 It is however, recommended that functional tests are carried out by running the engines and utilising bleed air or air supplied from engine-driven blowers, as this enables all components to be tested simultaneously.

12.3.3 When carrying out tests, additional test instruments and equipment may be required and reference should be made to the relevant Aircraft Maintenance Manual for precise details of the type and method of connection into the pressurisation system. Generally, a portable vertical speed indicator and mercury manometer or pressure gauge are required, together with a stop watch and a pitot-static test set. The test set is normally used for checking for leaks from pressure controllers, pressure signal and static pressure pipelines, and also for checking the function of discharge valves in response to selected pressure signal settings from pressure controllers.

12.3.4 **Preparation.** Unless otherwise specified in the Aircraft Maintenance Manual, all internal doors or hatches within the pressurised area of the fuselage should be secured in the open position. In all cases, the doors of equipment which could be damaged by differential pressures, e.g. galley cupboards, ovens, should be opened. Unpressurised areas adjacent to the pressure cabin should be vented to atmosphere.

12.3.5 After entering the aircraft, the entrance doors, emergency exits and hatches, toilet servicing connections, sliding and direct vision windows in the crew compartment should all be closed. Where specified in the Aircraft Maintenance Manual, other apertures such as toilet ventilation bleed outlets should be blanked off.

.NOTE: Care must be taken to ensure that certain specified fuselage and compartment drains are not obstructed as allowance is made in the leak rates permissible during pressure tests. Reference must always be made to the relevant Aircraft Maintenance Manual for details of drain locations.

12.3.6 **Test.** Electrical power should be switched on and the controls of the appropriate cabin air temperature control system and pressurisation system units selected to the setting specified in the Aircraft Maintenance Manual for functional testing.

12.3.7 When introducing the air supply, the cabin pressure should be controlled in the manner appropriate to the system to ensure that the rate of pressure change (normally given in feet per minute) does not exceed the maximum values specified in the Aircraft Maintenance Manual.

12.3.8 The cabin pressure should be allowed to increase until it stabilises at the maximum working differential pressure for the aircraft type, and a check should be made to ascertain that the pressure remains constant with a temporary increase in air supply. If the differential pressure stabilises at a figure above or below the maximum value, the pressurisation control system should be investigated and rectified as necessary after conclusion of the test. After such rectification, a further test should be made.

12.3.9 Where multiple pressure control units are provided, each unit should be selected in turn and checks made to ensure that the differential pressure builds up and stabilises at the relevant maximum value.

NOTE: Whilst the cabin is pressurised, it may be required that all flying controls are operated to test the efficiency of cable seals etc, therefore reference should be made to the relevant Aircraft Maintenance Manual.

12.3.10 The automatic action of safety valves should also be checked during pressurisation system tests, with the discharge valves isolated from pressure signal sources. Air should be supplied to the cabin at the specified controlled rate and a check made on the pressure at which the valves open. The cabin should then be allowed to depressurise slowly until the valves close and the corresponding pressure noted. The pressures at which valves open and close should be within the limits specified in the relevant Aircraft Maintenance Manual.

NOTE: When checking the operation of cabin safety valves which are set to relieve at the maximum differential pressures permissible for the aircraft type, control of the air supply must be carried out with extreme care to ensure that the pressure never exceeds the maximum value.

12.3.11 If during a pressure test the leak rate increases unduly, as denoted by both a sudden fall in differential pressure and a sudden ascent indication on the cabin vertical speed indicator, the pressure must be released and the fuselage examined for the cause before continuing the test.

12.3.12 When all functional tests are concluded, the air supply should be cut off and the cabin pressure then allowed to fall gradually at a controlled rate. If the pressure is released too rapidly moisture precipitation may occur damaging electrical cables and cabin installations.

12.4 **Leak Rate Tests**

12.4.1 **General.** Leak rate tests are necessary at specified periods to ensure that no marked deterioration in the sealing standard of the aircraft fuselage has occurred. The tests should also be carried out whenever a component affecting the pressurised area is renewed, refitted or modified, and after a proof pressure test. Before testing, adequate time should be allowed for the drying of any freshly applied sealants. On certain aircraft, leak rate tests may be combined with functional tests; in other cases the tests should be carried out separately. The periods at which the tests and tests methods are to be carried out, are provided respectively in the relevant Approved Maintenance Schedules and Aircraft Maintenance Manuals.

12.4.2 As in the case of functional tests, observers are required inside the aircraft and the instructions given in paragraphs 12.2.2 of this Leaflet equally apply. It is preferable to supply air to the cabin from a ground air supply unit thus eliminating the danger from propellers or jet engine intakes and exhausts to personnel inspecting the outside of the fuselage.

12.4.3 The instructions given in the relevant Aircraft Maintenance Manual for leak rate testing should be closely followed. It is the practice on some aircraft to render the pressure controller inoperative by disconnecting it from the discharge valves, in which case the cabin pressure obtained is at maximum determined by the safety valves. On other aircraft the delivery rate of the air supply is controlled and the air is shut off when the pressure reaches a specified value lower than maximum.

12.4.4 A check should be made on permanent fuselage drain holes, battery compartment vents, hydraulic system reservoir bleeds etc., to ensure that they are unobstructed.

12.4.5 The air should be introduced to the cabin gradually until the pressure stabilises. In some cases manufacturers recommend that the pressure is raised slightly above the specified values and then allowed to fall to this value before checking the leak rate.

12.4.6 After the pressure has stabilised, the air supply should be shut off and the pressure allowed to fall by normal fuselage leakage. The time taken for the pressure to fall over the range appropriate to the aircraft type must not be less than that quoted in the relevant Aircraft Maintenance Manual.

12.4.7 If the leak rate is excessive, an inspection of the fuselage pressurised area should be carried out with the cabin pressure held to the value specified for the aircraft type. Escaping air may usually be detected by sound, or touch, but a soapy water solution may be used to trace certain leaks and this should be cleaned off after testing. When inspecting the outside of the aircraft for leaks, inspection personnel should exercise caution when entering nose-gear bays or similar breaks in the main pressurised area.

12.4.8 The sealing standard of the fuselage should be improved as necessary and in the manner detailed for the aircraft type, until the leakage rate is within limits.

12.4.9 At the conclusion of the tests the air supply should be shut off and the cabin depressurised ensuring that the rate of pressure change does not exceed the specified value. Before opening doors, windows, or hatches, it must be ensured that cabin pressure has been reduced to prevailing ambient conditions.

12.4.10 Electrical power should be switched off and all blanks and plugs used during tests should be removed.

12.4.11 Where pressure control system components have been removed or isolated for purposes of leak rate tests, they should be restored to their normal operating condition. Leak tests of the system should be carried out with the aid of a pitot-static test set and in the manner detailed in the relevant Aircraft Maintenance Manual.

12.4.12 The fuselage should be examined for obvious damage or distortion, particular attention being paid to the pressure bulkheads, cabin floor members, window and windscreen frames and panels, and suppressed antenna covers. The transparencies should be examined for signs of crazing. All doors, hatches and windows which are intended to open should be fully opened and then closed, to check for free movement and absence of deformation.

13 MAINTENANCE

13.1 **General.** Details of the operations necessary for the inspection and maintenance of pressurisation system components will be found in the relevant Aircraft Maintenance Manuals and Approved Maintenance Schedules, and reference must at all times be made to such documents. The information given in the following paragraphs is intended only as a general guide to the checks normally required on the principal components covered by this Leaflet.

13.2 Pressure Controllers

13.2.1 Functioning tests of the pressure controller, should be made when defective operation of the pressurisation control system is suspected, and at all other times specified in the relevant Approved Maintenance Schedule. Further checks can be carried out where electronic pressure controllers are equipped with Built In Test Equipment (BITE).Adjustments and rectifications which may be made in situ are limited, and therefore the relevant Aircraft Maintenance Manuals appropriate to the type of aircraft and controller should be referred to before any adjustments or tests are carried out. If the results of the functioning tests are unsatisfactory and the pressure controller is found to be defective, it should be removed from the aircraft and tested according to the manufacturer's recommended test schedule and as appropriate, repaired, overhauled or replaced.

13.2.2 At certain specified intervals, some pneumatic pressure controllers are required to be lightly lubricated using only lubricants recommended by the manufacturers. Checks should also be made for security, corrosion or damage, and the associated electrical circuits should be tested as necessary for continuity and insulation resistance (see Leaflet **EEL/1-6**.

13.3 **Discharge Valves and Ground Automatic Relief Valves**

13.3.1 At intervals specified in the Aircraft Maintenance Schedule, the pressure controlling function should be tested. These tests are normally done in situ and in conjunction with the associated pressure controller. The security and functioning of ditching system controls, where fitted, should also be carried out.

13.3.2 Valve faces and seats should be inspected for damage and deposits of dust and nicotine tar which should be removed in the manner specified in the relevant Aircraft Maintenance Manuals. The cleaning fluids used should be of the type recommended by the manufacturers, and on completion of a cleaning operation all traces of fluid should be removed and all surfaces cleaned using a dry, soft, lint-free cloth. High pressure air blasts should not be used to dry the seating surfaces of diaphragm-controlled discharge valves as damage may be caused to the diaphragms. Bonding leads and their attachment points should be inspected for security of attachment and checked for electrical continuity (see Leaflet **EEL/1-6**).

13.3.3 At specified periods, discharge valves should be removed, inspected, and leak tested to ensure that the leak rate is within specified permissible limits. After reinstatement or replacement of a discharge valve a full functional check should be carried out as detailed in paragraph 12.3.

NOTE: On some aircraft types, shims are installed to aerodynamically align the discharge valve, with the fuselage. When removing the valve from the aircraft these shims should be retained in order to maintain that alignment when replacing the valve. (See also paragraph 11.3.2.)

13.4 **Safety Valves and Inward Relief Valves**

13.4.1 Mountings, pipe unions, electrical actuator where fitted, (and its connections) should be checked for signs of damage, deterioration and security.

13.4.2 Leak tests and functioning tests should be made after installation, when the serviceability of valves is suspect, during cabin pressure testing (see paragraph 12), and at the periods specified in the Approved Maintenance Schedule. The requirements for functional testing of inward relief valves is normally restricted to checking freedom of movement.

13.4.3 Valve faces and seats should be inspected and deposits of dust and nicotine tar removed in the same manner as that specified for discharge valves (see paragraph 13.3.2). After cleaning, a check should be made to ensure that valve faces and seats make good contact.

13.4.4 Electrical and manual override controls should be checked for security and tested for correct operation, particular attention being paid to the settings of actuator limit switches, lost motion in linkages, cable tension and static friction. Where specified, moveable parts should be lightly lubricated using only the specified lubricants.

13.4.5 Certain types of safety valves can be adjusted in situ, but before any attempt is made to alter the relief pressure setting it should be established that any error in the pressure at which the valve relieves is not due to a defect in the valve mechanism. After making adjustments to a valve its operation must be checked by repeating the appropriate cabin pressure and functional test as described in paragraph 12.

13.5 **Filters and Air Driers**

13.5.1 The element of cartridge type filter units should be removed and replaced by a new element when necessary. Before fitting the element the filter casing and connecting union orifice should be cleaned with the recommended cleaning agent as prescribed in the relevant Aircraft Maintenance Manual.

13.5.2 Checks should be made on the condition of Silica Gel Crystals and the appropriate air drier containers recharged as necessary. The condition of sealing rings should also be checked.

13.5.3 Baffle type air driers should be checked for security paying particular attention to the condition of the sealant. The filter gauze which is also provided must be free from corrosion and cleaned with the recommended cleaning agent.

AL/3-24

Issue 2

September, 1988

AIRCRAFT

SYSTEMS AND EQUIPMENT

AIR CONDITIONING

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide general guidance and advice on the installation, maintenance and testing of equipment forming part of aircraft air conditioning systems.

1.2 The information contained in this Leaflet is of a general nature, and should therefore be read in conjunction with the relevant Aircraft Maintenance Manuals and Approved Maintenance Schedules.

1.3 **General**

1.3.1 The air conditioning system of an aircraft is designed to maintain selected temperature conditions within flight crew, passenger and other compartments, and comprises five principal sections: air supply, heating, cooling, temperature control, and distribution. In some aircraft a humidity control section also forms part of the air conditioning system.

1.3.2 In pressurised aircraft, the air conditioning and pressurisation systems are intrinsically linked, and it is the controlled discharge of pressurised and conditioned air, which maintains the selected cabin altitude. For further information on aircraft pressurisation systems and cabin pressure control equipment, see Leaflet **AL/3-23.**

1.4 Brief descriptions of some principal units which form a typical air conditioning system are given in the relevant paragraphs of this Leaflet. For precise details of specific systems reference must be made to the relevant Aircraft Maintenance Manuals.

1.5 The subject headings are as follows:—

1.6 Related CAIP Leaflets and Airworthiness Notices:—

AL/3-8 — Fire — General Precautions
AL/3-23 — Pressurisation Systems
AL/3-26 — Auxiliary Power Units
Airworthiness Notice No. 40
Airworthiness Notice No. 41

2 AIR SUPPLIES

2.1 **General.** The source of air supply and arrangement of essential components depends on the type of aircraft and air conditioning system employed, but in general one of the methods described in the following paragraphs may be adopted.

2.2 **Ram Air.** This method is adopted in certain small types of unpressurised aircraft utilising either combustion heating or engine exhaust heat exchanger systems (see paragraphs 3.2 and 3.3). A typical system is diagrammatically illustrated in Figure 1. Typical locations for a ram air intake are at the nose of an aircraft or in a dorsal fairing at the base of the fin or vertical stabiliser. The air, after circulating through the cabin, is discharged to atmosphere via a spill vent.

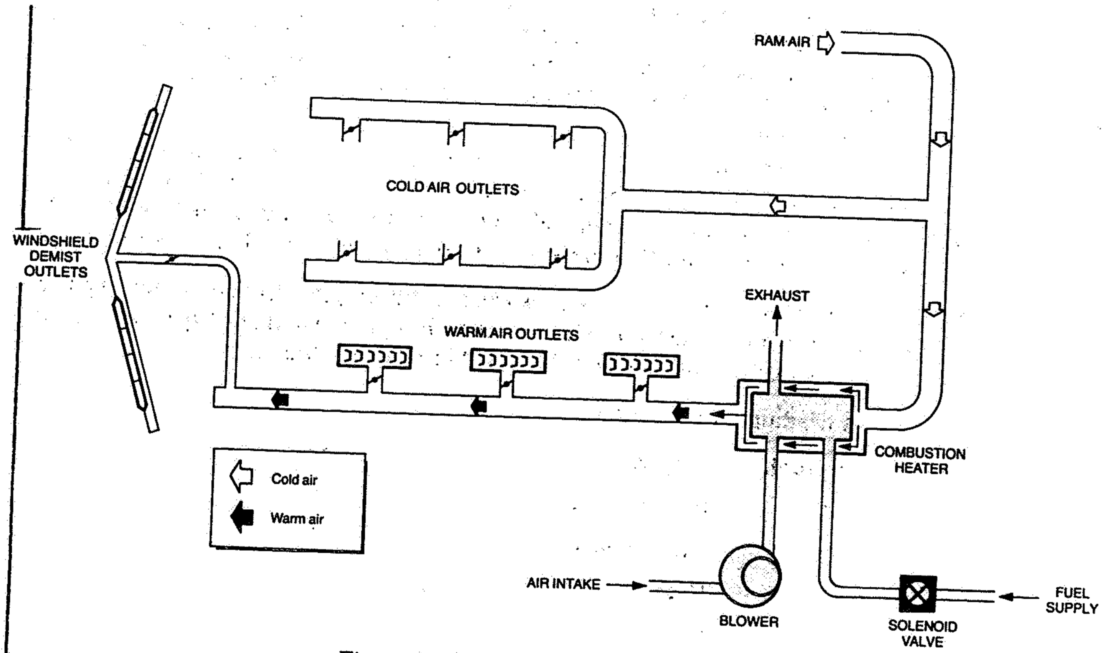


Figure 1 TYPICAL RAM AIR SYSTEM

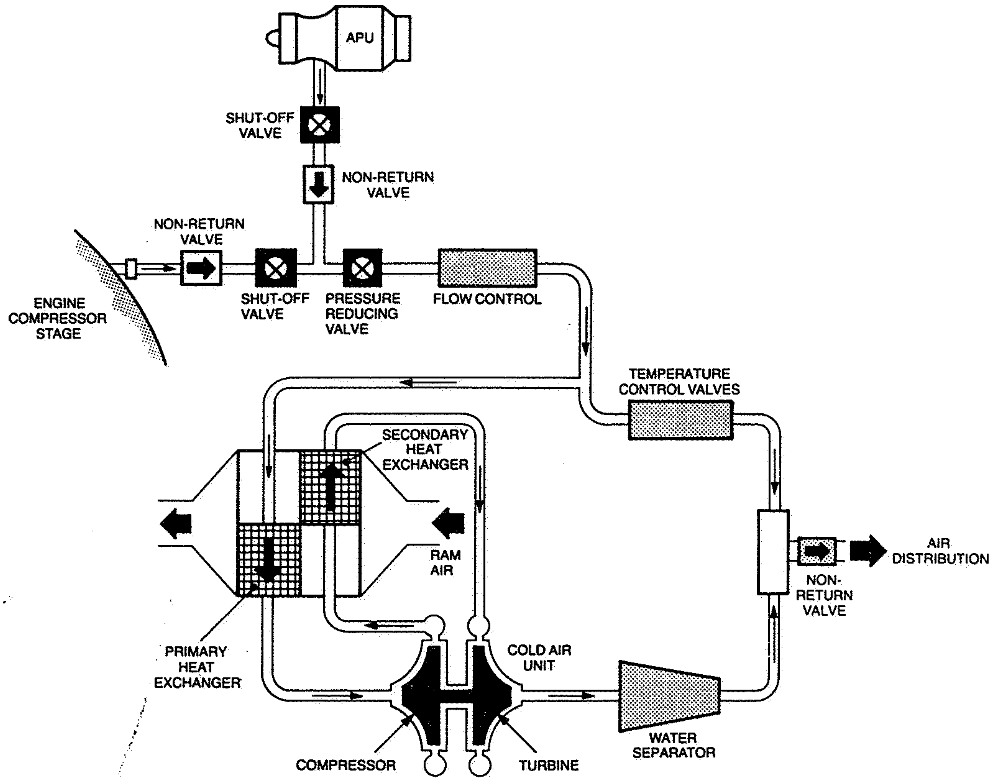


Figure 2 TYPICAL BLEED AIR ('BOOTSTRAP') SYSTEM

2.3 **Engine Bleed Air.** This method is adopted in certain types of turbo-jet aircraft, in which hot air, readily available from main engine compressors is tapped off and supplied to the cabin. Before the air enters the cabin it is passed through appropriate control valves and a temperature control system (see paragraph 5) to reduce its pressure and temperature. A typical bleed air system of the 'bootstrap' type is illustrated diagrammatically in Figure 2.

2.4 **Auxiliary Power Unit (APU).** The auxiliary power unit, where fitted, is an independent source of pressurised air. Operation of the APU is, however, subject to certain limitations, and further information is contained in Leaflet AL/3-26.

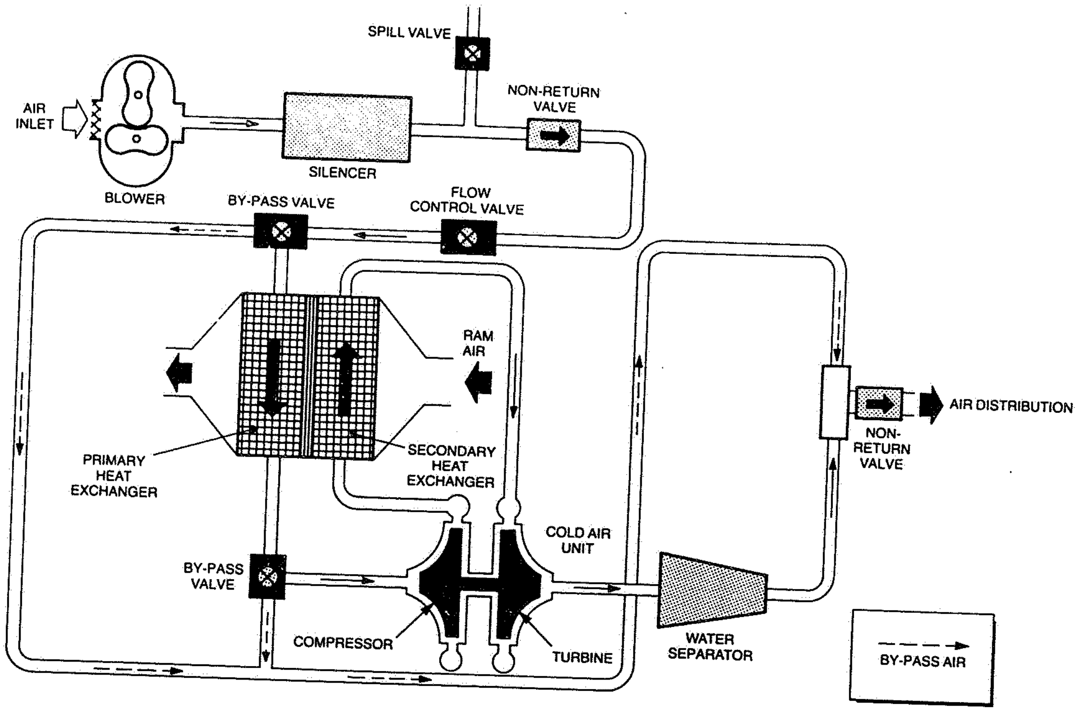


Figure 3 SYSTEM EMPLOYING A DISPLACEMENT TYPE BLOWER

2.5 **Compressors or Blowers.** This method is utilised in some types of turbo-jet, turbo-propeller and piston-engined aircraft, the compressors or blowers being driven by the engines via accessory drives, gear boxes or bleed air. Figure 3 diagrammatically illustrates a typical system employing an air displacement type of blower.

Air is drawn in through a ram air intake located in a wing leading edge or an engine nacelle fairing. A filter unit may be provided to protect the blower rotors from foreign matter and to ensure a clean air supply. In order to reduce the level of noise emanating from the blower, silencers are incorporated in the main supply ducting.

3 HEATING

3.1 **General.** The method of heating the air depends on the type of air supply system and one of the methods outlined in the following paragraphs may be adopted.

3.2 **Combustion Heating**

3.2.1 This method is normally associated with a direct type of ram air ventilating system, and depends for its operation on the combustion of a fuel and air mixture within a special cylindrical combustion chamber (see Figure 1).

3.2.2 Air for combustion is obtained from a blower and the fuel is metered from the aircraft fuel system by a solenoid-operated control valve. A filter and safety valve are also incorporated in the fuel supply line to the combustion chamber. The fuel-air mixture is ignited by a spark plug, the burning gases travelling the length of the combustion chamber and passing through transfer passages to an exhaust outlet. Ventilating air from the ram air intake passes through the heater and is heated by contact with the outer surfaces of the combustion chamber.

3.2.3 Blower operation and supply of fuel is normally controlled by a single switch. Regulation of the cabin temperature is carried out by the manual setting of a mechanically controlled switch installed in the ducting downstream of the heater.

3.3 **Engine Exhaust Heating.** This method is also associated with ram air ventilating systems, but heating of the air supply is effected in a simpler and more direct manner. Air enters through an intake connected to a heater muff which surrounds the exhaust pipe of a piston engine exhaust system. After heating, the air passes into the cabin via a chamber through which cold air also flows from an intake situated either in the fuselage or in the wing depending on the installation. Mechanically operated valves are provided to control the mixing of the air flows and so regulate the temperature.

3.4 **Compression Heating.** This system of heating relies on the principle whereby the air temperature is increased by compression and forms the basis of the heating method employed in air supply systems utilising engine driven compressors or engine bleed air (see paragraph 2.3 and Figure 3).

4 COOLING

4.1 **Ram Air.** In ram air supply systems the cooling method is of the simplest type whereby the cold air can be directly admitted to the cabin via adjustable louvres (see Figure 1). In the more complex systems cooling may be accomplished by either the air cycle or the vapour cycle method.

4.2 **Air Cycle Cooling**

4.2.1 The operation of an air cycle cooling system is based on the principle of dissipating heat by converting its energy into work. The principle components of a typical system are the primary and secondary air-to-air heat exchangers, a turbo-compressor cold air unit and a water separator. The interconnection of these components in a 'bootstrap' arrangement, is illustrated in Figures 2 and 3.

4.2.2 Heated air is directed through air passages of a matrix assembly within the primary heat exchanger and is pre-cooled by air entering a ram air intake and passing across the matrix. The pre-cooled air then enters the cold air unit via the axial inlet of the compressor and is compressed by the action of the compressor impeller and diffuser assembly.

The air leaves the compressor outlet and passes through a matrix assembly of the secondary heat exchanger which dissipates a large proportion of the heat produced by compression. From the secondary heat exchanger the air enters the turbine of the cold air unit. The air expands through the turbine and in causing the latter to drive the compressor, sufficient pressure drop across the turbine is achieved to cause further cooling of the air.

4.2.3 The water separator (coalescer) is installed downstream of the cold air unit to extract a percentage of free moisture from the air which subsequently ventilates and pressurises the cabin. Air from the cold air unit turbine enters the separator and passes through an assembly in which the moisture in the air coalesces into large water droplets. The droplets are then carried by the air to a separator assembly which extracts the water. The water is then drained away through a drain line to an overboard vent, or into the heat exchanger ram air supply to provide additional cooling. To ensure that the flow of air to the cabin is maintained in the event of the water separator assembly becoming obstructed by ice, a safety valve is normally provided.

NOTE: In some systems, the water separator is combined with an airflow silencer unit.

4.3 Vapour Cycle Cooling

4.3.1 The principle of vapour cycle cooling is based upon the ability of a refrigerant to absorb heat through a heat exchanger in the process of changing from a liquid into a vapour. The major components of a typical system and their interconnection with each other is diagrammatically illustrated in Figure 4. These components are generally mounted together to form a refrigeration pack, and comprise the following:—

(a) **A Liquid Receiver:** to provide a storage area for the liquid refrigerant.

(b) **A Thermostatic Expansion Valve:** to control and meter the liquid refrigerant into the evaporator.

(c) **An Evaporator:** which is a form of heat exchanger designed to extract heat from the main air supply prior to distribution into the aircraft.

(d) **A Compressor:** to provide the motive force for refrigerant re-circulation, and in conjunction with the thermostatic expansion valve, maintain a pressure differential between the condenser and evaporator. The effect of this differential improves both vaporisation and condensation of the refrigerant as follows. The compressor in drawing vapour from the evaporator assembly, decreases the effective pressure acting upon it, the consequence of which reduces the boiling point of the refrigerant. Conversely, on the discharge side of the compressor, vapour pressure is increased. This has the effect of increasing the boiling point and condensation point of the refrigerant, which returns to a liquid state when the latent heat is removed in the condenser.

NOTE: The coupled turbine of the compressor may be driven by an independent air supply (e.g. a tapping from a wing de-icing system), the main air supply, or electrically.

(e) **A Condenser:** which is a form of heat exchanger designed to extract heat from the vaporised refrigerant.

(f) **A Condenser Fan:** which provides (in the absence of ram air), cooling air for the condenser.

(g) **The Refrigerant:** which is a low boiling point volatile liquid such as; ammonia, sulphur dioxide, or dichlorodifluoromethane generally referred to by the trade name of 'Freon'.

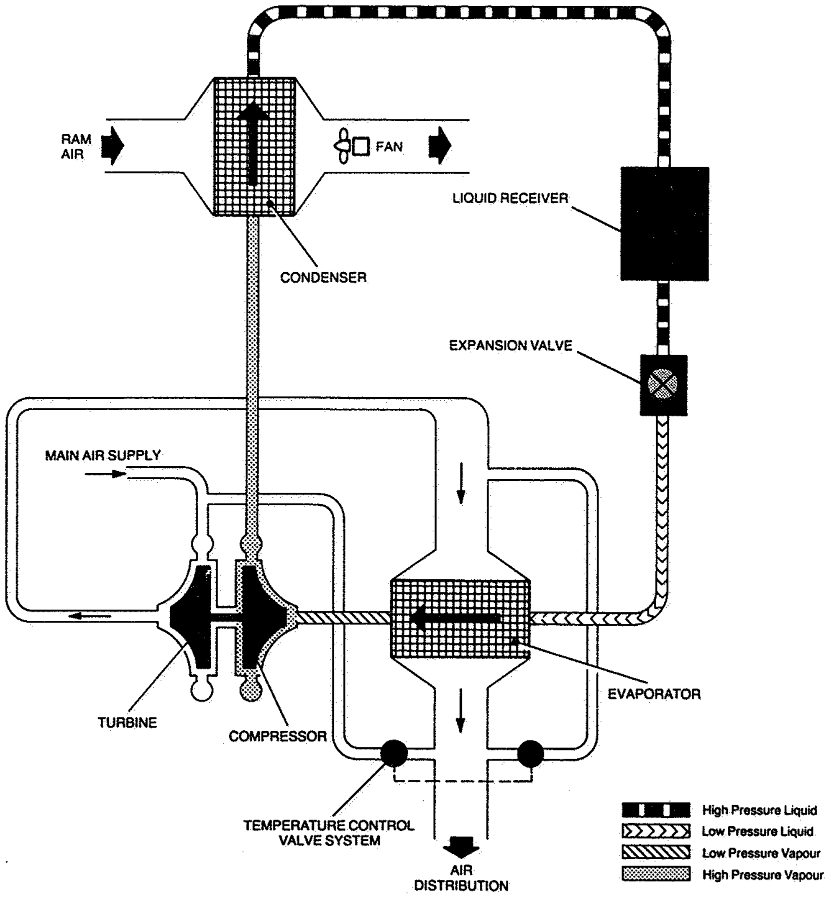


Figure 4 VAPOUR CYCLE COOLING SYSTEM

4.3.2 The Vapour Cycle is as follows (see Figure 4):—

(a) Liquid refrigerant passes from the liquid receiver to the thermostatic expansion valve for controlled release into the matrix of the evaporator.

(b) Heated air from the main air supply system (prior to entry into the cabin distribution system) passes through the evaporator matrix and by induction releases heat into the liquid refrigerant.

NOTE: The main air supply entering the distribution system is now at a reduced temperature.

(c) As a consequence, the liquid refrigerant boils to a vapour.

(d) The vaporised refrigerant is then drawn into the compressor, compressed to a high pressure and temperature (see paragraph 4.3.1 (d)), to enter the condenser.

(e) The condenser; cooled by ram air, reduces the temperature of the vaporised refrigerant, and as a consequence returns the vapour back to a liquid form which then flows back into the liquid receiver to repeat the cycle.

5 TEMPERATURE CONTROL

5.1 **General.** Control of air temperature conditions in passenger cabins, flight crew and other compartments, is accomplished by modulating the valves installed in the air ducting of heating and cooling sections of the air conditioning system. The methods of control vary and depend on the type of aircraft and the air conditioning system employed. In general, two principal methods are adopted, mechanical and electromechanical. The information given on these two methods in the following paragraphs is of a general nature, and reference should always be made to specific Aircraft Maintenance Manuals for full operating details.

5.2 **Mechanical Control.** One mechanical method, which, for example, is employed in aircraft utilising an engine exhaust heating system, and consists of valves which can be manually positioned to regulate the temperature by varying the proportions of hot and cold air passing through a mixing box before delivering it to the cabin. In some installations, hot and cold air enters the cabin through separate valves and ducting.

5.3 **Electromechanical Control**

5.3.1 The electromechanical method of temperature control used in some types of combustion heating system, is also used in all air conditioning systems which utilise the compression method of heating, and air cycle or vapour cycle methods of cooling. In a combustion heating system, the electrical power supply to the solenoid valve is automatically controlled by the duct thermostat. When the temperature of the air flowing from the heater exceeds the thermostat setting, the thermostat de-energises the solenoid valve to isolate the fuel supply to the heater. As the heater cools, the thermostat opens the valve to restore the fuel flow and combustion process. By cycling on and off, the heater maintains an even temperature in the cabin.

5.3.2 In systems utilising compression heating, air cycle, or vapour cycle methods of cooling, the electromechanical temperature control system is designed to automatically modulate actuator motors which control particular valves. A typical system comprises, a duct temperature sensing element, a temperature selector, cabin temperature sensing element and automatic control unit. These components are electrically interconnected to form a resistance bridge circuit which is only in balance when the cabin air temperature is at the selected value.

If the bridge circuit is placed out of balance by a resistance change in either of the sensing elements due to temperature variation, or by varying the selector switch setting, an error signal is produced which is fed to an amplifier stage of the control unit. The amplified signal is then fed to the appropriate actuator motors which position their respective valves to adjust the air flows and so correct the temperature change until the bridge circuit is restored to a balanced condition. Manual controls are provided to permit overriding of the automatic circuit. Low temperature and high temperature limit control devices are also provided and respectively they prevent icing in the water separator, and ensure that upper limits of supply air temperature are not exceeded.

NOTE: In some aircraft employing compression heating, control is by manual means only and is effected by placing a temperature control valve switch to a 'COOL' or 'HEAT' position as appropriate.

6 DISTRIBUTION

6.1 General

6.1.1 The air used for conditioning purposes is distributed by a ducting system the layout of which depends on the type of aircraft and its air conditioning system. In a basic system, such as that employing a ram air supply and combustion heating (see Figure 1) the ducting is generally in two distinct sections and provides for separate flows of cold and heated air. The outlets for cold air are normally of the adjustable louvre type and are installed so that air flows from such points as below hat racks, cockpit and cabin sidewalls.

Heated air is distributed through outlet grilles situated at floor level, the degree of heat being regulated by mechanical valves directly controlled at the outlets, or by control knobs in the flight compartment. The heated air duct also has a branch duct which directs heated air to the windshield panels for demisting purposes.

6.1.2 In larger aircraft the air conditioning equipment is normally grouped together in its own compartment or bay. The conditioned air is distributed to passenger cabins through underfloor and hat rack ducting, the latter containing outlet grilles and the requisite number of individual adjustable cold air louvres which are supplied from a cold air source. The distribution of air to flight crew compartments may, in some cases, be through separate ducting or it may be through ducting tapped into the passenger cabin ducting. Typical locations for the air outlets are at floor and roof levels and in sidewalls.

Tappings are taken from the cabin and flight crew compartment ducting systems for supplying warm air to cabin windows and windshields for demisting purposes. After circulation the air is exhausted to atmosphere through the discharge or outflow valves in the pressurisation system.

6.2 **Materials.** Materials used in the manufacture of typical ducting systems are light-alloy, plastic, fibreglass reinforced plastic and stainless steel, the latter being normally used for the hot air sections of engine bleed air supply systems. There are various methods of joining the duct sections together and to components. In those most commonly used the joints are made by flanges and ring clamps of V-section, by rubber sleeves fitted over the ends of duct sections and secured either by adjustable clamps or by a rubber adhesive, and by bolted flanges.

Fibreglass, formed into blanket sections by a covering of synthetic material e.g. nylon, is used for lagging of duct sections. To permit longitudinal movement of ducting as it expands and contracts, expansion bellows, sliding clamps and gimbal mountings are provided in some of the larger aircraft systems.

7 HUMIDITY CONTROL

7.1 **General.** In some aircraft operating for long periods at high altitudes, it is necessary to increase the moisture content of the air used for conditioning and pressurising the cabin in order to overcome physical discomfort arising from low relative humidity. Various humidity control methods may be adopted but a typical system consists of a humidifier unit supplied with water (from an individual tank or galley water system) and also with air under pressure. The water and air supplies; which are controlled by electromagnetic valves, pass through a jet nozzle system within the humidifier in such a manner that the water is atomised and enters the distribution ducting in the form of a fine spray.

7.2 At the other extreme, operation of aircraft at low altitude and on the ground in regions of high relative humidity, necessitates a reduction of the moisture content of the air supply. In addition to the passenger comfort aspect, it is necessary to decrease the humidity in order to reduce condensation and its effects. Therefore, a water separating device similar to that described in paragraph 4.2.3 is installed for this purpose.

8 GROUND AIR CONDITIONING

8.1 **General.** In some aircraft provision is made for the conditioning of cabin air while an aircraft is on the ground. The methods adopted depend on the type of aircraft and the associated air conditioning system.

8.2 In aircraft employing combustion heating systems, cabin heating is normally obtained by switching on the heater and a ventilating fan located in the main air supply ducting. On the ground, limited cooling of the cabin air can be obtained by switching on the ventilating fan.

8.3 For heating the cabin air in aircraft equipped with an engine exhaust heating system it is necessary for the engine(s) to be running, and for the mechanical air flow control valves to be appropriately adjusted to provide the desired conditions. Limited cooling may be obtained in a manner similar to that referred to in paragraph 8.2.

8.4 Aircraft using more complex methods of air conditioning are often provided with special external connections to which ground service equipment can be coupled. These units supply either pre-conditioned air into the main cabin air distribution system, or pressurised air into the air conditioning packs. In some cases ground service equipment may be used when carrying out ground test procedures.

8.5 In addition to the ground connections, some aircraft are equipped with an auxiliary power unit (see Leaflet **AL/3-26**) for use in the absence of ground conditioning units. Electrically operated blowers may also be fitted for use either as simple cool air ventilators, or in conjunction with a 'bootstrap' air conditioning system, to provide a flow of cooling air to the heat exchangers.

9 INSTALLATION PROCEDURES

9.1 **General.** The information given in the following paragraphs is of a general nature, and is intended as a guide to the procedures associated with the installation of the principal components of air conditioning systems. Full details are contained in the Aircraft Maintenance Manuals for specific aircraft types. Therefore, reference must be made to these publications.

9.2 Compressors and Blowers

9.2.1 Before installation a check should be made to ensure that units are free from damage and that ducts, air inlets and outlets, and mating surfaces are free from oil, dust and other foreign matter. Rotors should also be checked for freedom of rotation observing any special precautions and procedures specified for the appropriate types of unit.

Pipes, metering units and filters of bearing lubricating oil systems should also be inspected for cleanliness and signs of cracks or other damage. Priming of the lubricating oil system should be carried out as specified in the Component and Aircraft Maintenance Manuals (see paragraph 10.2.2).

9.2.2 Units must be adequately supported during installation to ensure that their weight is not allowed to bear on parts of the main drive; for example, a quill shaft which drives a displacement blower. In some aircraft employing compressors a special hoist is provided for installation and removal of units and this should be used in the prescribed manner.

9.2.3 After a compressor or blower has been lowered on to the engine or gearbox mounting pad, its securing nuts or bolts, as appropriate, should be torque-tightened to the values specified in the Aircraft Maintenance Manual. In some compressor installations the units must also be secured by bolting them to the casing of their respective engines via link assemblies.

9.2.4 Inlet and outlet duct attachment flanges should be clean and free from damage. In displacement blower systems, manifolds normally provide for the attachment of duct sections to the blower casing. The bolts securing each manifold to the blower, are, in some cases, of different lengths. Therefore to avoid distortion of the inner face of the blower casing they must be refitted in their correct position before tightening. New sealing rings should be fitted between duct sections and corresponding attachment points on compressors and blowers. The sections should fit squarely and not be subjected to undue strain or load, or be in contact with other components which may abrade duct surfaces.

9.3 Combustion Heaters

9.3.1 Before installation, combustion heaters should be inspected, and when necessary, pressure tested in the manner prescribed in the Aircraft Maintenance Manual to ensure that no fuel or combustion products leak into the cabin air supply (see Airworthiness Notice No. 40).

9.3.2 Heaters should be installed in the manner specified in the Aircraft Maintenance Manual concerned, taking care that air and fuel leakages do not occur at duct joints or connections. There should be no connection between the combustion air and cabin air supplies and no leakage of air or exhaust gas into the aircraft.

9.3.3 Equipment associated with the heating system such as flow valves, air regulators, thermostatic devices and ducts should be correctly interconnected, and mechanical movements, flows and temperature settings checked and adjusted.

9.3.4 After the installation of a heater the system should be ground tested in the manner specified in the relevant Aircraft Maintenance Manual.

NOTE: **Unburnt fuel or fuel vapour should not be allowed to accumulate within the combustion system or aircraft particularly during component functioning tests (see Leaflet AL/3-8).**

9.4 Engine Exhaust Heaters

9.4.1 When installing heater muffs around piston engine exhaust systems it must be ensured that they are in such isolation that exhaust gases cannot enter the muff and subsequently be discharged into the heating and ventilating system (see Airworthiness Notice No. 40).

9.4.2 Cooling air intakes and hot air ducting should be installed so that no obstruction or leakage of the air supply can occur. All joints should be correctly aligned and clamps securely fixed.

9.5 **Heat Exchangers**

9.5.1 Before installation, heat exchangers should be inspected to ensure that no foreign matter has entered the various connections, that there are no evident cracks or other damage and that ram air passages are free from obstruction.

9.5.2 Heat exchangers are heavy units and they must therefore be adequately supported during installation to prevent them fouling ducting, other system components and parts of the aircraft structure.

9.5.3 The fore-and-aft and transverse clearances for mounting flanges and bolts should be checked to ensure that they are within the limits specified in the relevant Maintenance Manuals. Mounting bolts should be tightened to the required torque values.

9.5.4 New seals and O-rings should be fitted to the joints between system ducts, cooling air inlet and outlet flanges, and charge-air connections. Nuts, bolts and clamps should not be overtightened as connection flanges may distort and cause damage to adjacent brazed joints. After installation the joints should be leak tested in accordance with the procedure laid down in the relevant Aircraft Maintenance Manual.

9.5.5 If disturbed during installation of a heat exchanger, cooling air shutters or flaps should be tested and adjusted as necessary. Movable parts should operate freely, and the limit switches of electrical actuators should isolate the power supply when the shutter or flap has moved through its full travel.

9.6 **Cold Air Units**

9.6.1 When installing cold air units care is necessary to exclude dirt and oil from the air ducts and casings. Dirt and other foreign matter may damage the rotating parts and oil may introduce unpleasant or flammable vapours into the cabin air supply. Duct attachment flanges, unit mounting flanges, and casings, should be examined for signs of burns, cracks, distortion or other damage.

9.6.2 Units with integral wet sump lubrication should be primed with oil to the approved specification to ensure that all bearing surfaces have been lubricated. Reference should be made to the Maintenance Manuals of relevant units for details of the lubricants required. The unit should be supported on a bench in the normal operating attitude while the quantity of oil specified for the unit is poured in. To ensure that oil is distributed to the bearings, the rotating assembly of the unit should be spun over by hand at the same time checking that the rotation is free and without noise or vibration (see Note). The unit should then be drained and installed in the aircraft and after securing it to its appropriate mounting, refilled with oil to the level marked on the sump dipstick.

NOTE: In some cold air units, air bearings are used to support the main rotating assembly, which do not allow free rotation from the idle state. Therefore reference should be made to the specific Maintenance Manual for further details.

9.6.3 The lubricants recommended for Cold Air Units are various and possibly incompatible with each other. Therefore, when priming or servicing these units, care should be taken to ensure that the oil is of the correct type and specification and the containers used are clean and free from contamination of any kind.

9.6.4 New seals should be fitted between the air distribution ducts and attachment flanges on the cold air unit, and when securing the ducts it should be ensured that they fit squarely and are not subjected to undue strain or load. Leak checks on units should be carried out during functional testing of the air conditioning system.

9.7 **Refrigeration Systems.** The individual components of a refrigeration system can usually be removed and installed separately. However the Maintenance Manuals appropriate to the system and aircraft should always be referred to before attempting such work. Some of the general precautions applicable to closed circuit Vapour Cycle Systems are as follows:—

(a) Gloves and goggles should be worn when handling liquid refrigerants which can be harmful to the skin and eyes.

(b) Before charging a newly installed system, or recharging a system which has been partly disconnected, all air should be evacuated in the manner prescribed in the relevant Maintenance Manual.

(c) While refilling is in progress, care should be taken to ensure that refrigerant used is of the specified type, and quantity, and that all precautions recommended by the manufacturer are observed.

NOTE: The Refrigerant used in Vapour Cycle Cooling Systems, usually contains a specific amount of oil to lubricate the compressor bearings. Therefore, in order to maintain the correct ratio of constituent parts, reference should be made to the relevant Maintenance Manual for the correct volume of oil to be added.

9.8 **Temperature Control System Components**

9.8.1 The temperature control of complex air conditioning systems is usually accomplished either electrically or electronically. Consequently the following precautions are normally adopted when installing such equipment.

9.8.2 As temperature-sensing elements are positioned so that they will be directly affected by the changes in duct and cabin air temperatures. Therefore, care should be taken to ensure that elements sensing cabin air temperature are not shielded by loose upholstery, and are protected if paint spraying or similar operations are performed in their vicinity.

9.8.3 The damping effect of shock absorbers and anti-vibration mountings which may provide support for electronic amplifiers and similar sensitive equipment, should be checked by hand after installation.

9.8.4 Cables interconnecting components must be of the rating specified by the manufacturer and all connections must be clean and securely made.

9.8.5 When installing control units, care should be taken that such controls as pre-set potentiometers and fine adjustment resistors are not disturbed.

9.8.6 On completion of the installation of a component, sensitivity tests and final balance adjustments should be carried out in accordance with the procedure laid down for the specific aircraft system. Tests of the overall controlling function should also be made by selecting various temperature settings and noting that the actuators controlling such components as heat exchanger cooling air flaps, by-pass valves, etc., move in the appropriate directions.

9.9 **Valves**

9.9.1 Mechanically and electrically-operated valves are employed in the various types of heating, ventilating and air conditioning systems and therefore Maintenance Manuals should always be referred to for the appropriate installation procedures. The details given in the following paragraphs are of a general nature.

9.9.2 All valves should be inspected before installation for cleanliness, signs of damage and freedom of movement. Functional checks should be made on electrically-operated valves, e.g. spill valves, by-pass valves and choke valves to ensure that limit switches are correctly adjusted at the extremes of valve travel.

9.9.3 Valves are often marked with arrows to indicate the direction of flow and particular care is necessary to ensure that the valve is installed in correct relation to flow.

9.9.4 The attachment of valves to their respective mountings and duct sections must be secure and torque loadings strictly observed.

9.9.5 Electrical connections to actuators and to position indicators where fitted, should be checked against the relevant wiring diagrams, and plugs, sockets and terminal screws checked for security.

9.9.6 On completion of the installation of a valve, an in-situ functional test should be carried out in accordance with the procedure specified in the relevant Component and Aircraft Maintenance Manual.

9.10 **Distribution Systems**

9.10.1 **General.** The methods of installing ducting and other components of distribution systems depend on the type of air conditioning system and reference must, therefore, always be made to the relevant Aircraft Maintenance Manual and the procedures specified carried out.

9.10.2 The following summary serves as a guide to some important aspects common to installation procedures:—

(a) Ducting should be inspected externally and internally for cleanliness, signs of damage and security of end fittings.

(b) Lagging, where fitted, should be inspected to ensure freedom from tears, damage and evidence of deterioration.

(c) When fitting ring clamps, the sealing rings must be correctly positioned between duct and fittings and the fittings should abut each other squarely before the clamps are tightened.

(d) Ring clamps should be torque-tightened to the loads specified; the loadings should be rechecked after the engine run following installation.

(e) Ducts made from fibreglass, plastic and reinforced plastic should not be subjected to any weight or load during installation, and the straps or clamps attaching the ducts to support brackets should not be overtightened.

(f) After replacement of a duct, the disturbed joints should be checked for leakage.

(g) Where specified, ducts must carry identification labels.

(h) When assembled on ducts, rubber sleeves should be in a free condition, i.e. they should not be twisted, stepped or collapsed.

(i) Bedding tape or metal clips must be fitted between rubber sleeves and adjustable clamps to prevent damage to the sleeves when tightening the clamps. Expansion bellows, sliding clamps or gimbal mountings where installed, should be checked for full and free movement.

(j) Electrical bonding leads must be properly secured.

10 MAINTENANCE

10.1 **General.** The information given in the following paragraphs on maintenance, periodic inspection and testing, is of a general nature and should be read in conjunction with the Maintenance Manuals and Schedules for the components and aircraft concerned.

10.2 Compressors and Blowers

10.2.1 Units should be inspected for damage and for security of mounting attachment to engine drives and accessory gearboxes, and also duct attachments.

10.2.2 Oil transfer pipes should be examined for security of attachment, signs of chafing and other damage, and for leaks. At the periods specified in the Maintenance Manual, oil filters should be removed for examination and cleaning or renewed as appropriate. If it is suspected that dirt is present in the lubrication system, all pipes and oil passages should be cleaned in the manner prescribed in the Maintenance Manual for the relevant unit. In units having an integral lubricating system, the oil level in the sump should be checked and replenished as necessary taking care that the equipment for dispensing the oil is scrupulously clean.

10.2.3 Where magnetic chip detectors are fitted to the lubrication system they should be removed and inspected for metal particles. If no particles are found, the chip detector, together with a new sealing ring, should be refitted and wire locked. If metal particles are present the unit should be replaced with a serviceable item.

NOTE: When refitting bayonet type chip detectors extreme care should be taken to ensure positive engagement.

10.3 Combustion Heaters

10.3.1 Heaters should be examined for security of attachment and signs of malfunctioning, the fuel system should be carefully checked for signs of leakage and drain pipes should be checked to ensure freedom from obstruction. At the specified inspection periods, igniter plugs should be cleaned, and heaters should be subjected to a pressure test in accordance with the procedure laid down by the manufacturer.

10.3.2 Electrical wiring and associated components should be checked for security of attachment, loose connections, chafing of insulation, etc. The sheath of the igniter plug cable should be examined for any possible indications of arcing, which would be evidenced by burning or discolouration of the sheath.

10.3.3 Filters, air and fuel regulating devices, safety devices (e.g. overheat switches, fuel cut-off valves, etc.), and all controls should be inspected, adjusted and tested as required by the Approved Maintenance Schedule.

10.3.4 System operation should be checked in accordance with the procedure laid down in the relevant Aircraft Maintenance Manual.

NOTE: In order to reduce the risk of the cabin air supply becoming contaminated by high concentrations of carbon monoxide from the exhaust system, it is imperative that the procedures for inspection, servicing and overhaul of combustion heaters and their associated exhaust systems are maintained to a high level (see also Airworthiness Notice No. 41).

10.4 **Engine Exhaust Heating.** Careful examination of heater muffs is necessary to ensure that no leakage of exhaust gases into the air delivered to the cabin can occur (see Airworthiness Notices Nos. 40 and 41). Unless damage can be rectified within the scope of an approved repair scheme, exhaust pipes or muffs which show signs of cracking, corrosion or excessive high temperature scaling should be renewed. All muffs should be pressure-tested when specified in the Maintenance Schedule.

Hot and cold air ducts associated with the heating system should be free from obstruction and all controllable shutters, valves, etc., should be checked for correct functioning. The operation of the complete system should be checked during engine running.

10.5 **Heat Exchangers**

10.5.1 Heat exchangers should be inspected for security of attachment to the aircraft structure, security of air duct connections and freedom from damage.

10.5.2 The external surfaces of a heat exchanger matrix must be clean and the cooling air passages free from obstruction. If dirt or other forms of contamination are found the surface and air passages should be cleaned by means of a clean dry air blast.

NOTE: Instructions laid down in specific Aircraft Maintenance Manuals regarding the closing of cooling air flaps to ground blower units and ground test connections must be observed.

10.5.3 If a matrix has not been satisfactorily cleaned due to the contamination being excessive or hardened on to the surfaces, or if internal contamination or leakage from the charge air passages is suspected, the heat exchanger should be removed for cleaning and repair and replaced by a serviceable unit.

10.5.4 Cooling air shutters or flaps, linkages and actuators should be examined for freedom of movement and should be lubricated when necessary. Linkages and hinges of shutters or flaps should be checked for excessive play and lost motion.

10.5.5 During functional testing of a complete air conditioning system, a check should be made at all joints for air leakage.

10.6 **Cold Air Units**

10.6.1 Cold air units should be inspected for security of mountings and external locking devices, cleanliness, freedom from damage, oil leaks, and leakage of air from duct connections. In some units a magnetic chip detector is fitted to the oil sump drain plug; this should be removed and inspected for metal particles. If particles are present, the cold air unit should be replaced by a serviceable unit. If no particles are present, the chip detector together with a new sealing ring should be refitted and wire-locked.

10.6.2 The oil level must be checked and replenished if necessary taking care that the oil is to the specification approved for the unit (see paragraph 9.6.2), that the equipment for dispensing the oil is scrupulously clean, and that the system is not overfilled.

10.7 **Refrigeration Systems.** Refrigeration packs and associated components should be checked for security of mountings, security of pipe line connections between components, and level of refrigerant. If the level is low the system should be checked for leaks and, after rectification, recharged with the refrigerant specified for the system taking care that all precautions are observed (see also paragraph 9.7 and Note).

10.8 **Temperature Control Systems**

10.8.1 All components should be inspected for security of attachment and electrical connection, signs of damage, deterioration of electrical cables etc.

10.8.2 The operation of individual components should be checked during specified ground tests to ensure that they respond correctly whenever different heating and cooling conditions are selected, and also that, in combination, they maintain cabin temperature conditions within a comfortable range. It should be borne in mind that, apart from considerations of comfort, cabin temperature control limits the misting and icing of windscreens and windows and therefore affects the safe operation of aircraft. The operation of components, systems and circuits, designed specifically for emergency operating conditions, must also be checked during ground test procedures.

10.8.3 The test procedures vary and the extent to which a system can be tested may be limited, particularly in relation to ram air methods of cooling. On the other hand, full-range temperature control of a system in some aircraft may be checked on the ground. Reference must therefore always be made to the relevant Aircraft Maintenance Manual and Maintenance Schedule for the procedure to be adopted and precautions to be observed.

10.9 **Valves**

10.9.1 The maintenance of valves associated with air temperature control is usually confined to; inspection for cleanliness, security of attachment ducting attachments and, where applicable, security of electrical connections, functioning tests and light lubrication specified by the manufacturer of the component.

10.9.2 Sliding or rotating parts of valve assemblies should be free from scores, damage or excess static friction. The maximum effort required to move a valve should be checked when necessary and should not exceed the figure recommended by the manufacturer. However some electro-mechanically operated valves are not designed to operate without the application of an electrical supply. Therefore reference should be made to the specific Maintenance Manual for test instructions, before manual operation.

10.9.3 Lubricants should be of the type specified for the component and should be applied sparingly taking care to prevent oil entering air supply ducts.

10.9.4 Valve seats and valves faces should be kept free of dust or traces of lubricant.

10.9.5 Checks on the operation of valves should normally be carried out during ground testing of temperature control systems since their functions are integrated.

10.10 **Distribution Systems**

10.10.1 All ducting and associated air distribution components should be inspected for security and general condition, particular attention being given to joints between duct sections and components.

10.10.2 Lagging should always be properly secured and free from oil, hydraulic fluids etc. It should be remembered that duct sections in some parts of a system often become heated to a degree sufficient to make oil-soaked lagging flammable (see Leaflet **AL/3-8**).

10.10.3 When specified, ducts should be proof-tested at the pressure recommended by the manufacturer; normally a workshop function. Pressure tests are however, more often made with the object of detecting leaks, in which case the test pressure is not critical provided it does not exceed a value which might damage the duct.

10.10.4 It is usually more convenient to test a complete distribution system by dividing it into sections and applying a recommended pressure separately and in sequence. The sections should be selected so that all critical joints are subjected to the test pressure; advantage being taken of shut-off valves, non-return valves, etc., where these provide convenient boundaries between sections.

10.10.5 Leaks can be detected by sound or feel, although these are sometimes revealed by discolouration and holes blown in the lagging. If there is difficulty in locating leaks, the soap and water method can be used.

NOTE: Because of the high operating temperatures and pressures involved, it is recommended that care should be taken when carrying out a physical check for air leaks.

AL/3-25

Issue 1.

11*th June*, 1974.

AIRCRAFT

SYSTEMS AND EQUIPMENT

OXYGEN SYSTEMS

1 INTRODUCTION This Leaflet gives information of a general nature on the types of gaseous oxygen systems and equipment used in aircraft, installation and maintenance practices, and precautions to be observed. Because of the wide variation in the design of oxygen equipment installed in different types of aircraft it is important that this Leaflet is read in conjunction with the appropriate aircraft Maintenance Manual and the approved Maintenance Schedule. The following Leaflets contain information associated with the subject covered by this Leaflet and reference should be made to these as appropriate:—

AL/3-14 Installation of Rigid Pipes in Aircraft
AL/3-23 Pressurisation Systems
BL/6-15 Manufacture of Rigid Pipes
EEL/1-6 Bonding and Circuit Testing

1.1 The Air Navigation Order, 1972, prescribes the conditions under which oxygen equipment is required, and British Standards N1, 2N 100, and N2 specify general requirements for aircraft oxygen equipment and materials and processes to be used in its manufacture. The breathing oxygen used in aircraft systems should comply with British Standard N3 and International Standard ISO 2046.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet AL/6-6, Issue 1, dated 21st June 1968.

2 PURPOSE OF OXYGEN SYSTEMS With increase in altitude the pressure of the atmosphere and the partial pressure of its oxygen content decreases, resulting in a deficiency of oxygen in the blood and tissues of individuals subjected to such pressures. This condition, known as "anoxia", seriously impairs physical and mental abilities and prolonged exposure to it can prove fatal. The purpose, therefore, of oxygen systems in aircraft, is to offset the varying effects of anoxia by supplying oxygen through a breathing mask at a controlled rate of flow.

2.1 Information on the physiological effects of altitude may be obtained from BS 2N 100, but for the purpose of this Leaflet the following is quoted from that document: "Unless oxygen is administered at high cabin altitudes unconsciousness and finally death will occur, the time of onset of unconsciousness depending on the cabin altitude, for example, without added oxygen the time of useful consciousness at 25,000 feet is approximately three minutes and at 40,000 feet it is twenty seconds." Table 1 also contains some relevant information extracted from a more detailed Appendix to the British Standard 2N 100.

TABLE 1

Physiological Effects of Altitude	Feet
Maximum altitude without oxygen at which flying efficiency is not seriously impaired	8,000
Altitude at which the incidence of decompression sickness increases rapidly with exposures exceeding ten minutes	25,000
Maximum altitude at which sea level conditions can be maintained by breathing 100 per cent oxygen	33,000
Maximum allowable altitude without pressure breathing	40,000

3 OXYGEN SYSTEMS Civil transport aircraft cruise at altitudes where cabin pressurisation (see Leaflet **AL/3-23**) is necessary to maintain conditions inside the cabin approximately equal to a maximum altitude of 8,000 feet, regardless of the actual altitude of the aircraft above this figure. Under such conditions oxygen is not normally needed for the comfort of the passengers and crew. However, as a precaution, oxygen equipment is installed for use in the event of a cabin pressurisation system failure. In addition, portable oxygen sets are also provided for therapeutic purposes, and for cabin attendants' use while moving about the passenger cabin during low cabin pressure emergencies.

3.1 In some of the smaller and medium size aircraft designed without a cabin pressurisation system, oxygen equipment may be installed for use by passengers and crew when the aircraft is flown above 10,000 feet. In other cases where there is no oxygen system installation, passengers and crew depend on portable oxygen sets stowed in convenient positions.

3.2 The design of the various oxygen systems used in aircraft depends largely on the type of aircraft, its operational requirements and, where applicable, the pressurisation system. In some aircraft the continuous flow oxygen system (see paragraph 3.3) is installed for both passengers and crew but the diluter demand system (see paragraph 3.4) is widely used as a crew system, especially on the larger types of transport aircraft. Many aircraft have a combination of both systems which may be augmented by portable sets.

3.2.1 The oxygen is normally stored in gaseous form but, in some cases, systems may be used in which oxygen is produced when required, by special oxygen generators operating on a chemical reaction principle (see paragraph 3.5). Gaseous oxygen is stored at approximately 1,800 lb/in^2 and is reduced to the low pressure required for breathing purposes by pressure regulator valves or reducer valves. In oxygen generator systems the gas is produced directly at low pressure.

NOTE: The pressure in most systems is normally reduced in one stage from high to low, but in some aircraft a two-stage reduction is effected, i.e. from high pressure to medium, and then to low pressure.

3.3 **Continuous Flow Oxygen Systems.** A typical continuous flow oxygen system is illustrated in simplified form in Figure 1. When the line valve and cylinder valve are turned "on" oxygen will flow from the charged cylinder through the high pressure pipe to the pressure reducing valve which reduces the pressure to that required at the mask connection points. Reducing valves may be fitted directly to cylinders together with shut-off valves, or they may be separate units designed for "in-line" coupling. A calibrated orifice is normally provided in the sockets to control the flow of oxygen delivered to the mask.

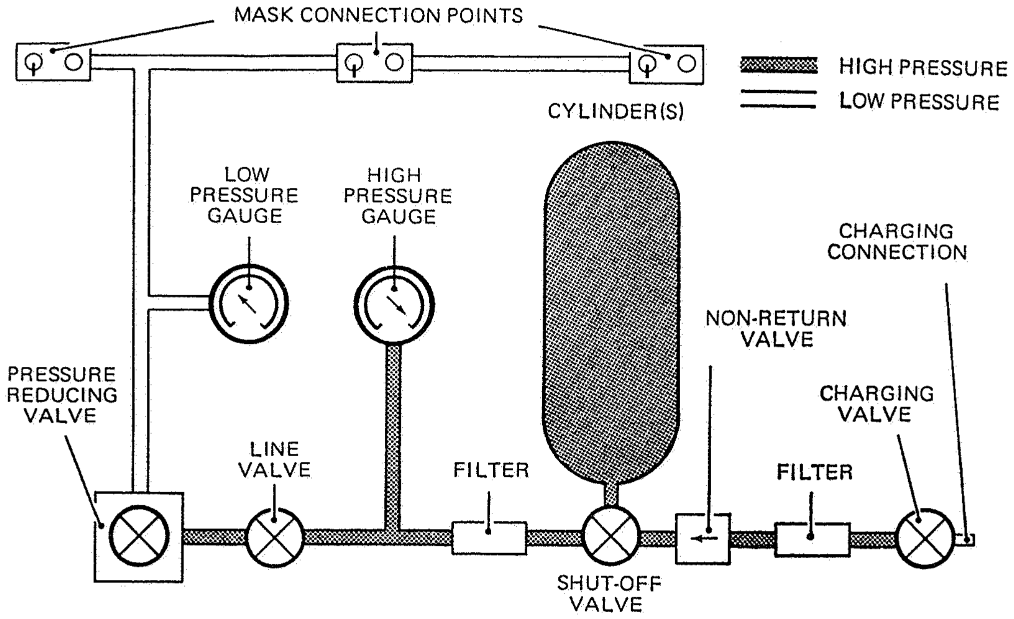


Figure 1 TYPICAL CONTINUOUS FLOW SYSTEM

3.3.1 The passenger system may consist of a series of supply sockets with mask plug-in connections at each passenger seat group, or it may be the "drop-out" mask arrangement where, in the event of pressurisation system failure, individual masks are presented automatically to each passenger from service units. When the masks are pulled to the useable position, valves are opened to permit oxygen to flow to the masks, the flow being indicated by a simple flow indicator within each mask hose. Any automatic control (e.g. barometric control valve) in the ring main supply can be overridden manually by a member of the crew. Service units are also provided with a plug-in receptacle for attaching a separate mask for therapeutic use.

3.3.2 Figure 2 illustrates a continuous flow system commonly used in some types of light aircraft carrying a pilot and five passengers. The cylinder contains gaseous oxygen at 1,800 lb/in^2 and has the pressure regulator and pressure gauge fitted directly to it. The shut-off valve is also on the regulator and is opened and closed by a mechanical linkage connected to a control knob in the cockpit. Mask connections are of the plug-in type and each mask hose contains a simple device which indicates that oxygen is flowing. A cylinder charge valve is incorporated in the system and is usually of the self-sealing, automatic opening and closing type.

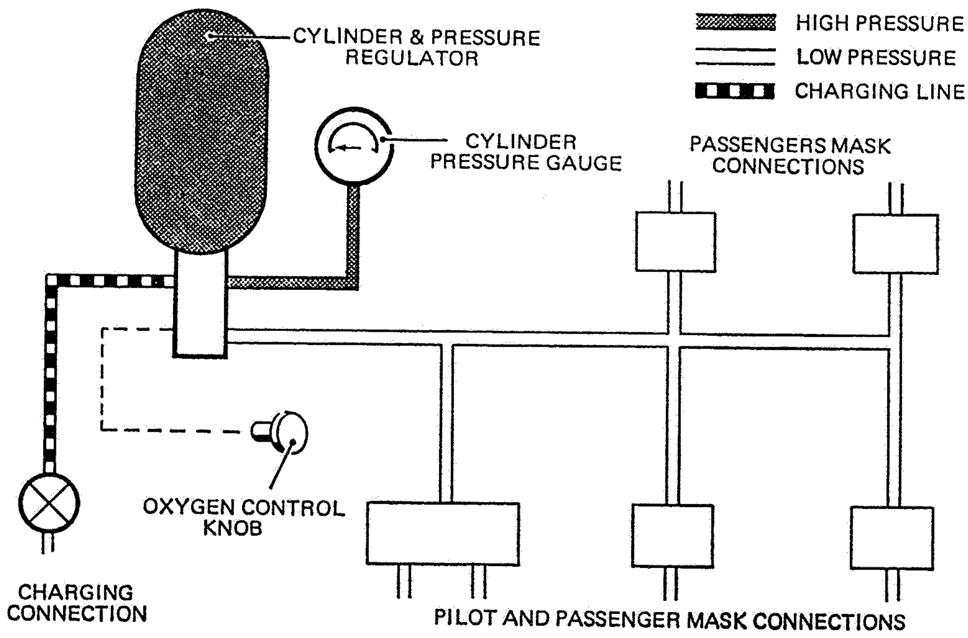


Figure 2 TYPICAL LIGHT AIRCRAFT SYSTEM

3.4 **Diluter Demand System.** A diluter demand system is one in which the oxygen is diluted with air and the mixture is supplied only when the user inhales, i.e. as demanded by an individual respiration cycle. The interconnection of a typical system is illustrated in simplified form in Figure 3. It will be noted that there is a regulator for each crew member who can control the regulator according to his requirements. The operation of a typical regulator is described in paragraph 4.7.

3.5 **Chemical Oxygen Generator Systems.** In these systems, oxygen is produced by chemical generator and dispenser units which are contained within service panels at each group of passenger seats and other essential locations.

3.5.1 In the basic form, a unit consists of a generator, a "drop-out" mask and hose. The generator (see Figure 4) is comprised of a corrosion resistant steel cylinder containing a thermal insulating liner, a compressed block of sodium chlorate and iron powder, a filter, and an electrically operated firing mechanism mechanically connected to the mask by a lanyard. The power supply required for electrical operation is 28 volts d.c. The mask is ejected automatically from the service panel by a release mechanism controlled by an aneroid switch, the contacts of which are set to make at the appropriate cabin altitude, e.g. 14,000 feet.

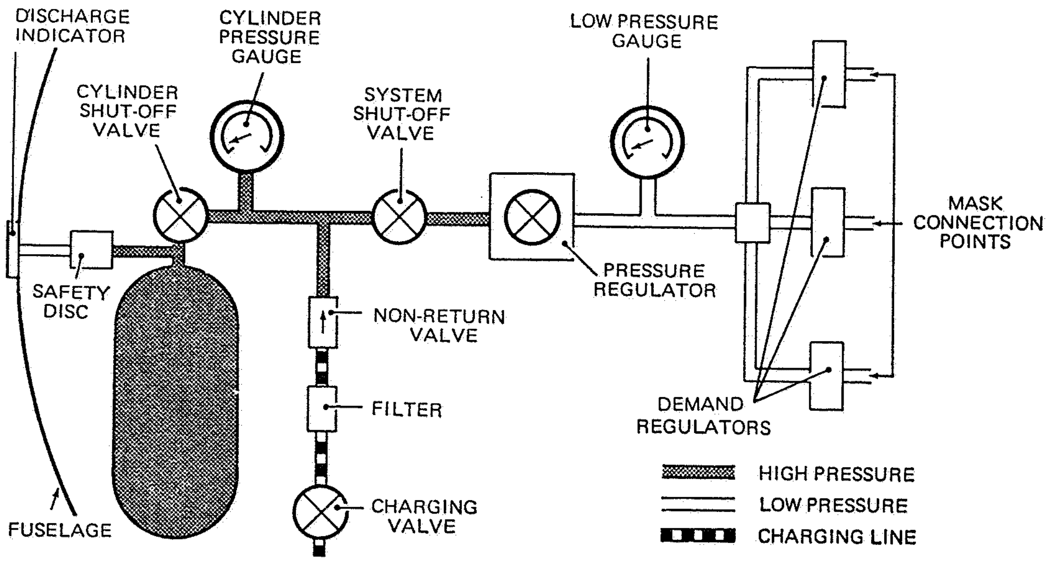


Figure 3 TYPICAL DILUTER DEMAND SYSTEM

3.5.2 When the mask is pulled towards the user, the lanyard trips the generator firing mechanism which then ignites the sodium chlorate charge block. As the temperature of the block is raised a chemical reaction is created, thereby producing a supply of low pressure oxygen which flows through the filter to the mask. This process continues until the charge block is expended. Oxygen normally flows for a period of 15 minutes, and although extremely high temperatures are generated, the temperature of the oxygen delivered at the mask does not exceed 10°C above ambient.

NOTE: In some generator systems, the sodium chlorate charge block is ignited by current supplied through the aneroid switch.

3.5.3 Oxygen generators are made in three sizes depending on the number of passenger masks to be supplied. A valve to relieve any excess pressure is incorporated, and an indication of an expended generator is also provided by the change in colour of a band of thermal paint around the outside of the case.

3.6 **Portable Oxygen Sets.** A typical portable oxygen set consists of an alloy steel lightweight oxygen cylinder fitted with a combined flow control/reducing valve and a pressure gauge. A breathing mask, with connecting flexible tube and a fabric carrying bag with the necessary straps for attachment to the wearer completes the set. The charged cylinder pressure is usually 1,800 lb/in^2. The capacities of sets vary, a size most commonly used being 120 litres.

3.6.1 Depending on the type of set, it is normally possible to select at least two rates of flow, "Normal" and "High". With some sets three flow rate selections are possible, i.e. "Normal", "High" and "Emergency" which would correspond to 2, 4 and 10 litres per minute with an endurance under these flow rates of 60, 30 and 12 minutes respectively for a cylinder of 120 litre capacity.

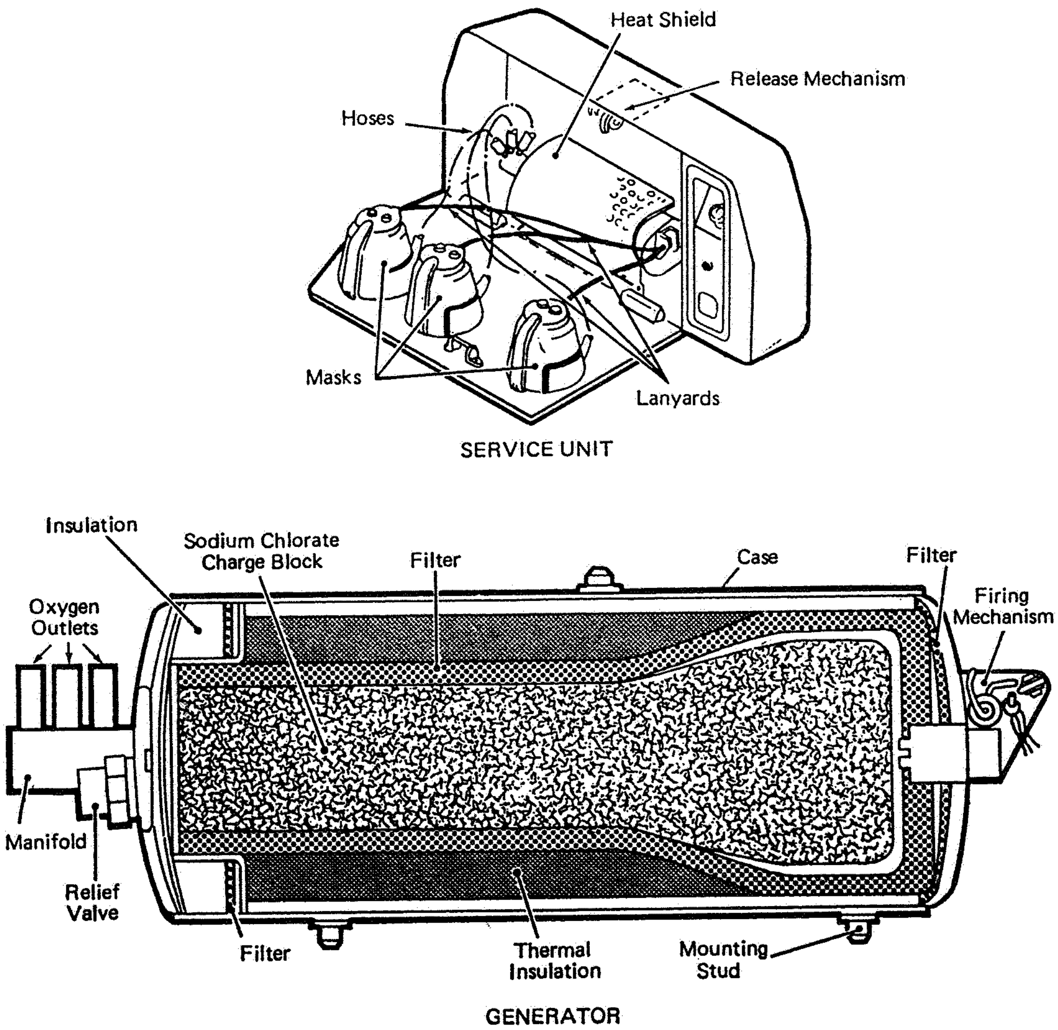


Figure 4 CHEMICAL OXYGEN GENERATOR SYSTEM

4 COMPONENTS

4.1 Brief details of some of the components commonly used in oxygen systems are given in the following paragraphs. Full descriptive details of the components installed in specific types of aircraft are contained in the relevant Maintenance Manuals and reference should be made to these documents.

4.2 **Oxygen Storage Cylinders.** Cylinders designed for the storage of gaseous oxygen are made from drawn high tensile alloy steel and normally have a manual stop valve and, in many instances, a pressure regulator and a pressure gauge threaded into the neck of the cylinder. The charged pressure is usually 1,800 lb/in^2 and capacities vary from 80 litres for portable sets to 2250 litres for large installations.

4.2.1 Cylinders are often provided with an excess pressure rupture disc, usually fitted in the valve body, which vents the cylinder contents to the outside of the aircraft in the event of a dangerous pressure rise. An indicator is provided in some aircraft to indicate discharge resulting from pressure relief (see paragraph 4.13).

NOTE: The disc is designed to rupture before excessive pressure could cause damage.

4.2.2 Cylinders for use in aircraft oxygen systems are colour coded for identification purposes, and there are two codes presently adopted: (i) black for the main body and white for the top hemispherical portion (the valve end) and (ii) green for cylinders of American origin. As a means of further identification of cylinder contents, it is also necessary for the name of the gas and its chemical formula to be marked at the valve ends of cylinders in accordance with British Standard 2N 100 and International Organisation for Standardisation recommendation ISOR448. In addition, the following information is painted or stencilled on the bodies of the cylinders:—

(i) In red letters on a white background: "Use No Oil".

(ii) In white letters on the black cylindrical portion:

Name of manufacturer

Drawing assembly No.

Capacity .... litres

Test pressure ....

Working pressure ......

Test date.................

NOTE: The test date refers to a pressure test and may also be stamped on the neck ring of a cylinder.

4.3 **Pipe Lines.** The characteristics of the pipe systems vary widely between different types of aircraft and the particular oxygen system installed and reference should be made to the relevant manuals for full details. High pressure pipes are usually made of either stainless steel or copper-based alloys, while pipes for low pressure areas of systems are made of aluminium-based alloys. Pipe also vary in size and some typical values are $\frac{3}{16}$ to $\frac{1}{4}$ inch outside diameter for high pressure pipes, and $\frac{5}{16}$ inch outside diameter for low pressure pipes.

4.3.1 The types of couplings normally used for pipe joints are of the standard AGS type and MS flareless tube type (see Leaflet **BL/6-15**). Because of the difficulty of ensuring the complete removal of flux and scale, silver soldered connections are, generally, not used.

4.3.2 Identification of pipes in the system by symbols and colour coding is widely used and should comply with BS 3M.23. Tie-on metal tags or metal identification rings should not be used as they may cause damage through vibration, or become detached and foul moving parts of control systems.

4.4 **Non-Return Valves.** These components are designed to prevent flow reversal and are installed in a pipe line or at a connector adaptor. Of the two basic types commonly used, one consists of a housing containing a spring-loaded valve which is forced against the spring when pressure is applied to the inlet side, thus breaking the seal and allowing oxygen to flow. When pressure is equalised the spring returns the valve onto its seating, so preventing any reversal of oxygen flow. The other type is a bell-mouthed hollow cylinder fitted with a captive ball in its bore. When pressure is applied at the bell-mouthed (i.e. inlet) end, the ball is forced onto the seating of a port at the opposite end and at the same time, its displacement uncovers holes in the wall of the valve to allow oxygen to flow into the pipe or connection. Any tendency for the flow to be reversed is prevented by the oxygen forcing the ball back onto its seating at the inlet end. The normal direction of flow for both types of valve is indicated by an arrow on the valve body.

4.5 **Filters.** Filters, generally of the gauze or sintered bronze type, are provided at points downstream of oxygen cylinders and in some cases, immediately after the ground charging connection. In most systems in current use a filter, usually of the sintered bronze type, is normally embodied in the supply connection of a particular component, e.g. a regulator or a reducing valve. In some instances the charging connection is counter-bored to house a slug-type sintered bronze filter which also acts as a restrictor to guard against too rapid charging of the system.

4.6 **Pressure Reducing Valves.** These valves reduce the high pressure oxygen from the storage cylinders to the pressure required in the low pressure part of the system. In a continuous flow system the reduced pressure is supplied to the mask connection points. In a pressure demand system the pressure from the reducing valve is comparatively higher than that for a continuous flow system and further pressure regulation is necessary at each regulator.

4.6.1 Design features vary considerably, but in general, reducing valves comprise a pressure reducing pre-set spring and valve control mechanism with a relief valve to safeguard against overloads. Pressures can be reduced to the pressure required for a particular system (e.g. from 1,800 lb/in² to 80–100 lb/in²).

4.7 **Oxygen Diluter Demand Regulators.** These regulators are used in crew oxygen systems (see paragraph 3.4) and are designed to adjust the output ratio of oxygen and air in accordance with cabin pressure and to supply, on demand, the correct air/oxygen mixture. A typical diluter demand regulator operates as follows:—

(i) With the oxygen supply "on" and "normal oxygen" selected by the appropriate control lever on the regulator, diluted oxygen in accordance with cabin altitude will be supplied to the crew member's mask when the user inhales. The amount of air mixed with oxygen is controlled by the regulator and the air decreases with increase in cabin altitude until a cabin altitude of 32,000 feet is reached when approximately 100 per cent oxygen is supplied.

(ii) If the crew member selects "100% oxygen" the regulator air valve is closed and 100 per cent oxygen is supplied when the user inhales, irrespective of cabin altitude.

(iii) If "Emergency" is selected, e.g. to provide protection against smoke and other harmful gases, a flow of 100 per cent oxygen is supplied at a positive pressure to avoid any inward leakage into the mask. Depending on the type of regulator, the oxygen may either flow only when the user inhales, or continuously and irrespective of the user's respiration cycle.

(iv) When "Test mask" is selected oxygen is supplied at a higher pressure than that provided for the "Emergency" condition and is used for testing the masks and equipment for fit and leakage.

4.8 **Supply Sockets.** These components provide connections between the aircraft system and individual oxygen mask connecting tubes. Some embody two socket points for "Normal" or "High" flow and others may have only one socket point with a flow selector lever. Calibrated orifices in the socket points of continuous flow systems control the flow rate to the masks. Socket points are made with self closing shut-off valves, spring loaded in the closed position, and open when the mask tube connecting plug is inserted in the socket.

4.9 **Pressure and Contents Indicators.** Pressure indicators are provided to indicate cyclinder pressure and, where necessary, medium and low pressure in the supply lines. The indicators are normally of the direct-reading Bourdon tube type calibrated in lb/in^2, and may be located on cylinders, pressure regulators and at oxygen system servicing panels. In aircraft requiring monitoring of system high pressure at a flight engineer's station, electrical indicating systems are also employed. These consist of a transducer which senses high pressure and converts it to a variable electrical signal for controlling an indicator at the flight engineer's panel. The power supply required for operation is 28 volts d.c. and a regulating circuit is incorporated to ensure that pressure indicators are not affected by fluctuations in supply voltage.

4.9.1 Pressure switches are installed in the low pressure sections of some passenger oxygen systems to illuminate warning lights, thereby indicating that a system is in use. The lights are located on a cockpit overhead panel and on cabin attendants' panels.

4.9.2 Contents indicators, as opposed to pressure indicators, are fitted to some types of cylinders and they are normally marked with coloured sectors to indicate contents in terms of "FULL", "¾ FULL", etc.

4.10 **Oxygen Masks.** There are numerous types of oxygen masks in use which vary widely in design and detailed information is outside the scope of this Leaflet. It is important that the masks used are suitable for the particular oxygen system concerned.

4.10.1 In general, crew masks can be fitted to the wearer's face with minimum leakage and may be of the self-contained re-breather type. Crew masks also contain a microphone cord and jackplug for connection into the aircraft communications system. In some instances there is a requirement for pressurised aircraft to carry oxygen masks designed for the protection of crew members in a smoke- or fume-laden atmosphere. These masks are of the full-face type consisting of a transparent visor, oxygen supply hose and adjustable head straps, or of the "sweep-on" type with pre-set head straps and/or elasticated sides. A demand regulator may also be fitted to some masks to control the flow. The hose connections are of the plug-in type designed for insertion into the supply sockets of a ring main system or, alternatively, a portable cylinder.

4.10.2 The masks provided in automatic drop-out systems for passengers are normally simple cup-shaped rubber mouldings sufficiently flexible to obviate individual fitting. They may be held in position by a simple elastic head strap, or may require holding to the face by the passenger. In non-automatic systems, the masks are usually plastic bags fitted with a simple elastic head strap.

4.11 **Flow Indicators.** Oxygen flow is often indicated by a direct type of flow indicator, e.g. a float inside the transparent hose of a mask, or by a pressure-operated blinker type of instrument.

4.12 **Thermal Compensators.** Thermal compensator assemblies are installed in the charging lines of some oxygen systems for the purpose of minimising temperature build-up when oxygen, at charging pressure, flows through. A compensator consists of a brush-like wire element approximately 5 inches long, inserted into a stainless steel tube provided with connectors at each end.

4.12.1 There are two types of thermal compensators in use, one for connection to oxygen cylinders and the other for connection to shut-off valves or regulators. Those fitted to oxygen cylinders have a coupling nut fitting that attaches direct to a cylinder and the downstream end has a flareless tube connection. The second type of compensator is attached to the component by means of a corrosion-resistant steel union through which the wire element extends. A flareless tube connection is fitted to the upstream end.

4.13 **Discharge Indicators.** In some aircraft, discharge indicators are mounted flush to the fuselage skin in an area adjacent to the oxygen system servicing panels. They are connected to the pressure relief lines from the oxygen cylinders and consist of a green plastic disc which is normally retained within its holder by a circlip. In the event of an excess pressure within a cylinder the safety valve opens and escaping oxygen will blow out the indicator disc, thereby providing a visual indication that discharge has occurred.

4.14 **Ground Charging Valves.** Oxygen systems are provided with valves to permit "in-situ" charging of the cylinders from special ground servicing units. The charging connections to the valves are normally sealed off by blanking cap nuts. A short length of chain between a cap nut and an adjacent part of the structure, ensures retention of the nut at the charging point location when removed for charging purposes.

4.14.1 In some systems, the charging valve incorporates manual temperature and pressure compensation adjustments which allow the system cylinder to be charged to optimum pressure at the ambient temperature in the vicinity of the cylinder. The charging rate is automatically controlled by the valve to a safe value thereby minimising the hazard of heat build-up. A pressure/temperature correction chart is normally displayed near the charging valve for reference purposes.

NOTE: An air temperature indicator is sometimes fitted at the location of aircraft cylinders to record ambient temperature conditions.

5 INSTALLATION AND MAINTENANCE PRACTICES To ensure that oxygen systems serve their purpose of supplying hygienically clean oxygen under emergency conditions in an efficient and safe manner, strict observance of servicing instructions, and the necessary safety precautions, is essential during the installation and maintenance of components. Failure to observe such precautions could result in fire and explosions and consequent serious injury to personnel and severe damage to an aircraft. The emphasis is, at all times, on cleanliness and on the standards of the work to be carried out at the appropriate stages of installation and maintenance.

5.1 The information given in the following paragraphs is intended to serve as a guide to practices and precautions applicable to systems in general. Details relevant to specific types of aircraft systems are contained in the approved Maintenance Manuals and the schedules drawn up by an aircraft operator, and reference must always be made to these documents.

5.2 **Servicing Personnel.** Servicing personnel must fully understand the operation of an aircraft system, the relevant ground charging equipment and its connection to charging points, and must have a full knowledge of any appropriate engineering and maintenance regulations in force. Personnel should also be alert to emergency situations which could arise during oxygen system servicing.

5.3 **Oxygen Fires or Explosions.** An oxygen fire or explosion depends on a combination of oxygen, a combustible material and heat. The danger of ignition is in direct ratio to the concentration of oxygen, the combustible nature of the material exposed to the oxygen, and the temperature of either the oxygen or the material, or both.

5.3.1 Oxygen itself does not burn but it supports and vigorously intensifies a fire with any combustible material. The term "combustible material" is used in its widest sense, denoting not only flammable materials but also such materials as steel, normally considered to be non-combustible, but which is in fact combustible at high temperatures in the presence of oxygen under pressure.

5.3.2 Any oxygen system leak can lead to a build-up of near-pure oxygen in unventilated zones, particularly in aircraft that remain idle. A concentration of oxygen in such a zone, e.g. behind upholstery, or thermal/acoustic lagging, or in control panels, could result in a fire or explosion by contact with grease, oil or electrical hot spots. Any indication of pressure loss or leaks must, therefore, be treated as hazardous and must be traced and eliminated before further flight (see also Airworthiness Notice No. 12, Appendix No. 3).

5.3.3 Heat can be generated in an oxygen system by sudden compression or by resonance of oxygen under relatively low pressure impinging into a dead-end cavity. It can also be caused by the vibration of a seal, "O" ring, or other non-metallic material which is exposed to oxygen under pressure. A small high pressure leak could cause ignition of the material through which it is leaking due to heat generated by friction.

5.3.4 Many materials such as oils, grease, fuel, paint, flammable solvents and metal swarf (e.g. from a damaged thread or a pipe coupling) are liable to ignite or explode spontaneously when exposed to oxygen under pressure. Similarly, extraneous matter such as dust, lint from a cleaning rag or natural oil from the hands getting into the system or into a component could cause ignition or explosion. It is essential therefore to keep these materials and other extraneous matter away from exposed parts of oxygen systems to prevent contamination. Clean areas should be used for dismantling and assembly of all oxygen system components.

5.4 **Safety Precautions.** Before carrying out any work on an oxygen system, the following precautions against fire should be taken:—

(i) Provide adequate and properly manned fire-fighting equipment.

(ii) Display "No Smoking" and other appropriate warning placards outside the aircraft.

(iii) If artificial lighting is required, use explosion-proof lamps and hand torches (e.g. equipment complying with BS 229 and BS 889).

(iv) Testing of aircraft radio or electrical systems should be avoided.

(v) Ensure that the aircraft is properly earthed.

(vi) Ensure that charging or servicing units, appropriate to oxygen systems are used and that they, and all other necessary tools, are serviceable and free of dirt, oil, grease or any other contaminants.

(vii) Where work on an oxygen system is to be performed in a confined space within the aircraft, adequate ventilation must be provided to prevent a high concentration of oxygen.

(viii) Pipe and component connections should be wiped clean and dry if contamination is present.

(ix) One of the most serious hazards with oxygen is the penetration of the gas into clothing which can take place when a person has been exposed to an oxygen-rich atmosphere. In this state an infinitesimal particle of hot ash from a pipe or cigarette, can ignite the clothing which will immediately burst into a fierce flame. Clothing which has been saturated by oxygen should be kept away from naked lights or any other source of heat until a period of a quarter of an hour has elapsed, or until thorough ventilation with air has been effected.

(x) A clean area, with bench surfaces and tools free of dirt and grease, should be used whenever it is necessary to carry out work on oxygen system components.

5.4.1 The following general procedures and precautions should be followed when handling, testing and cleaning any part of an oxygen system:—

(i) Clean, white, lint-free cotton gloves should be worn by servicing personnel.

(ii) Before installing a component it must have been cleaned in accordance with the cleaning instructions laid down in relevant manuals (see also paragraph 5.10). In order to avoid contamination, protective/blanking caps should not be removed until immediately before the installation of the component. When the caps are subsequently removed, the fittings of the component should be checked to ensure they are clean and free of contaminants e.g. flaked particles from protective caps.

(iii) Shut-off valves should always be opened slowly to minimise the possibility of heat being generated by sudden compression of high pressure oxygen within the confined spaces of valves or regulators. Particular attention must also be paid to any torque values specified for valve operation.

(iv) Before uncoupling a connection the oxygen supply must be turned off. Connections should be unscrewed slowly to allow any residual pressure in the line or component to escape.

NOTE: If a cylinder valve is not completely closed, or is leaking, and there is a time lag after bleeding a line, sufficient oxygen pressure could build up in the line to become potentially dangerous.

(v) Certain components are stored in polythene bags which should not be opened until immediately prior to installation. If a bag containing a component has been torn or unsealed during storage, the component should be re-cleaned.

(vi) All open pipe ends or component apertures should be kept capped or plugged at all times, except during installation or removal of components. Only protection caps or plugs designed for the purpose should be used (see also paragraph 5.5.3. (viii)).

(vii) On replacement of a component requiring electrical bonding or power supply connections e.g. an electrical pressure transducer, the circuit should be tested (see also Leaflet EEL/1-6).

(viii) For leak testing, only those solutions specified in the relevant manuals must be used. Care must be taken to prevent a solution from entering any connection, valve or component. All tested parts must be wiped clean and dried immediately (see also paragraph 5.7).

(ix) For the testing of components, clean dry filtered air or nitrogen may be used instead of oxygen. On completion of the tests, components should be purged with breathing oxygen.

NOTE: Guidance on the requirements for gases to be used for testing is given in Appendix "C" to British Standard 2N 100.

5.5 **Components.** The following paragraphs detail some of the procedures and precautions generally applicable to the installation and maintenance of the principal components comprising oxygen systems. Reference should always be made to the approved Maintenance Manual relevant to a specific aircraft and system for full details.

5.5.1 **Cylinders.** The handling and transportation of cylinders requires that extreme care be exercised at all times. They must not be allowed to fall over, or be knocked or jarred against hard or sharp objects, or against each other. On no account must they be rolled from a truck or trolley directly onto the ground.

(i) Rapid opening of valves to allow a sudden release of oxygen under pressure from the outlet connections should be avoided. This applies particularly to cylinders which do not incorporate a pressure reducing valve. Apart from the fire risk, the reaction from the pressure discharge can cause an insecurely held cylinder to become a dangerous uncontrollable object.

(ii) Cylinders must be checked to ensure that the date of the last pressure test (see paragraph 5.8) has not expired and that the storage pressure is not below the minimum specified in the relevant manual. A pressure of 200 to 300 lb/in^2 is typical.

(iii) Where specified, it is necessary to carry out tests to ensure that there is no leakage of oxygen from the seats and spindle glands of cylinder valves.

(iv) Control valves and, where appropriate, pressure regulators and gauges, are fitted by the cylinder manufacturers and no attempt should be made to remove them during service.

(v) The exterior of cylinders should be checked for signs of corrosion and damage such as dents, cuts, gouging, or marking by metal stamps other than that prescribed by the manufacturer on defined areas of the body. If the acceptability of a cylinder is in question after making these checks it must be withdrawn for more detailed inspection and overhaul.

(vi) Checks on threads of connections should be carried out to ensure they are clean and free from damage. Thread lubricants should not be used (see also paragraph 5.6). Protective caps should remain on the connections until a cylinder is ready for installation and should be replaced immediately a cylinder is removed.

(vii) During installation of cylinders a check must be made that they are properly aligned with their respective pipelines before finally tightening cylinder clamps and pipe connecting unions.

(viii) After installation, cylinder valves should be slowly opened to pressurise the high pressure lines, and a leak test carried out at the cylinder connections and any other connections which may have been opened. On satisfactory completion of a leak test, cylinder pressures should be checked and recharging to normal system pressure carried out where necessary (see also paragraph 5.12) and valves should be wire locked in the open position.

(ix) If cylinders are inadvertently discharged below the minimum specified pressure, condensation will occur. Cylinders in this condition should be identified for special action when re-charging (see also paragraph 5.12.2 (vii)).

5.5.2 **Chemical Oxygen Generators.** Unexpended generators should be handled with extreme care to prevent inadvertent removal of the firing pin. A blanking cap is normally fitted over the pin and this should remain in position until the generator is finally installed and the lanyard is tied to the disconnect ring of the mask. If a generator should become activated it should be immediately placed on a non-combustible surface.

(i) A minimum clearance of ⅝ inch must exist between a generator and its heat shield to allow proper cooling when the generator is activated.

(ii) Oil or grease must not be used to lubricate the hinges or latch mechanism of a service panel door.

(iii) When closing the door of a service panel it should be checked that the hoses between the generator and masks will fold without kinking or twisting.

5.5.3 **Pipes and Fittings.** Pipes and fittings should be inspected for damage, cleanliness and signs of corrosion. If a pipe is damaged or deformed it should be removed and a new pipe fitted. The security of pipe attachments such as "P" clips, support brackets, etc., and the conditions of electrical bonding connections should be checked.

(i) Only pipes and fittings designated for use with oxygen and cleaned by an approved method must be installed (see also paragraph 5.10).

(ii) Clearances between pipes and aircraft structure should be in agreement with those specified in the relevant aircraft manuals and installation drawings, otherwise damage may be caused by vibration. Particular care is necessary to ensure clearance between pipes and moving parts such as aircraft control rods, and levers.

(iii) Before making a connection it is important to verify that any loose parts which may form part of the connection such as nipples and filters, are properly positioned and that any identification (e.g. filter notice or direction of flow) relating to the connection is clearly shown.

(iv) Pipes and fittings should align with each other and with components such as cylinders, valves, etc., and be assembled without using undue force, and no gap should exist between the fittings.

(v) Pipes should, in the first instance, be positioned and only partially coupled (i.e. turning union nuts through one or two threads) to each other or components as the case may be. The alignment of the tubes should then be adjusted for optimum clearance, and the tubes partially secured to the structure by the appropriate attachment method. Commencing at either end of the pipe run, the union nuts should be backed off and a check made on the seating of the fittings. If satisfactory, union nuts should be re-fitted and tightened and the pipe attachments finally secured.

(vi) Torque values specified for a particular oxygen system should be strictly observed when tightening the fittings. A fitting should never be overtightened to effect a seal or to establish a proper electrical bond; loosen the fitting and retorque it several times, if necessary, until the seal or bond has been established.

(vii) When tightening or disconnecting a pipe coupling, a second spanner should be used as a back-up to prevent rotation of the fitting to which the pipe union is attached.

(viii) If a section of the pipeline system is left open or disconnected during installation or removal, clean blanking caps must be fitted to open lines, fittings or parts to prevent contamination of the system. In connection with the application of blanking caps, the following points should be particularly noted:—

(a) Plastic caps should only be used on plain sections of pipes, e.g. flareless pipes. Plastic caps should not be re-used.

(b) Where caps are to be fitted to threaded unions or fittings they should be of the metal type.

(c) Plugs which can be jammed into pipes should not be used.

(d) Metal caps may be re-used after cleaning in accordance with an approved method.

(e) Blanking caps should be sealed in polythene bags and should not be opened until ready for use. After opening, the bags should be re-sealed immediately to prevent contamination of unused caps.

(ix) During installation and removal of thermal compensators care must be taken not to separate the connector couplings and nuts. The elements should not be rotated within unions since damage to the wire bristles and jamming of the element may result.

(x) Flexible hoses should not be twisted, kinked or collapsed during installation. In some aircraft, flexible hose assemblies are used in both the high and low pressure systems and these can be connected to standard pipe connectors. Care must, therefore, be taken to ensure that the hoses are not interchanged.

(xi) On completing the installation of pipes a leak test must be carried out on all relevant connections and fittings (see also paragraph 5.7). If a connection leaks, a check should be made that the specified torque values were used in tightening. If the leak persists, using the specified torque value, the connection should be re-opened and inspected to find the cause. Defective pipes or fittings should be replaced by serviceable items.

5.5.4 **Masks.** The procedure for the installation of masks depends largely on whether they are of the plug-in type or automatic drop-out type, and full details should, therefore, be obtained from relevant manuals. In general, the following points should be observed during installation and maintenance:—

(i) Masks should be properly stored without kinking or twisting of the hoses.

(ii) Masks and hoses should be free from cracks, breaks and other damage or deterioration. Plug-in couplings should be checked for proper insertion and removal.

(iii) Stowage compartments should be inspected for cleanliness and general condition.

(iv) Reservoir bags, where used in service panels, must be correctly positioned and folded to ensure efficient drop-out.

(v) Masks should be cleaned and disinfected before installation, and also whenever the oxygen system has been used, and at the periods specified in approved Maintenance Schedules (see also paragraph 5.10.1 (vii)).

5.6 **Thread Lubrication.** With the exception of teflon sealing tape to specification MIL-T-27730, it is recommended that the application of any other lubricants or anti-seize compounds to the threads of pipe or component connections be avoided. The tape, which contains a lubricating compound, should be applied to all except the first two threads of male fittings, and not more than three wraps of tape should be used. The tape should be wrapped in a direction opposite to the running thread; any excess should be trimmed off.

NOTE: All traces of previous tape should be removed from threads and extreme care must be taken to prevent debris from entering the oxygen system.

5.7 **Leak Testing.** Whenever a system component e.g. cylinder, pipe or regulator, etc., has been removed, re-installed, or the system has in any way been disconnected, tests for leakage should be carried out. The system pressure should be at its normal maximum value.

5.7.1 Leaks should be located using a leak detecting solution free from any combustible substances unless, of course, particular leaks are large enough to be heard or felt. Solutions recommended for this purpose are those conforming to specifications MIL-L-25567 "B" and MIL-L-25567 "C" Type 1.

5.7.2 The solution should be applied with a soft brush and the suspected connections checked for signs of frothing or bubble formation. After testing, all traces of solution must be removed by a thorough rinsing with clean water and drying with a soft lint-free cloth.

5.7.3 Where it may be necessary to check a leak-rate (e.g. through a valve) a leak-rate tester should be used. A simple tester consists of a flexible tube into which has been inserted a length of ¼ inch bore glass tube. To check a leak-rate, the free end of the flexible tubing is fitted over the outlet to be tested whilst the glass tube is immersed one inch below the surface of water in a glass jar. The leak-rate can then be calculated from the number of bubbles passing through the water. Eight bubbles are considered equal to 1 c.c. therefore eight bubbles per minute would show a leak-rate of 60 c.c. per hour.

NOTE: Where very accurate leak-rate measurement is necessary, special leak-rate testing instruments are available and should be used as appropriate.

5.8 **Pressure Tests.** Pressure testing of oxygen cylinders is required at stated periods (e.g. every four years) normally indicated in the relevant manuals and schedules. The date of pressure test is usually stamped on the neck ring of a cylinder or painted on the top hemispherical portion.

NOTE: The dates of any previous pressure tests should not be over-stamped or obliterated.

5.9 **Flow Testing.** Where the testing of flow rates is required at various points in a system (e.g. at mask socket connections) special oxygen flowmeters should be used in accordance with the manufacturer's instructions. These flowmeters generally consist of a float inside a glass cylinder graduated for the appropriate flow ranges in litres per minute.

5.10 **Cleaning.** Cleanliness is of the utmost importance in the installation and maintenance of an oxygen system since contamination can provide noxious or toxic fumes to the user, prevent system components from operating properly, or cause fires and explosion. Contamination of the exterior surfaces of components may also cause fires in the presence of leaking oxygen and possible sources of ignition (e.g. electrical equipment). In addition to observing the handling precautions noted earlier in this Leaflet, it is necessary for cleaning operations to be performed at certain stages of installation and maintenance procedures.

5.10.1 Details of the methods to be adopted, the solvents to be used, and periods at which cleaning is to be carried out are given in relevant manuals, drawings and schedules and reference should always be made to these documents. The following paragraphs detail certain important aspects applicable to cleaning operations generally.

(i) For external cleaning of components and pipelines after testing and installation, and at specified inspection periods, a clean, lint-free cotton cloth should be used moistened, if necessary, with the approved solvent.

(ii) Pipes and fittings should be cleaned by a vapour degreasing process. After cleaning, pipes must be washed through with boiling water followed by a thorough flushing with demineralised water, and finally purged and dried (see paragraph 5.10.1 (iv)).

(iii) Thermal compensator assemblies where required, should be cleaned by either an ultrasonic or vapour degreasing process.

(iv) After cleaning, pipes, fittings or components should be purged and dried with clean dry nitrogen, clean, dry, water-pumped air, or breathing oxygen. Particular attention should be paid to the evaporation of degreasing fluid from reverse or "U" bends in pipes. When thoroughly dry, all openings should be blanked by the appropriate type of blanking caps (see also paragraph 5.5.3 (viii)).

(v) Air which has been compressed by an oil-lubricated compressor must not be used unless it has passed through an oil separator, dehydration unit or filter system specifically designed to ensure clean air for use with oxygen components. Compressed air can be checked for freedom from oil or water by allowing the air to impinge on to a clean mirror held at about 45 degrees to the air stream. The mirror should remain clean and dry. If a deposit does appear, warming the face mirror will evaporate the water and any oil will remain on the surface.

(vi) If components or fittings are not to be used immediately after cleaning they should be individually sealed in polythene bags. The bags should be identified as to their contents and also contain the date on which the parts were cleaned and sealed.

(vii) Oxygen masks should be cleaned by a mild solution of soap, or other detergent product, and warm water. The solution should be applied to facepieces with an absorbent cheesecloth or sponge applicator. After cleaning, all traces of solution should be removed with clean warm water and the masks dried with cloth or allowed to air-dry. An approved disinfectant should then be applied from an antiseptic spray or an aerosol can.

NOTE: When cleaning crew masks, microphones should be removed to prevent contact with cleaning solutions.

5.11 **Functional Testing.** The functional testing of systems "in-situ" should be carried out at the periods specified in approved Maintenance Schedules and whenever a component has been changed. The methods of conducting tests, and the equipment required, vary between types of systems and reference should always be made to the relevant manuals for full details. In general, the methods include tests for leakage (see also paragraph 5.7), flow checks at mask connections and, where appropriate, the simulation of the automatic drop-out action of masks.

5.12 **Charging of Oxygen Systems.** For the charging of oxygen system cylinders, breathing oxygen to British Standard N3 must be used. Oxygen produced for other applications, e.g. welding, may contain excess water which could freeze in and obstruct pipelines, regulators and valves of the oxygen system.

5.12.1 To facilitate the charging procedure, the oxygen is supplied in large transport cylinders at a pressure of 3,600 lb/in², several of which are interconnected and mounted in a special oxygen servicing trolley. The pressure is reduced to between 1,800 and 1,900 lb/in² for charging purposes by a regulator consisting basically of a manually adjustable reducing valve and a shut-off valve. The regulator is mounted in the servicing trolley together with pressure gauges which indicate the transport cylinder pressure and the charging pressure. A special oxygen high pressure hose for connecting the trolley to the aircraft's charging point completes the basic equipment.

NOTE: An oxygen servicing trolley must never be used for the charging or testing of systems and components designed for operation by compressed air or other gases.

5.12.2 Before charging a system, reference should be made to the relevant aircraft Maintenance Manual to determine any special procedures to be adopted for the particular system, and also to the operating instructions appropriate to the type of servicing trolley. In addition to the safety precautions referred to in paragraph 5.4 of this Leaflet, the following points which apply generally to charging should be observed:—

(i) The servicing trolley and aircraft should be properly bonded.

(ii) The operation of ground power units should not be permitted in the vicinity during charging operations.

(iii) The aircraft and servicing trolley hose charging adaptors and servicing panels, where appropriate, should be scrupulously clean both internally and externally.

(iv) Before coupling to the aircraft, the charging hose should be purged by slowly opening the trolley shut-off valve to produce a low pressure flow of oxygen in the hose.

(v) Care should be taken when coupling the hose and aircraft coupling adaptors since, in many instances, the adaptors have a left-hand thread.

(vi) Charging valves and cylinder valves must be opened slowly and pressures allowed to stabilise. Servicing trolley and aircraft system pressure gauges should be continuously monitored to ensure that excessive pressures are not applied and to prevent high cylinder temperatures.

(a) Charging graphs are located at the servicing points of many types of aircraft and the maximum permissible charging pressure should be determined from the graphs, after having checked the ambient temperature in the vicinity of the aircraft cylinders.

(b) In charging a system that incorporates manual temperature and pressure compensation adjustments, the dials should be set to the most restrictive setting, i.e. that corresponding to the lower pressure of the system and to the lower value of ambient temperatures in the vicinity of the aircraft cylinders. This will ensure that a conservative rate of charging is applied and that the maximum pressure is not exceeded.

(vii) If a cylinder has been emptied, contamination resulting from moisture can develop (see paragraph 6). In such cases, the cylinder should be blanked off either by closing its shut-off valve or by using blanking caps. It should be removed and suitably identified as requiring purging before recharging.

NOTE: Depending on the degree of exposure to moisture, it may be advisable to examine a cylinder for internal corrosion.

(viii) On completion of charging, the trolley shut-off valve and aircraft charging valve should be closed and the pressure in the aircraft system allowed to stabilise. A check should then be made on the cylinder pressure gauges and other system gauges if fitted, to ensure that the cylinders are fully charged.

(a) Trolley hose adaptors should always be removed slowly from the aircraft charging adaptor to dissipate any trapped pressure.

(b) Aircraft charging adaptor blanking caps must be checked to ensure that they are scrupulously clean before re-fitting.

6 OXYGEN CONTAMINATION

6.1 At specified periods, or if for any reason the system is thought to be contaminated, the oxygen should be tested and if necessary the system purged. Purging should always be carried out if it is known that a system is empty.

6.2 The main cause of contamination is moisture in the system and this may be due to damp charging equipment, charging of cylinders when their pressure is below a certain minimum value, and the small amount of moisture contained in breathing oxygen may, due to repeated charging especially in very cold weather, also cause contamination.

NOTE: In some cases it has been known for the system to freeze due to the presence of moisture, thus restricting the flow of oxygen.

6.3 Although the introduction of moisture into the aircraft oxygen system can be considerably reduced by using the correct charging procedure, cumulative condensation in the system cannot be entirely avoided. There have been instances where oxygen systems, unused for long periods, have developed an unpleasant odour which necessitated purging to clear the system of moisture.

6.4 **Oxygen Moisture Tests.** To test the moisture content of oxygen in the aircraft system a hygrometer, based on the dew-point principle, is normally used.

6.4.1 By determining the dew-point (i.e. the temperature at which the gas becomes saturated) of the oxygen and referring this to a conversion chart the moisture content of the oxygen can be established.

6.4.2 The type of apparatus normally used depends on a flow of oxygen (at a constant rate and pressure) impinging on the surface of a mirror, the temperature of which is gradually lowered (e.g. by means of carbon dioxide) until a film of moisture is formed on the mirror thus determining the dew-point.

NOTE: Breathing oxygen dew-point is −40°C at 300 lb/in^2 with a flow rate of 15 litres per minute. This corresponds to a moisture content of 0·0056 grammes per cubic metre at Standard Temperature and Pressure.

7 SOLDERING If soft soldering or silver soldering is required on any part of an oxygen system it is important that only specified materials are used, particularly in the case of fluxes. After soldering, or silver soldering operations have been completed, it is of the utmost importance to ensure that all traces of flux or scale are completely removed by thorough cleaning. A trace of flux or a minute piece of scale inside a pipe or component could cause an explosion when in contact with high pressure oxygen. Resin-based soldering fluxes should never be used for soldering nipples, connections, etc. on oxygen system pipes.

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AIRCRAFT

SYSTEMS AND EQUIPMENT

AUXILIARY POWER-UNITS

1 INTRODUCTION Auxiliary power-units (APUs) are employed in many types of transport aircraft, their purpose being to provide a source of electrical power and pressurized air (e.g. for air conditioning and main-engine starting) thereby rendering aircraft less dependent on ground support equipment. Operation of an APU is based on a small turbine engine which, not infrequently, is left running unattended for prolonged periods between flights. In addition, the installation design of some systems may require in-flight operation of an APU. The integrity and satisfactory operation of APUs must, therefore, be ensured by regular monitoring, and by observing maintenance practices which, in many respects, are similar to those applied to the main power-units of an aircraft.

1.1 This Leaflet outlines typical constructional features of APUs and also provides guidance on their operation, installation and maintenance. As relevant details can vary between types of unit and aircraft, the information is of a general nature only. The Leaflet should, therefore, be read in conjunction with the Maintenance Manuals and other approved documents for the APU concerned, and for the type of aircraft in which it is installed. Reference should also be made to the following Leaflets which contain certain relevant information:—

AL/3-8	Fire—General Precautions
AL/3-9	Fire Detection Equipment
AL/3-10	Fire Extinguishing Equipment
AL/3-23	Pressurization Systems
AL/3-24	Air Conditioning
EL/3-10	Turbine Engines
EL/3-12	Turbine Engines—Starter and Ignition Systems

2 GENERAL DESCRIPTION An APU is a self-contained unit which, generally, consists of a small gas turbine engine coupled to a gearbox which provides the means for driving a generator of a similar type and power rating to the generator driven by each of the main engines of the aircraft. The gearbox also drives the APU accessories such as the fuel pump, oil pump, tachometer generator and a centrifugal switch. The purpose of the centrifugal switch is to control the starting and ignition circuits, the governed speed indication circuit and the overspeed protection circuit of the APU (see also paragraph 3.3).

2.1 **Location.** An APU is located in an unpressurized compartment of the fuselage of an aircraft, usually in the tail section. The compartment is separated from the remainder of the fuselage by a firewall and the unit is secured to the fuselage structure by rubber-bonded anti-vibration mountings. Access to the compartment is normally via hinged cowling panels positioned either one at each side of the compartment, or a single panel at the bottom of the compartment.

2.2 **Air Supply.** Air for the APU compressor is drawn in through either single or twin intakes, connected, via ducting, to the APU intake section. Doors are provided in the intake sections of most APU installations, and are normally opened and closed by electric actuators; the actuator circuits are interconnected with the APU master control switch to ensure the correct operating sequence during starting and shut-down. In one type of aircraft the doors are operated by a pneumatic ram, the air supply being controlled via an electromagnetic valve energized from the APU control system. Door positions are indicated by indicator lights which, depending on the installation, are connected to either micro-switches, or proximity switches at the door locations.

2.2.1 The APU compressor discharges air into a plenum chamber which is connected, via ducting, to the air conditioning system and the main-engine air-starting system of the aircraft. The bleed air thus supplied, is automatically regulated to provide the correct amount without overloading the APU. The bleed-air system of some types of APU is also designed to by-pass air not required by the aircraft, into the engine exhaust duct. In addition to supplying bleed air, the plenum chamber also serves to distribute air to the engine combustion system, in which a mixture of air and fuel is burned to drive the turbine.

2.3 **Fuel Supply.** Fuel is supplied to the APU from one of the tanks in the main fuel system of the aircraft via a solenoid-operated valve, and is regulated by a fuel control unit which controls the acceleration of the APU and maintains the speed by proportioning fuel flow to load conditions.

2.4 **Lubrication.** Lubrication of all gears and bearings within an APU is provided by a self-contained system consisting of an oil tank, pump, filter, cooler, oil jets and associated supply lines. Monitoring of system operation is effected by indicator lights and instruments associated with such functions as oil pressure, quantity and, in some cases, oil temperature.

2.5 **Starting and Ignition.** Rotation of the engine for starting is accomplished by an electric starter motor connected to a drive shaft in the accessories gearbox. The motor is normally powered by the aircraft batteries and, in some instances, power may also be obtained from an independent APU starter battery. The ignition system is of the high-energy type (see Leaflet **EL/3-12**) and is controlled from the master control switch, and via the centrifugal switch (see paragraph 3.3).

2.6 **Cooling.** Cooling and ventilation of the APU compartment is normally provided by a fan driven by the APU accessories gearbox. Air is also ducted from the fan for cooling the a.c. generator and APU lubricating oil.

2.7 **Anti-icing.** In some types of APU the air intake area is protected against ice formation by bleeding a supply of air from the compressor and using it to heat vulnerable surfaces.

2.8 **Fire Detection and Extinguishing.** The detection and extinguishing of a fire in an APU compartment is normally accomplished by a continuous-wire detection system and a single-shot fire extinguisher (see Leaflets **AL/3-9** and **AL/3-10**). In some aircraft having a centre rear-mounted main engine, the fire extinguisher installation for that engine is also designed to discharge into the APU compartment in lieu of an independent extinguisher system. Detection circuits are so arranged that, in addition to actuating warning lights and/or warning horn systems, they automatically shut down the APU. The extinguishant is discharged by manually-operated switches on the appropriate APU system control panel. In one particular installation, discharge also takes place automatically whenever the detection system is activated.

2.9 **Controls and Indicators.** All switches, warning lights and indicating instruments necessary for the starting, stopping and normal operation of an APU are located on control panels in the flight compartment and in fuselage compartments accessible from outside the aircraft. An APU can normally only be started from the flight-compartment control panel, although in some installations, provision for starting is also made at a fuselage compartment panel. Shut-down of an APU is accomplished from either of the panels (see also paragraph 3.4).

2.9.1 Operation of an APU is monitored by an exhaust gas temperature indicating system, and, in the majority of installations, an hourmeter or an elapsed time indicator, the latter instruments recording the number of hours an APU has been in continuous operation. Depending on the installation, provisions for monitoring APU starting current, engine rev/min, generator output voltage and frequency, generator bearing temperature, and connection of an APU test set may also be included.

3 APU OPERATION The operating characteristics of an APU are such that the possibility of injury to personnel and damage to aircraft and associated equipment exists. It is, therefore, necessary in the interests of safety to observe certain precautions, and to carry out checks prescribed for the particular APU installation.

3.1 **Precautions.** The following precautions are those which, in general, must be observed. Additional precautions appropriate to specific operating or maintenance tasks are outlined in the relevant paragraphs of this Leaflet.

(a) As with any type of turbine engine operating under ground-running conditions, danger zones are created around the air intake and exhaust unit of an APU. These zones should, therefore, be kept clear of personnel, loose debris and equipment. The area of danger zones varies with the type of engine and the location of the APU, and reference should be made to the appropriate manuals for details of zone clearances.

(b) During operation, an APU has a high noise level; maintenance personnel should, therefore, wear appropriate types of ear-protection devices, when working in close proximity to a unit.

(c) In some installations, prolonged ground operation of an APU in high ambient temperature conditions may cause an extreme build-up of temperature in the APU compartment, and in any adjacent compartment. Reference should, therefore, be made to the relevant aircraft Maintenance Manual for details of any operating limitations or procedures which may make it necessary for compartment cowlings or access doors to be left open.

(d) Fire extinguishers should be positioned adjacent to the aircraft during all ground-running operations of an APU.

(e) When an APU is used for pressurization tests, it must be ensured that smoke masks are available for use by personnel within the aircraft, in the event of fire.

(f) A communication link should be established between ground crew members outside the aircraft and at the APU control panel in the flight compartment, to ensure safe operation of the APU. In most types of aircraft, this is facilitated by the provision of headset jackplug points connected to the intercommunication system of the aircraft.

NOTE: An APU may be cleared to run unattended, subject to the provision of various automatic shut-down facilities (see paragraph 3.4.1) or that the possibility of hazardous failure occurring is extremely remote.

(g) The height of an APU location from the ground varies between types of aircraft, but normally it is such that a fall from a workstand, or platform, could result in a person sustaining serious injuries. Stands or platforms must, therefore, permit adequate freedom of movement by personnel, and must be equipped with protective rails.

(h) Before attempting any work on an APU 'in situ', the power supply to the unit must be isolated by opening the circuit breaker and placing the master control switch in the OFF or STOP position. The circuit breaker and switch should each be placarded to the effect that work on the APU is being performed.

(j) In some aircraft, bleed air from the APU is supplied to the leading-edge flap control system. Before starting the APU or before operating the bleed valve, a check should, therefore, be made to ensure that the flap control system will not be inadvertently operated.

(k) When working on an APU located in a compartment below the rudder of an aircraft, personnel should keep clear of the rudder. A notice should be displayed in the flight compartment warning personnel not to operate the rudder controls while work is being undertaken on the APU.

(l) The electrical energy stored in the ignition system of an APU is potentially lethal and certain precautions are necessary before carrying out any work on system components. The power supply to the system should be switched off, the circuit breaker tripped, and at least 3 minutes allowed to elapse before touching the high-energy ignition unit, high tension lead or igniter plug. After disconnecting an HT lead the complete discharge of the capacitors in the high-energy ignition unit should be ensured by immediately grounding the ignition lead.

(m) Air intake doors must remain closed when APU operation is not required and on occasions prior to the use of de-icing fluids around the tail area of an aircraft.

(n) An APU should be allowed to operate at 'no-load' governing speed for approximately two minutes prior to shut-down.

(o) After shut-down, sufficient time should be allowed for an APU to cool down before carrying out any work on the unit.

3.2 **Pre-starting Checks.** In addition to observing the precautions outlined in paragraph 3.1, it is necessary to carry out certain checks on an APU and its installation, before starting. The following checks are those which are generally applicable:—

(a) Ensure that there is sufficient fuel available in the relevant tanks of the aircraft to supply the APU for the period of ground running required.

(b) Check the quantity of oil in the lubricating system against the dip stick and, where appropriate, against the oil quantity indicator. Replenish the tank as necessary. The tank should not be overfilled, otherwise oil may be forced into the engine exhaust casing to cause exhaust smoke, carbon deposits and lowering of system performance.

NOTE: Oil must be to approved specifications detailed in the relevant Maintenance Manuals. Any substitution, use of non-approved lubricants, or mixing of brands may be harmful.

(c) Ensure that there are no fuel or oil leaks.

(d) Check all overboard drains to ensure that they are open.

(e) Remove all covers and blanks.

(f) Ensure that the appropriate source of d.c. power is available, and check that the fuses and circuit breakers of all systems associated with APU operation are intact and closed.

(g) Note the battery voltage and ensure that it is not below the minimum specified for starting (a typical value is 23 V).

(h) With d.c. power on, check that indicator lights are illuminated as appropriate to the APU installation. A check should also be made on indicating devices associated with automatic shut-down circuits, to ensure that they are clear of relevant warnings.

(j) Note and record the outside air temperature, and the hours run as indicated by the hourmeter.

(k) Check the fire detection system for serviceability, and also check the fire extinguishing system to ensure that the extinguisher is in a charged condition.

3.3 **Starting Procedure.** The sequence of starting an APU is fundamentally the same for all types of unit, and is initiated by either a toggle- or push-type master control switch on the APU control panel in the flight compartment of the aircraft. When the control switch is operated, the air inlet doors are opened, and the APU engine is 'motored up' to a speed at which the fuel and ignition system controls are activated. After ignition, or 'light up', has taken place, the engine with the assistance of the starter motor, begins to accelerate to its governed speed. At a certain percentage of the governed speed (typical values are from 35 to 50%) the circuit to the starter motor is automatically interrupted by the centrifugal switch, and the motor is disengaged from the driving gear. The engine continues to accelerate under turbine power until at 95% of governed speed, the centrifugal switch interrupts the ignition circuit and combustion becomes self-sustaining. Acceleration then continues until the no-load governed speed is reached. Governing of speed and bleed-air load is carried out by a sensing system which automatically meters the fuel supply to the engine in response to variations in speed and exhaust temperature. The APU should be allowed to run at its no-load governed speed for one minute before selecting bleed-air and electrical loads. If the speed regulation system fails, an overspeed sensing circuit is activated (normally at 110% of governed speed) by the centrifugal switch, and automatically shuts down the APU.

3.3.1 Careful monitoring of APU behaviour throughout the complete starting and operating procedure is vital for the purpose of detecting failure to 'light up', and in particular, the detection of high exhaust gas temperature when a load is applied in the governed speed condition.

(a) If 'light up' does not occur, or the APU does not reach governed speed within the time specified for the relevant unit, the master control switch should be selected to the OFF or STOP position. Before attempting to re-start, sufficient time should be allowed for excess fuel to drain overboard. The number of successive attempts to start should not exceed that specified in the relevant aircraft Maintenance Manual. In addition, the specified duty cycle of the battery should be strictly observed to ensure that batteries and APU starter motors are not overheated. If an APU fails to start after the specified number of attempts, the fault should be investigated and rectified.

NOTE: After setting the master control switch to its OFF or STOP position, it should not be returned to the starting position until the APU engine has ceased running. Damage to the starter motor and drive is possible if they are engaged with a rotating engine.

(b) When an APU is operated at governed speed, the exhaust gas temperature indications should be carefully monitored to ensure that specified limitations are not exceeded regardless of load applied. In the event of limitations being exceeded, the electrical and/or bleed-air load should be shed as soon as possible and the APU shut down. The fault should then be investigated and rectified as appropriate.

3.4 **Shut-down.** An APU is normally shut down by allowing it to operate at no-load governed speed for approximately two minutes, and then selecting the OFF or STOP position of the master control switch located at either of the two control panels.

3.4.1 Depending on the type of APU and its installation requirements, shut-down of an APU can also take place automatically as a result of any one of the following conditions:—

(a) Overspeed.

(b) High exhaust gas temperature.

(c) Loss of exhaust gas temperature signal to the electronic control system.

(d) Low oil pressure.

(e) High oil temperature.

(f) APU fire detection system operation.

(g) Opening or closing of cooling air shut-off valve before 95% of governed speed has been attained.

(h) Overheating of the APU bleed-air delivery duct just forward of the APU compartment.

(j) When specified airspeed or altitude limitations are exceeded.

(k) Operation of landing gear shock-strut micro-switches on take-off.

3.4.2 In some installations, the APU can also be shut down in an emergency by using a FIRE switch on the control panels, or by pulling a FIRE handle on the flight compartment panel. When using a FIRE switch, the fire extinguisher discharge circuit is armed, and care must be taken to prevent inadvertent discharge of extinguishant.

3.4.3 After an automatic shut-down has occurred, the master control switch should be selected to the OFF or STOP position. The reason for the shut-down should then be determined and appropriate remedial action taken.

NOTE: In order to indicate which circuit or system has caused a shut-down, most APU installations incorporate appropriate indicating devices, e.g. magnetic 'doll's eye' type indicators.

4 INSTALLATION The procedure to be adopted for the installation of an APU varies between types of aircraft, and reference should always be made to the relevant Maintenance Manuals for precise details. Certain aspects are, however, of a common nature and these are given in the following paragraphs.

4.1 **Pre-installation Checks**

(a) Circuit breakers relevant to the APU and its systems should be open, and the master control switch selected to the OFF or STOP position before installation. The switch should be placarded to the effect that work on the APU installation is being undertaken.

(b) Dirt and foreign matter which may have accumulated within the APU compartment should be removed. Sound proofing, heat-shields and any fireproofing seals should be checked for security and possible oil soakage.

(c) Mountings, attachment fittings and structural attachment points should be checked for damage and general security.

(d) Air intake and other ducting should be checked for security, signs of damage, and freedom from obstruction.

(e) The APU cooling fan should be checked for freedom of movement and signs of damage to blades.

(f) All blanking caps and plugs should be removed from APU connections within the APU compartment.

(g) Pipelines and drains should be checked to ensure that they are undamaged and free from obstruction.

(h) Cable harness assemblies and components associated with the APU electrical circuits, e.g. starting, ignition and generator, should be checked for security of attachment and for signs of damage to insulation and connectors.

(j) On satisfactory completion of all requisite checks within the APU compartment, the APU itself should be checked to ensure that it is undamaged and is complete. Inhibiting fluid should be drained out.

4.2 **Installation**

(a) The installation of an APU is carried out by means of a hoist and cable assembly which, for many types of aircraft, is supplied as an item of ground equipment. If an alternative type of hoist assembly is to be used, it must be ensured that the hoist is capable of adequately supporting the weight of the APU.

(b) Hoists should be connected to the attachment points normally provided in the APU compartment, and, with the APU and its mounting stand, or 'dolly', positioned below the compartment, the hoist cables should be connected to the 'slinging' points on the APU.

(c) After taking up slack in the hoist cables, the APU should be released from its attachment points on the stand, or 'dolly', and then hoisted into its compartment. During hoisting it must be ensured that the APU clears all obstructions to prevent damage to compartments and aircraft structure.

(d) The APU should then be carefully manoeuvred into alignment with its mountings and appropriate ducts, and the mounting bolts inserted and torque-tightened to within their specified limits.

(e) The hoist assembly and cables should be disconnected and removed, and all requisite mechanical and electrical connections should be made in accordance with the procedures specified in the relevant Maintenance Manual.

(f) In installations employing electrically-actuated air inlet doors and an exhaust door, the air inlet doors should be driven to the closed position before connecting the flexible shaft to the exhaust door, otherwise the actuator jack shafts will hit their internal stops, resulting in damage to, or failure of, the flexible shaft. Care must be taken to keep hands away from door areas when doors are in operation.

(i) Door-actuating gearbox shafts must be properly indexed with door torque shafts to ensure that the correct opening and closing relationship is obtained.

(g) The APU fuel system should be bled (see also paragraph 5.2.6), and the oil tank contents should be checked and replenished as necessary.

4.3 **Inspection and Tests**

4.3.1 On completion of the procedures in paragraphs 4.1 and 4.2, a post-installation inspection should be carried out to ensure that:—

(a) Pipelines, ducts and cables have adequate clearance to prevent fouling or chafing.

(b) Pipelines are not kinked or twisted.

(c) All mountings, connections, fittings and clamps are secure, and also that they have been made 'safe' in accordance with the appropriate installation requirements.

(d) The sensing element of the fire detection system is correctly routed and connected to its associated warning circuit.

(e) All tools, equipment, spilled fluids, loose hardware and debris have been removed from the APU compartment.

4.3.2 On completion of the installation procedures, the APU should be started, and appropriate functional tests and adjustments carried out.

5 INSPECTION AND MAINTENANCE The frequency at which inspection and maintenance of an APU is to be carried out is given in the aircraft Maintenance Schedule, and details concerning the procedures to be adopted, type of test equipment required, and any precautions to be observed, are contained in the appropriate Maintenance Manuals. It is essential, therefore, to refer to these documents at all times. The information given in the following paragraphs, although based on some typical installations, is intended to serve only as a general guide.

NOTE: Details of all tests, adjustments, and abortive starting cycles, should be recorded in the APU log book or record card.

5.1 **Inspection.** The inspection of an APU may be considered under two main headings: (a) external inspection and (b) 'hot end' inspection.

5.1.1 **External Inspection.** This inspection comprises visual checks for security and signs of damage to the APU and all its components, pipelines, electrical cables, etc., which are externally mounted.

5.1.2 **'Hot end' Inspection.** This inspection is one requiring checks on the combustion system, turbine assembly and exhaust unit of the engine of an APU for signs of excessive carbon deposits, cracking, erosion, blade rubbing and heat distortion. The checks, which are most indicative of a critical engine condition having occurred, may normally be carried out 'in situ', by removing such items as the combustion chamber and the turbine torus assembly, and also by means of borescopes inserted through inspection ports. Permissible limits associated with the checks are given in the relevant Maintenance Manual together with illustrations to show the probable location and extent of cracks and other damage.

5.2 **Maintenance**

5.2.1 **Proof Test.** This test is carried out after the installation of an APU and, where specified, after changing certain components.

(a) Before starting, all necessary precautions relevant to the ground running of an APU must be observed, and the appropriate pre-starting checks carried out (see paragraphs 3.1 and 3.2).

(b) During the starting procedure (see also paragraph 3.3) the following should be noted and recorded:—

(i) Reduction in battery voltage (a typical minimum value is 18 V).

(ii) Time taken for the engine to 'light up'.

(iii) Maximum exhaust gas temperature and its duration, e.g. 760°C for 15 seconds.

(iv) Engine speed at which the starter motor is disengaged from the engine. This check is normally applicable only to those installations which incorporate an indicator light in the starter motor circuit.

(v) Engine speed at which the oil pressure warning light, where appropriate, goes out.

(vi) No-load governing speed and exhaust gas temperature.

(c) With the APU running at its no-load governing speed, check that there are no fuel, oil or air leaks.

(d) If the APU is a new one, it should be shut-down after five minutes running at no-load governing speed and the oil and fuel filters changed.

(e) With the APU supplying bleed air to the air conditioning system, the latter should be checked for proper functioning, and the APU checked for stable operation under load. Exhaust gas temperature indications should be monitored to ensure that the specified maximum is not exceeded.

(f) The bleed air supply for main-engine starting should be checked by selecting a main engine and allowing the APU to 'blow' the engine for 30 seconds. The stability of APU operation under these conditions should also be checked.

(g) The APU generator output voltage and frequency should be checked to ensure that they are within the specified limits; typical values are respectively 200 $\pm$ 4 V and 400 $\pm$ 4 Hz. This check should be carried out with the APU also supplying bleed air to the air conditioning system.

(h) On completion of the foregoing checks, the APU should be shut down, and the 'run down' time recorded from the moment of setting the master control switch to OFF or STOP. Checks should be made that there are no abnormal noises coming from the APU and that drainage from fuel drains is not excessive.

(j) With the engine stationary, a check should be made that there are no oil or fuel leaks.

5.2.2 **Adjustments.** Various adjustments are required after an APU has been installed, and whenever a control system component has been changed. The nature of the adjustments, which are carried out with the aid of appropriate test sets, depends on the type of APU and as already indicated in paragraph 5, the procedures detailed in the relevant manuals must be followed. Some of the adjustments commonly required, and typical methods of carrying them out are outlined in the following paragraphs.

(a) **Exhaust Gas Temperature.** The purpose of this adjustment is to ensure that the APU engine is operated within its proper maximum gas temperature limits. The adjustment is normally required after installing an APU and after installing such components as a fuel control unit, thermocouple and harness assembly, load control valve, and electronic temperature control unit. The APU is started, and, after allowing it to run at no-load governed speed for one minute, the bleed-air and electrical loads are selected. A check is then made on the exhaust gas temperature, and, if it is necessary to bring it within the specified operating range, adjustments are made by turning a screw-controlled potentiometer on the temperature control unit in the appropriate direction. The directions are normally in the sense, clockwise to decrease and anti-clockwise to increase. Potentiometer sensitivity is typically 22°C for each quarter of a turn of the adjusting screw control.

(b) **Load Control.** This adjustment should be carried out after installation of a load control valve, the purpose of which is to maintain the electrical and bleed-air loads on the APU within the specified limits. The APU is started in the normal manner, and, after allowing it to stabilize at its no-load governing speed, the generator load is switched on and the exhaust gas temperature allowed to stabilize. The full bleed-air load is then selected, and from the moment of selection it should be noted that the time taken for the exhaust gas temperature to rise to its stabilized value on full load is within the specified limits (a typical time is from 18 to 22 seconds). If it is necessary to increase the valve operating rate, the APU should be shut down and the metering valve of the load control valve adjusted accordingly. The foregoing operations should be repeated until the correct valve operating rate is achieved. On satisfactory completion of the adjustment procedure, the adjusting device should be made 'safe' in the appropriate manner.

NOTE: Care must be taken not to over-adjust the valve. In the event that the operating rate is greater than the specified time, the valve should be removed for rectification and re-calibration.

(c) **Surge Control Valve.** This valve operates in conjunction with the load control valve to modulate the bleed-air load and thereby prevent pressure surges, and also prevent stalling of the APU engine compressor. The valve should normally be adjusted after installation of an APU whenever the valve is changed, and whenever there is a reduction of maximum bleed-air load performance or a tendency for the APU to surge. The APU is run at its no-load governed speed, and a check is then made on the difference between the total pressure and static pressure which are sensed by a flow sensor unit in the ducting between the APU plenum chamber and load control valve. Both pressures are supplied to the surge control valve, and measurement is facilitated by connecting a differential pressure gauge (or a test rig manometer) and specially calibrated restrictor assemblies to two test points provided on the valve. Depending on the type of APU, differential pressure limits can vary between 3 and 8 in. Hg. The pressure is adjusted within the specified limits by turning an adjusting screw on the surge control valve in the appropriate direction, i.e. anti-clockwise to increase the pressure differential and clockwise to decrease it. On completion of adjustments, the APU should be shut down, the measuring equipment disconnected, and the blanking caps or plugs refitted to the test points. The APU should then be re-started and checked for correct operation.

(d) **Fuel Control Unit.** Adjustment of a fuel control unit is necessary whenever the unit has been changed, the purpose of the adjustment being to bring the speed of the APU within its prescribed limits. Adjustment is effected by a governor adjusting screw while the engine is running at the no-load governed speed. The direction of screw rotation is normally clockwise to increase speed and anti-clockwise to decrease speed.

(e) **Air Inlet Doors.** These require adjustment each time a door, or part of its actuating mechanism, is changed. Such adjustment is necessary to ensure that doors fair with the fuselage skin and that excessive gaps are reduced or eliminated between doors and frames. On completion of adjustments, doors should be cycled from their fully-closed to their fully-open positions, and back to closed. During cycling, a check should be made to ensure that the doors do not interfere with other components or parts of the airframe structure. The time taken for doors to fully open, and close, should also be checked.

(f) **Proximity Switches.** In some APU installations, a proximity switch is provided at each air-inlet door location. Each switch consists of two components which are so designed that when in very close proximity they complete a circuit to a 'door open' indicator light. During checks on door operation, the clearance between the components and switches should also be checked as their respective doors near the fully-open position. If a clearance is not within the specified limits, the position of the switch component mounted on the appropriate inlet door, should be adjusted.

5.2.3 **'Motoring'.** 'Motoring' refers to the procedure of rotating the APU engine compressor and turbine by means of the starter motor only; it can be either 'wet' or 'dry' depending on whether relevant maintenance checks are to be carried out with or without a flow of fuel to the engine. In both cases, the times specified for starter motor operation must not be exceeded. During 'wet motoring' a fire hazard is created as a result of fuel passing through drains and into the engine exhaust unit. All appropriate safety precautions must, therefore, be strictly observed.

5.2.4 **Starter Motor.** At the periods specified in the approved Maintenance Schedule, the brushes of the starter motor should be checked for wear, by measuring the distance from the tops of the brush holder caps to the tops of the brushes. Brush assembly leads should also be checked for discoloration and security. If wear exceeds the limit specified in the relevant Maintenance Manual, or if the leads are discoloured, the starter motor should be removed for the fitting of new brushes and subsequent 'bedding-in' procedures. Before refitting the clamping strap around the brush and commutator end of the starter body, any accumulation of brush residue should be removed by means of clean, dry, low-pressure compressed air.

5.2.5 **Lubrication System.** The following paragraphs outline some of the checks normally required during routine maintenance of the lubrication system.

(a) **Oil Changing.** When it is necessary to change the oil, draining of the system should be carried out while the oil is at, or near, its normal operating temperature. The drained oil should be examined for the presence of metal particles. A similar examination should also be made on the oil filter and the magnetic chip detector of the oil tank drain plug. If any particles are found, the engine should be inspected before replenishing with fresh oil, to determine the extent of any damage and the remedial action to be taken.

(i) A new filter element and housing gasket should be fitted (see (b)) and, after refitting the oil tank drain plug, the tank should be replenished with fresh oil to the same specification as that of the oil drained from the system (see also paragraph 3.2 (b)). The lubrication system should then be primed, and, after 'dry motoring' for 30 seconds, the APU should be started and run at 'no-load' governed speed for 3–5 minutes in order that the oil pressure indications may be monitored and the oil system may be checked for leaks.

(ii) If the tank is replenished with another type of approved oil, then, after running the engine for approximately 5 minutes, the tank should again be drained and the oil checked for metal particles or other contaminants. If the oil is uncontaminated, the tank should be replenished and the engine started and run for approximately 15 minutes; during this period the oil pressure and temperature should be carefully monitored. If either the oil pressure or temperature fluctuates, the entire draining and replenishing procedure should be repeated until fluctuations cease.

(b) **Filters.** Filter elements should be inspected and renewed whenever the oil is changed and also at the periods specified in the relevant aircraft Maintenance Schedule. Filter housings should be cleaned with the specified solvent and dried with clean, dry compressed air, but housing seals should be discarded and replaced by new seals, which should be coated with a specified lubricant. Before fitting a new filter element, it should be dipped in oil to the same specification as that used in the system. After installation, the oil level should be checked and the tank replenished as necessary. The APU should then be run in order to check for oil leaks. After the APU has been shut down, a further check on the oil level should be carried out.

(c) **Oil Pumps.** Oil pumps are normally designed for mounting on a pad of the APU accessory gearbox, but in some types of APU the pump may be submerged in the oil tank. In the latter case, pump removal and replacement cannot be accomplished as a single unit operation.

(i) Whenever a pad-mounted pump is installed, a new seal should be fitted between the pump and gearbox drive. After installation, the oil system should be primed, and, after 'dry motoring' for 30 seconds, the APU should be started and run at 'no-load' governed speed for 3–5 minutes in order that the oil pressure indications may be monitored, and the system may be checked for oil leaks. After the APU has been shut down, the oil level should be checked and the tank replenished as necessary.

(d) **Chip Detector Plugs.** Plugs should be removed and examined for traces of metallic particles. If particles are found, the cause should be investigated and remedial action taken in accordance with the procedures set out in the relevant Maintenance Manual.

(i) Plugs should be washed in clean kerosene and dried with clean, dry compressed air, before refitting. Where appropriate, a new seal, lightly coated with lubricant, should be fitted to a detector plug before it is installed.

(ii) The magnetic strength of a plug should also be checked against the weight of ferrous material it will lift; a typical weight is half an ounce.

5.2.6 **Fuel System.** Some of the checks normally required during routine maintenance of the fuel system of an APU are outlined in the following paragraphs.

(a) **Bleeding.** Bleeding of the system should be carried out on the following occasions: (i) after installation of an APU, (ii) whenever it is suspected that air leaks in the system are causing difficulties in starting, and (iii) after removal and replacement of such fuel system components as filters, pumps, fuel control units and fuel supply lines. Bleeding is carried out by connecting an overboard drain line, or special bleed tool, to the appropriate discharge port, and 'motoring' the APU until 'solid' streams of fuel are observed flowing from the drain line. The APU ignition system must be isolated during bleeding, and the times specified for starter motor operation must not be exceeded. Whenever the fuel tank supplying the APU has been drained, or the low pressure system between the tank and APU has been opened, the relevant section of the aircraft fuel system should be bled in the manner appropriate to that system.

(b) **Fuel Atomizer.** Whenever a fuel atomizer assembly is suspected of causing erratic combustion, and also prior to the installation of an assembly, its functioning should be checked. Briefly, this check is carried out by setting up the assembly in a test rig, and then observing the conical spray pattern of the fuel as it is pumped through the atomizer at varying pressures. The fuel is allowed to spray into a spray basin, while the angular limits of the pattern are referenced against a protractor. The pattern should always be steady and even. If any abnormalities appear in the spray pattern, such as sudden changes in spray angle, fluttering, bubbling, discontinuity or solid jets of fuel, the atomizer assembly should be rejected and sent for rectification.

5.2.7 **Ignition System.** High-energy ignition units should be inspected to ensure that they are undamaged and show no signs of corrosion. This also applies to igniter plugs but, in particular, these must be inspected to ensure that the ceramic insulation is not chipped or cracked, and that burning, or erosion of the central electrode and outer shell is within the limits specified in the Maintenance Manual. Whenever a high-energy ignition unit or an igniter plug has been changed, the functioning of the complete ignition system should be checked by energizing the power supply circuit to the system. When the necessary switches are selected, operation of the system will be heard as regular clicking noises from the igniter plug as electrical discharges occur.

NOTE: Before energizing the power supply circuit, it must be ensured that the APU engine fuel system is isolated, and that there is no possibility of fuel or fuel vapour being ignited. If, after the functioning check, it is necessary to change an ignition system component, sufficient time must be allowed for all electrical energy to decay before handling any component (see also paragraph 3.1(l)).

AL/7-1

Issue 3

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AIRCRAFT

STRUCTURES

INSPECTION OF METAL AIRCRAFT AFTER ABNORMAL OCCURRENCES

1 INTRODUCTION

1.1 Aircraft are designed to withstand flight and landing loads within specified limits; these limits are calculated to allow for all normal manoeuvres and exercises which may be undertaken by that aircraft, and include safety factors to allow for unforeseen circumstances. If design limits are exceeded due to abnormal occurrences, the integrity of the structure may be jeopardised and safety impaired. Any report or evidence on the aircraft which suggests that the design limits have been exceeded or equipment damaged should, therefore, be followed by a careful inspection appropriate to the nature of the occurrence and in accordance with the Approved Maintenance Manual.

1.2 The types of occurrence which may lead to structural damage are considered in the following paragraphs, but these should be considered as a general guide and not as a complete list; additional inspections may be required on some aircraft, and these will be described in the appropriate manuals. Inspections peculiar to helicopters are described in paragraph 7 of this Leaflet, and some guidance on the inspection of wooden aircraft structures is given in Leaflet **AL/7-9**.

1.3 **General.** The appropriate aircraft Maintenance Manual and other relevant literature, such as Service Bulletins, should be consulted to ascertain the particular inspections which are necessary, and the areas where damage has been known to occur in similar circumstances on aircraft of the same type. The aircraft should then be viewed for obvious damage such as distortion or twisting of the main structure, before carrying out the detailed inspections applicable to the particular incident.

1.4 The repairs necessary, if damage is found during inspection, are outside the scope of this Leaflet, and reference should be made to Leaflet **AL/7-14**, and to the manufacturer's Overhaul and Repair Manuals.

1.5 The subject headings are as follows:—

1.6 Related CAIP Leaflets:-

AL/3-23 Pressurisation Systems

AL/7-9 Inspection of Wooden Structures

AL/7-12 Rigging Checks on Aircraft

AL/7-14 Repair of Metal Airframes

2 HEAVY OR OVERWEIGHT LANDINGS

2.1 An aircraft landing gear is designed to withstand landing at a particular aircraft weight and vertical descent velocity. If either of these parameters is exceeded during a landing, then it is probable that some damage may be caused to the landing gear or its supporting structure. Overstressing may also be caused by landing with drift or landing in an abnormal attitude, e.g. nose or tail wheel striking the runway before the main wheels.

2.2 Some aircraft are fitted with heavy landing indicators, which give a visual indication that specified 'g' forces have been exceeded, but in all cases of suspected heavy landings, the flight crew should be consulted for details of aircraft weight, fuel distribution, landing conditions, and whether any noises indicative of structural failure were heard.

2.3 The damage which may be expected following a heavy landing would normally be concentrated around the landing gear, its supporting structure in the wings or fuselage, the wing and tailplane attachments and the engine mountings. Secondary damage may be found on the fuselage upper and lower skin and structure, and wing skin and structure, depending on the configuration and loading of the aircraft. On some aircraft it is specified that, if no damage is found in the primary areas, the secondary areas need not be inspected; but if damage is found in the primary areas, then the inspection must be continued.

2.4 Because of the number of factors involved, it is not possible to lay down precise details of the inspections which must be made after any incident, on any type of aircraft, but a preliminary inspection should normally include the items detailed in paragraphs 2.5 to 2.10.

2.5 **Landing Gear**

(a) Examine tyres for excessive creep, flats, bulges, cuts, pressure loss, excessive growth, and security of balance weights/patches.

(b) Examine wheels and brakes for cracks, other damage, and fluid leaks.

(c) Examine axles, struts and stays for distortion and other damage.

(d) Check shock struts for fluid leaks, scoring and abnormal extension.

(e) Examine landing gear attachments for signs of cracks, damage or movement. In some instances this may require removal of certain bolts in critical locations, for a detailed magnetic crack detection test.

(f) Examine structure in the vicinity of the landing gear attachments for signs of cracks, distortion, movement of rivets or bolts, and fluid leakage.

(g) Examine doors and fairings for damage and distortion.

(h) Jack the aircraft and carry out retraction and nose-wheel steering tests in accordance with the approved Maintenance Manual; check for correct operation of locks and warning lights, clearances in wheel bays, fit of doors, and signs of fluid leaks.

2.6 **Mainplanes**

(a) Examine the upper and lower skin surfaces for signs of wrinkling, pulled rivets, cracks, and movement at skin joints. Inertia loading on the wing will normally result in wrinkles in the lower surface and cracks or rivet damage on the upper surface, but stress induced by wing-mounted engines may result in wrinkles on either surface.

(b) Check for signs of fuel leaks, and seepage from integral tanks.

(c) Examine root end fillets for cracks and signs of movement.

(d) Check flying controls for freedom of movement; power-controlled systems should be checked with the power off.

(e) Check balance weights, powered flying control unit mountings and control surface hinges for cracks, and the control surfaces for cracks or buckling.

(f) Where possible, check the wing spars for distortion and cracks.

2.7 **Fuselage**

(a) Examine fuselage skin for wrinkling or other damage, particularly at skin joints and adjacent to landing gear attachments and centre section.

(b) Examine pressure bulkheads for distortion and cracks.

(c) Examine, for distortion and cracks, the supporting structure for heavy components such as galley modules, batteries, water tanks, fire extinguishers, auxiliary power units, etc.

(d) Check that the inertia switches for the fire extinguishers, emergency lights, etc., have not tripped.

(e) Check instruments and instrument panels for damage and security.

(f) Check ducts and system pipes for damage, security, and fluid leaks.

(g) Check fit of access doors, emergency exits, etc., and surrounding areas for distortion and cracks.

(h) Check loading and unloading operation of cargo containers, and condition of cargo restraint system.

(i) Check gyroscopic instruments for erection time, precession and unusual noises.

2.8 **Engines**

(a) Check engine controls for full and free movement.

(b) Examine engine mountings and pylons for damage and distortion. Tubular members should be checked for bow greater than prescribed limits, and cracks at welds. Mounting bolts and attachments should be checked for damage and evidence of movement.

(c) On turbine engines check freedom of rotating assemblies, and on piston engines check freedom of rotation with sparking plugs removed.

(d) Examine engine cowlings for wrinkling and distortion, and integrity of fasteners.

(e) Check for oil, fuel and hydraulic fluid leaks.

(f) Where applicable, check the propeller shaft for shock loading in accordance with the procedure in the Maintenance Manual.

(g) Check propeller attachments and counterweight installations.

(h) Check oil system filters/chip detectors.

2.9 **Tail Unit**

(a) Check flying controls for freedom of movement.

(b) Examine rudder and elevator hinges for cracks, and control surfaces for cracks and distortion, particularly near balance weight fittings.

(c) Examine tailplane attachments and fairings, screw jacks and mountings, for distortion and signs of movement.

2.10 **Engine Runs.** Provided that no major structural distortion has been found, engine runs should be carried out in accordance with the appropriate Maintenance Manual, in order to establish the satisfactory operation of all systems and controls. A general check for system leaks should be carried out while the engines are running, and on turbine engines the run-down time should be checked.

2.11 **Inspection of Damaged Areas.** If any superficial damage is found during the preliminary inspection, the supporting structure should be examined for distortion, loose rivets, cracks or other damage, and rigging and symmetry checks should be carried out; see Leaflet **AL/7-12** to ascertain whether the damage has twisted or warped the main airframe structure. Where flying controls pass through supporting structure, cable tensions should be checked. On pressurised aircraft a cabin leak rate check should be carried out; see Leaflet **AL/3-23** to ascertain whether the sealing of the fuselage is satisfactory and unaffected by the damage.

3 BURST TYRE INCIDENTS

3.1 Tyre failures on large transport aircraft particularly wide-body types, have resulted in serious incidents and accidents. The principal problem is that if one tyre fails, its axle companion becomes overloaded, and sometimes fails. If a tyre bursts during taxying, take-off or landing, fragments of the tyre may fly off the rotating wheel and cause damage to parts of the aircraft in line with the wheel disc. Where single wheels are employed, more serious damage may occur through the wheel rolling on the paved runway and transmitting shocks to the landing gear leg and supporting structure. Multiple wheel landing gears will generally be less seriously affected by a single burst tyre, but the axles, bogies, torque links or steering mechanism may become bowed or strained as a result of the effects of uneven loading. In some cases extensive damage, including fire, has resulted from tyre and wheel degradation and there has been an attendant reduction in braking performance.

3.2 In most cases the wheel on which the burst occurred will generally be damaged and must be returned for overhaul. In addition, the following inspections should be carried out:—

(a) Examine for damage, the wheels and tyres which have not burst.

NOTE: Where one of the tyres on a multi-wheel undercarriage has burst, it may be specified that all tyres on that leg or axle should be discarded, or removed for detailed examination.

(b) Examine the brake units on the affected leg for damage. On those wheels which are not fitted with fusible plugs, the tyre burst may have resulted from overheating caused by a binding brake, and when the replacement wheel is fitted attention should be given to the operation of the associated brake including, in particular, freedom of rotation of the wheel with brakes released.

(c) Examine the landing gear bay for damage and hydraulic fluid leaks.

(d) Examine the affected leg, including pipelines, operating jacks, etc., for damage and hydraulic fluid leaks.

(e) Inspect the supporting structure and attachments of the affected leg, for cracks, warped panels and loose rivets. In some instances it may be specified that certain highly-stressed bolts in the supporting structure or retraction mechanism should be removed for non-destructive crack detection tests.

(f) Examine the adjacent fuselage or wing skinning, and landing gear doors, for damage.

(g) Check rear-mounted engines for possible ingestion of debris.

4 FLIGHT THROUGH SEVERE TURBULENCE

4.1 If an aircraft has been flown through conditions of severe turbulence, the severity of the turbulence may be difficult to assess and report upon, but an indication may be obtained from the accelerometers or fatigue meters fitted to some aircraft. However, these instruments are designed to record steady loads, and force peaks recorded during flight through turbulence may be exaggerated due to instrument inertia, and should not be taken as actual loads. Generally, if readings exceeding −0·5 g and +2·5 g are recorded on transport aircraft, then some damage may be found. With other types of aircraft (e.g. aerobatic or semi-aerobatic), accelerometers and fatigue meters are seldom fitted, and reported flight through turbulence should always be investigated.

4.2 Severe turbulence may cause excessive vertical or lateral forces on the aircraft structure, and the effects may be increased by the inertia of heavy components such as engines, fuel tanks, water tanks, and cargo. Damage may be expected at main assembly points such as the wing-to-fuselage joints, tail-to-fuselage joints, and engine mountings. Damage may also occur in those areas of the wings, fuselage, tailplane and control surfaces where the greatest bending moment takes place, i.e. part way along their length, and may be indicated by skin wrinkles, pulled rivets or similar faults.

4.3 An inspection for damage, after a report of flight through severe turbulence, should include the inspections detailed in paragraph 2, except, in most cases, those covering the landing gear.

NOTE: Further dismantling and, in some cases, removal of some portions of the skin, may be necessary in order to inspect supporting structure where skin damage has been found.

5 LIGHTNING STRIKES

5.1 Lightning is a discharge of electricity between highly charged cloud formations, or between a charged cloud and the ground. If an aircraft is flying, or on the ground in the vicinity of such a cloud formation, the discharge may strike the aircraft and result in very high voltages and currents passing through the structure. All separate parts of an aircraft are electrically bonded together to conduct a lightning strike away from areas where damage may hazard the aircraft, e.g. fuel tanks or flying controls, and during manufacture special precautions are often taken with non-metallic components such as wing tips, external fuel tanks and nose cones.

5.2 Lightning strikes may have two effects on an aircraft; strike damage where the discharge enters the aircraft, and static discharge damage subsequent to the strike. Strike damage is generally found at the wing tips, leading edges of wings and tail unit, and at the fuselage nose, but on some aircraft types other areas may be particularly susceptible, and this information should be obtained from the appropriate Maintenance Manual. Static discharge damage will usually be found at wing tips, trailing edges and antennae.

5.3 Strike damage is usually in the form of small circular holes in the exterior skin, either in clusters or spread out over a wide area, and often accompanied by burning or discolouration, blisters on radomes and cracks in glass fibre. Static discharge damage is usually in the form of local pitting and burning at trailing edges.

5.4 **Inspection.** Since both lightning and turbulence occur in thunderstorms, an inspection for lightning damage will often coincide with an inspection following reported flight through severe turbulence. The areas mentioned in paragraph 5.2 should be examined for signs of strike or static discharge damage, and bonding strips and static discharge wicks should be examined for burning and disintegration. All control surfaces, including flaps, spoilers and tabs, should be inspected for damage at their hinge bearings; unsatisfactory bonding may have allowed static discharge and tracking across the bearings, causing burning, break-up or seizure. A check for roughness and resistance to movement at each bearing, will usually indicate damage at such points. In addition, the following inspections should be carried out:—

(a) Examine engine cowlings and engines for signs of burning or pitting. If a lightning strike is evident, tracking through the bearings may have occurred, and some manufacturers recommend that the oil filters and chip detectors should be examined for signs of contamination; this check should be repeated periodically for a specified number of running hours after the occurrence.

(b) Examine the fuselage skin and rivets generally, for burning or pitting.

(c) If the landing gear was extended when the lightning strike occurred, examine the lower parts of the gear for static discharge damage. Check for residual magnetism and demagnetize where necessary.

5.5 The inspections outlined in paragraph 5.4 should be followed by functional checks of the radio and radar equipment, instruments, compasses, electrical circuit, and flying controls, in accordance with the relevant chapters of the approved Maintenance Manual. On some aircraft a bonding resistance check on radomes may also be specified.

6 DAMAGE FROM JET BLAST

6.1 Considerable damage may be caused to an aircraft through the action of another aircraft turning or taxying in the vicinity. The damage may be caused by blast or impact from debris, and may be particularly severe in the case of light aircraft.

6.2 Flying control surfaces should be inspected for distortion, particularly where they were unlocked and may have been driven hard against their stops.

6.3 An inspection for impact damage in the form of skin dents and cracked or chipped windscreens or windows, should be made, and the air intakes for engines, heat exchangers, etc., should be examined for debris which may have blown into them.

6.4 With light aircraft, further inspections may be necessary to ensure that no structural damage has been sustained, particularly when the jet blast has been sufficiently strong to move the whole aircraft.

7 HELICOPTERS

7.1 The inspections necessary on helicopters following unusual occurrences, are broadly similar to those detailed in the preceding paragraphs, but additional checks are normally specified for the main rotor blades, head and shaft, tail rotor and transmission, following heavy landings or flight through severe turbulence. Inspections are also required following overspeeding of the rotors. The inspections outlined below are typical.

7.2 **Heavy Landings or Flight Through Severe Turbulence**

7.2.1 **Rear Fuselage or Tail Boom.** Examine for evidence of strike damage from the main rotor blades, and if damage is found check for cracks, security and symmetry.

7.2.2 **Main Rotor Blades.** Remove the rotor blades and examine them for twisting and distortion. Check the surface for cracks, wrinkles, or other damage, and check the security of the skin attachment rivets or structural bonding. If the main rotor blades are badly damaged through impact with the tail boom or ground, certain components in the transmission may be shock-loaded, and it is sometimes specified that, for example, the main rotor shaft, pitch change rods, and main gear box mounting bolts, should also be removed for inspection.

7.2.3 **Main Rotor Head.** Disconnect pitch change rods and dampers, and check that the flapping hinges, drag hinges and blade sleeves move freely, without signs of binding or roughness. Examine the rotor head and blade stops for cracks or other damage, and the dampers for signs of fluid leaks. Damage in this area may be an indication of further damage inside the main gearbox.

7.2.4 **Tail Rotor.** Examine the blades for damage and security, and the coning stops for evidence of damage. Damage to the tail rotor blades which is beyond limits, will normally entail either inspection or replacement of the hub, pitch change links, tail rotor gear box and drive shaft.

7.2.5 **Skid Type Landing Gear.** With the helicopter jacked clear of the ground, check cross tubes for excessive bowing, fasteners for integrity and security, and abrasion plates for wear. Where Float Gear is fitted, check for leaks, fabric scuffing, and integrity of attachment straps.

7.3 **Rotor Overspeeding.** The extent of the inspection will normally depend on the degree of overspeeding. Overspeeding below a specified limit will usually entail checking the rotor blades for distortion and damage, and the rotor head for cracks and smooth operation, but, if this limit is exceeded it is usually specified that both the main rotor head and tail rotor head should be removed for overhaul. If damage has occurred to the main rotor blades, the rotor head, shaft, pitch control rods, tail rotor and transmission should also be removed for overhaul, and the gearbox attachments should be inspected for damage.

8 OTHER OCCURRENCES Occurrences not covered in the preceding paragraphs, or peculiar to a particular aircraft type, may necessitate a special inspection, and this is often specified in the appropriate Maintenance Manual. Where no specific instructions exist, experience on the type of aircraft, combined with a knowledge of the structure and stress paths, will normally enable a satisfactory inspection to be carried out. As an example, if the flap limiting speed has been exceeded, the flaps should be examined for twisting and buckling, the hinge brackets on the wings and flaps should be examined for damage such as cracks and strained attachment rivets and bolts, and the operating mechanism should be examined for general distortion, bowing, cracks and security. Provided these checks are satisfactory, and operation of the system reveals no evidence of malfunction, or excessive friction, then the aircraft may be considered airworthy.

AL/7-2

Issue 1

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AIRCRAFT

STRUCTURES

AIRFRAME DESIGN AND CONSTRUCTION

1 INTRODUCTION The structure, or airframe, of an aeroplane or helicopter is designed to carry the loads imposed by the forces of lift, thrust, drag and weight and to do so in such a way that is efficient aerodynamically and yet still permit a commercially viable payload. The object of this Leaflet is to provide a simple introduction to the basic mechanics of an airframe structure and to consider different examples of structural components, the methods of their fabrication and the materials employed. A grasp of such fundamentals is important to an engineer who is responsible for the maintenance and inspection of airframe structures because an understanding of how loads and stress are distributed will provide essential guidance on where to look for problems.

2 BASIC MECHANICS Any structure can be divided into individual elements that will behave in a certain way when loaded in any direction. Generally speaking a simple structure is made up of three types of members, that is, beams, struts and ties. A member subject to bending is known as a beam, one subject to compression as a strut and one subject to tension as a tie. Each will be considered in turn in the following paragraphs.

2.1 The load applied to a member is the force in pounds, kilograms or Newtons, but the most important factor from the point of view of the strength of a member is not the load it has to carry but the relationship between the load and the cross-sectional area of the member. This is called the stress in the member and is measured in pounds per square inch, Newtons per square metre or some other suitable units.

2.2 When a load is applied to a member in a framework it will, to some extent, move under the load. For example, a tie will stretch under load. The vertical movement of the wing tips of a large aeroplane is evidence of the extension and compression of the upper and lower surfaces. This movement under load is called strain. Two statements will summarise this paragraph:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} \qquad \text{Strain} = \frac{\text{Change of length}}{\text{Original length}}$$

2.3 A beam was defined as a member subject to bending. A beam may be simply supported at the ends, the supports may be in a little way from the ends or it may be supported at one end only, in which case it is termed a cantilever. With any beam, as it takes up its deflected position due to loading, the surface that is on the outside of the bend will be in tension while the surface on the inside of the bend will be in compression. With a solid member there will be a plane in the middle that is neither in compression nor in tension and this is known as the neutral plane, or neutral axis.

2.4 In a simple beam there are two main stresses that are present to cause failure should they rise above the strength of the beam; stress due to bending, caused by the bending moment, and stress due to shear. If a beam supported at the ends is considered and a load is applied in the centre, the bending moment will be greatest in the centre where the load is applied and this is where the beam is most likely to break if the load is increased sufficiently. The bending moment distribution is simply represented on a graph or bending moment diagram (Figure 1(A)). In the case of a cantilever beam loaded at the free end, the bending moment is greatest at the support end, hence if the load is increased the failure would occur at this point (Figure 1(B)). In practice a beam can be tapered to provide a uniform distribution of stress along its length. But a beam is subject to shear as well as bending. This is the force that is trying to slice the beam through. Shear force is greatest near to the points of support and least in the centre of the span in a simply supported beam. In a cantilever beam, shear force does not vary along the length of the beam (assuming that the weight of the beam is neglected).

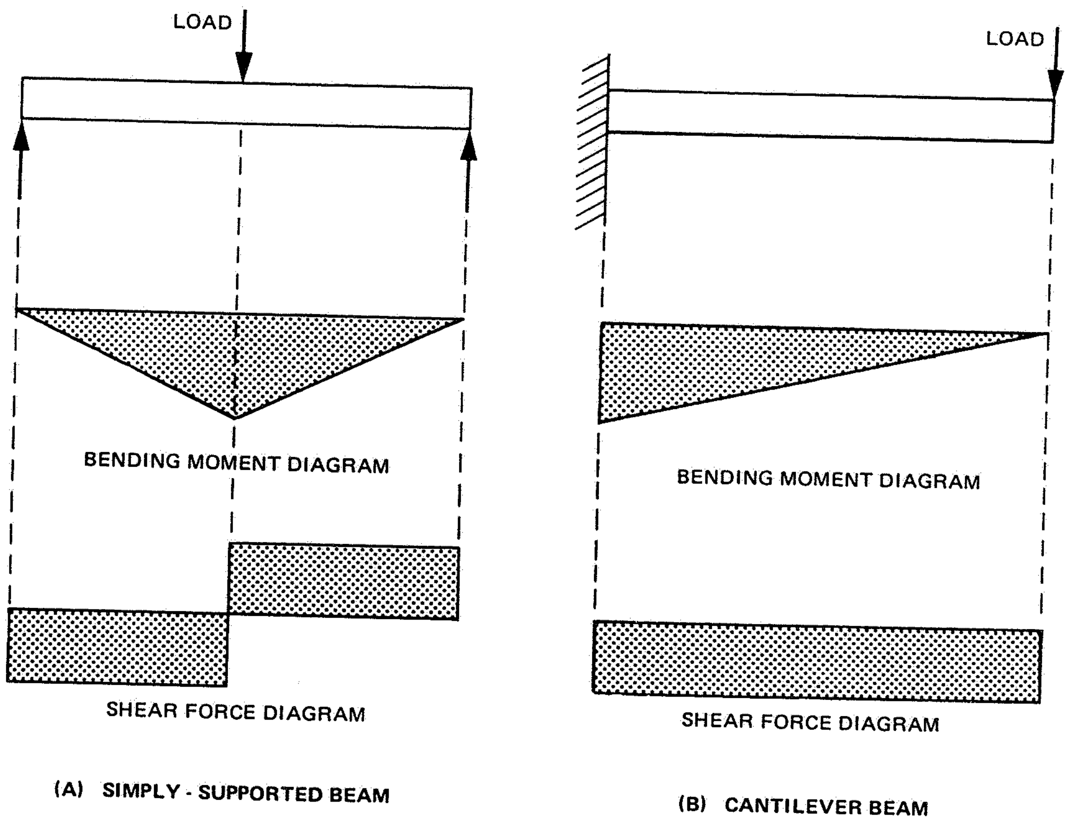


Figure 1 BENDING MOMENT AND SHEAR FORCE DIAGRAMS

2.5 A strut is a member in compression and a tie is a member in tension and it will have been noticed from everyday experience that a strut is usually hollow whereas a tie is often made from a solid rod or even a wire. In practice there are few members that are purely one thing or the other and their design takes into account the different loadings. A wire would make a poor strut because of its liability to bend when an end load is applied. When there is any tendency to bend it has been seen that the greatest stresses will always occur at the outside and at the inside of the bend, with hardly any stress along the neutral plane, or axis. A hollow tube is simply a rod from which the material at the centre has been removed and distributed round the edge. The cross-sectional area of the material is the same and so is its ability to resist tension or compression but its resistance to bending is considerably increased.

2.6 The structure of an aircraft is composed of a mixture of struts, ties and beams and this assembly is known as a framework. The roof truss of a hangar is an example of a framework containing the three structural elements. Figure 2 shows a simple cantilever framework and indicates which members are in tension and compression with the loading shown. In an aircraft structure the vertical members remain in the form of frames but the diagonal members are often replaced by the sheet metal skins. Since a large area of relatively thin sheet metal will not make a good strut it is often necessary for the sheet to be stiffened and reinforced with lighter members, known as stringers, in order to prevent buckling caused by compressive stresses.

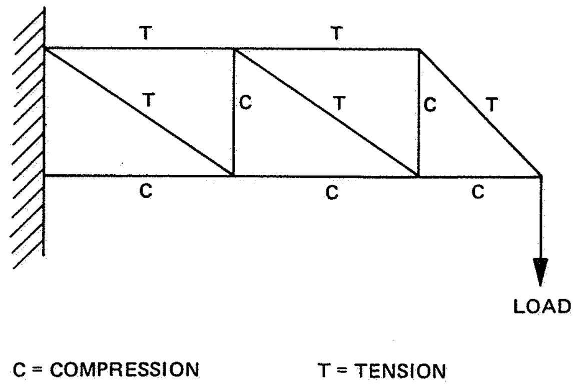


Figure 2 CANTILEVER FRAMEWORK

2.7 In a pressurised aircraft the structure is subjected to stress that derives from the fact that there is a difference in pressure between the inside and outside of the pressurised area of up to 65·5 kN/m^2 (9·5 lbf/in^2). This is known as hoop or circumferential stress (Figure 3). If the pressurised area is considered as a thin-walled cylinder then it can be understood that the internal pressure will tend to expand the cross-sectional area, this expansion creating a tensile load in the circumference of the cylinder. This load and its resulting stress is in addition to the loads deriving from normal ground and flight operations. The internal pressure also acts against the bulkheads at the ends of the pressurised area and creates stress along the length of the cylinder. However, the longitudinal stress is always less than the hoop stress, resulting in a difference in design strength between joints in different directions.

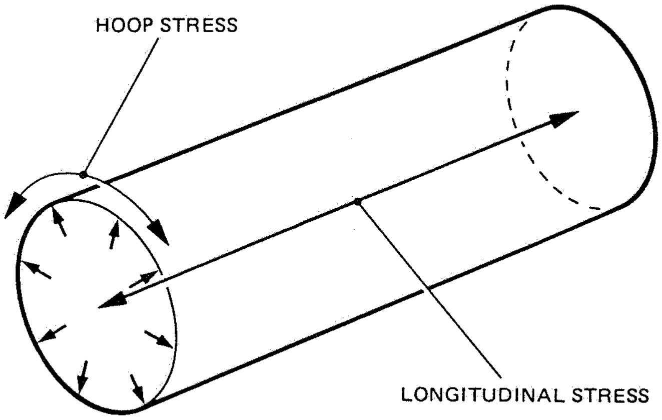


Figure 3 STRESS IN A THIN-WALLED CYLINDER

2.8 When the strength of a structure is being calculated, the main consideration is that of safety. There is no difficulty in making the design strong enough but there is a difficulty in designing a structure that has the necessary strength with a weight that makes the aircraft a viable commercial carrier. For an aircraft it is necessary to have a structure that is as light as possible and yet has sufficient strength to carry all the loads placed upon it. When the strength of a member is being considered it must be remembered that the elastic limit of the material is reached at a lower load than the breaking point, or ultimate strength — the elastic limit being the maximum load a material can carry and still return to its original shape and size when the load is released. So for practical purposes the member must be stronger than the normal working load in the member. In addition, an aircraft structure is subject to vibration, extra loads due to wind gusts and heavy landings and a certain level of general deterioration with age. The relationship between the strength of a member necessary to carry the working load and its ultimate strength is known as the factor of safety. The minimum factor of safety specified in British Civil Airworthiness Requirements is 1·5 with special provisions being made for castings and forgings. On this basis if a part has a working load of 100 pounds it must be designed to carry $(100 \times 1{\cdot}5) = 150$ pounds.

2.9 Large, modern aircraft are designed with a fail-safe structure. This can be described as a structure in which failure of a particular part is compensated for by another part that is able to carry the loads, for a limited period at least. Typically this is a structure which, after any single failure or crack in any one structural member, can safely carry the normal operating loads until at least the next periodic inspection. Examples of this type of construction in practice are the use of multiple spars in wings and tailplanes, instead of the more usual two spar layout, and the use of multiple hinges on control surfaces. It must be remembered that once an initial failure has taken place the redundancy in the structure is no longer present and an inspection programme capable of finding the failure before it progresses too far is essential. This programme is as much part of a fail-safe design as the actual hardware. The inspection cycle is determined on the basis that if a crack of detectable length has been missed at the first inspection, the structure will allow this crack to develop until a second inspection before it becomes critical. The minimum detectable length of a crack is agreed at the time of certification.

2.10 **Flight and Ground Loads.** Most of the parts of an aircraft cannot be simply classified as a strut, a tie or a beam because the loads applied to them can change direction dependent on whether the aircraft is in flight or on the ground. A typical example is the lift strut of a high-wing light aeroplane. It is in fact a strut only when the aircraft is on the ground and it is supporting the weight of the wing. In a heavy landing the compressive loads on the strut are increased considerably. In flight it is no longer a strut but acts as a tie since the lift developed by the wing has reversed the loads. The spar of a helicopter rotor blade will be in tension at the upper surface and in compression at the lower surface with the aircraft on the ground and the rotor stationary. In flight the situation is reversed with the upper surface experiencing the compressive stress. Each part of the aircraft can be treated in the same way for the different conditions of operation and an appreciation gained as to the direction of the loads applied. Such knowledge is useful when inspecting for possible damage. In addition to the loads imposed by lift and weight there are also loads imposed by thrust and drag and, on the ground, manoeuvres such as braking and turning.

2.11 There is another factor to be taken into account when considering the strength of a structure. If the load on a material is repeatedly applied and released, or if it alternates between tension and compression, a phenomenon called fatigue sets in and the material becomes weaker and weaker. Whilst the actual mechanism of fatigue is complex it can be simply demonstrated by repeatedly flexing a piece of metal in alternating directions. Eventually it will fail along the bend line.

3 FUSELAGE STRUCTURES Having outlined the basic mechanics of a structure, consideration will now be given to the way in which a practical airframe embodying these principles is constructed. An ideal airframe would be designed to provide perfect load paths in an efficient aerodynamic shape. However, it is unlikely that the requirements for both of these could be realised at the same time particularly if the aircraft is to carry a commercial load. Since the aircraft is designed as a load carrier the designer starts with the payload (and other operational requirements) and designs an airframe that is a compromise between the ideal and the practical.

3.1 **Fuselage Construction.** The fuselage, whether it be of an aeroplane or helicopter, provides space for the crew and the payload and transmits the weight of these to the lifting surfaces. It also provides the unit through which the reactions of control forces from tail and rotors are felt. In many cases the landing gear is attached to the fuselage and it also absorbs the inertia loading from wings, tail and rotors in the landing phase. Thus, whilst the shape is to some extent dictated by the nature of the payload, there will be well defined load paths through the structure to cater for the loads mentioned.

3.2 The cabin structure illustrated in Figure 4 is typical for a light, pressurised, twin-engined aircraft but it embodies the same principles as are applied to the much larger airliner. The wing panel attaches to the two carry-through spars by means of forgings and special close-tolerance bolts. The front spar is built up from two extruded aluminium alloy channel booms joined together with sheet metal shear webs. The webs are stiffened and reinforced with extruded or rolled angles to prevent buckling under compressive loads. It can be seen that the spar behaves in the same way as the theoretical beam already considered.

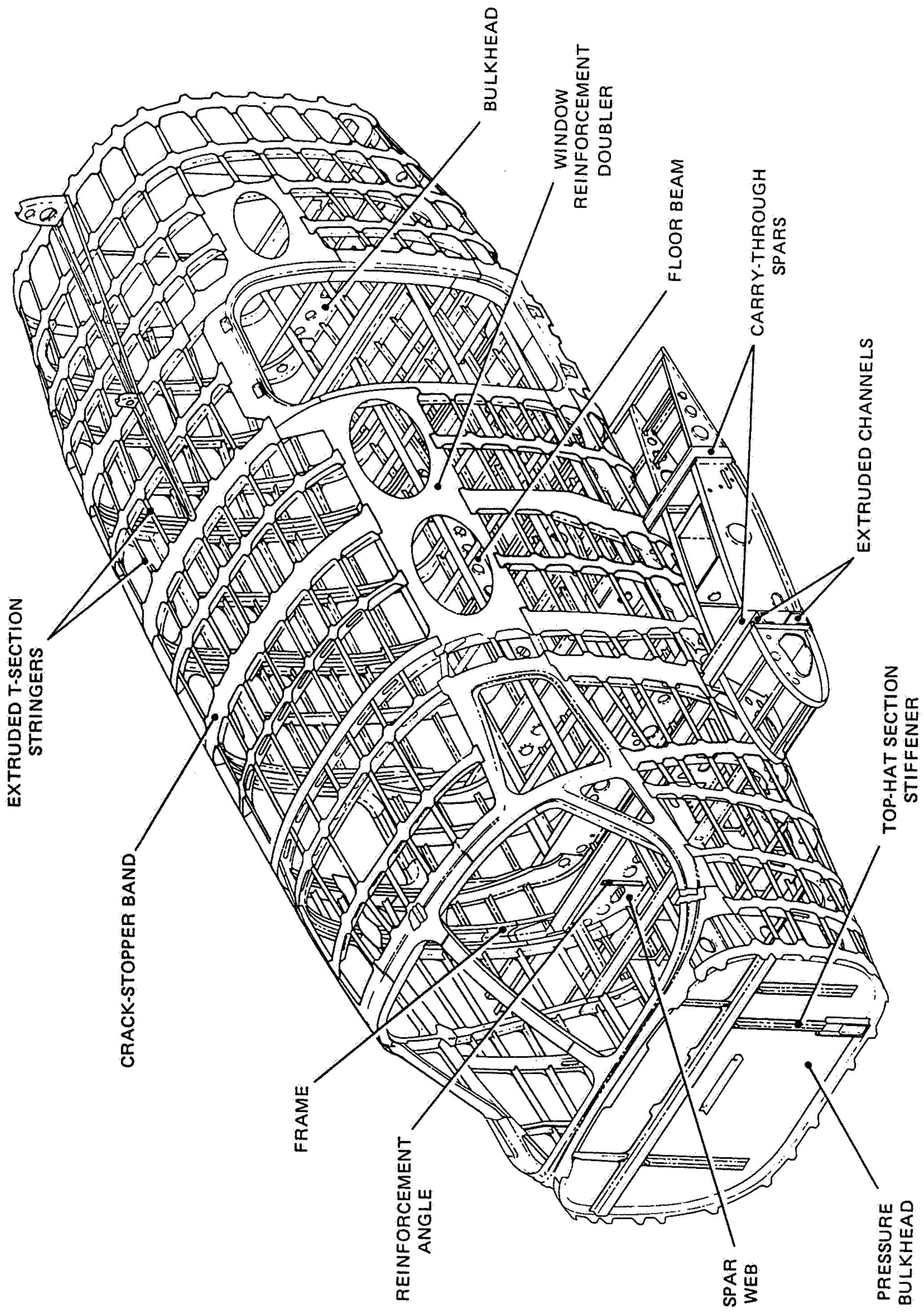


Figure 4 PRESSURISED FUSELAGE STRUCTURE

3.3 Attached to each spar is a heavy gauge frame which not only gives shape to the fuselage but integrates the spar into the rest of the fuselage structure. The frames are the primary members which, with the skin, absorb the stresses produced when the cabin is pressurised (see hoop stress in paragraph 2.7). The lower section of each main frame is joined to a bulkhead which consists of a sheet metal web flanged at the edges. These bulkheads provide the necessary support for the floor panels and hence the payload of the aircraft. The holes through the webs of the bulkheads are flanged or dished in order to stiffen the web. The holes also provide a means of lightening the structure without impairing the strength since it has already been seen that there is relatively little bending stress along the neutral axis of a beam. At each end of the pressurised area there is a pressure bulkhead consisting of a flat sheet filling in the centre area of the end frame. To stiffen the sheet and prevent buckling under the pressurisation loads, top-hat section stiffeners are riveted in place. The frames are joined together longitudinally by stringers which stiffen the skin against buckling. Different stringer cross-sections are used dependent upon the loads involved and the location of the stringer in the structure; typical stringer sections are illustrated in Figure 5. Open-section stringers are normally used in the lowest section of the fuselage, the bilge, in order to facilitate inspection and the drainage of moisture. Both extruded and rolled sections are employed, the former where higher stresses are involved. The frames are also joined together by heavy longitudinal members similar to bulkheads in construction. These are the floor beams and provide the attachments for the seat tracks and the floor panels.

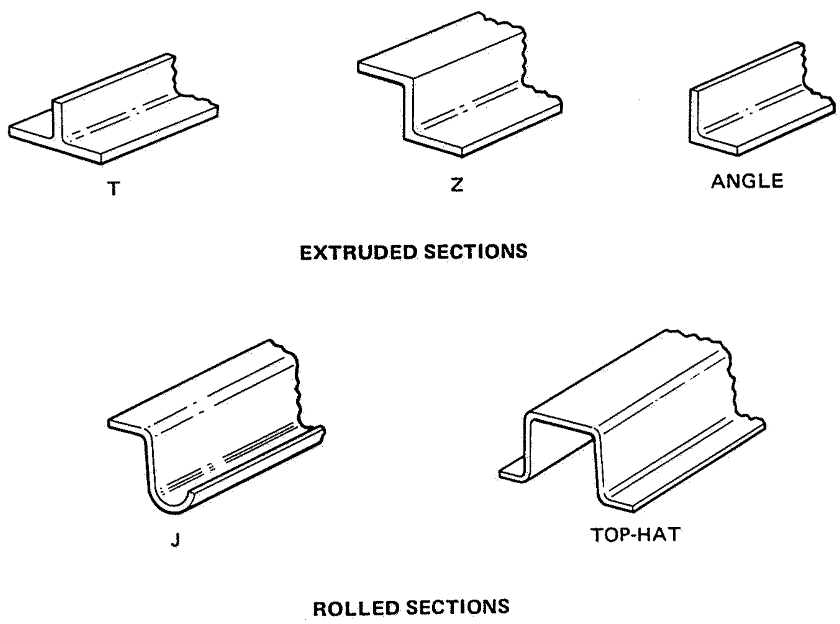


Figure 5 TYPICAL STRINGER SECTIONS

3.4 The structure illustrated in Figure 4 is of a fail-safe design, the integrity of which has been demonstrated during cabin pressure tests by cutting various elements of the structure without total failure of the structure. One fail-safe feature in this airframe example is the provision of crack stopper bands at each frame location between the frame and the skin. A further feature is the provision of reinforcement doublers round each opening in the pressure cabin, such as the cabin door, escape hatch and windows. Another fail-safe design found in some larger aircraft is that the frames and stringers are continuous and are joined to each other by cleats (Figure 6).

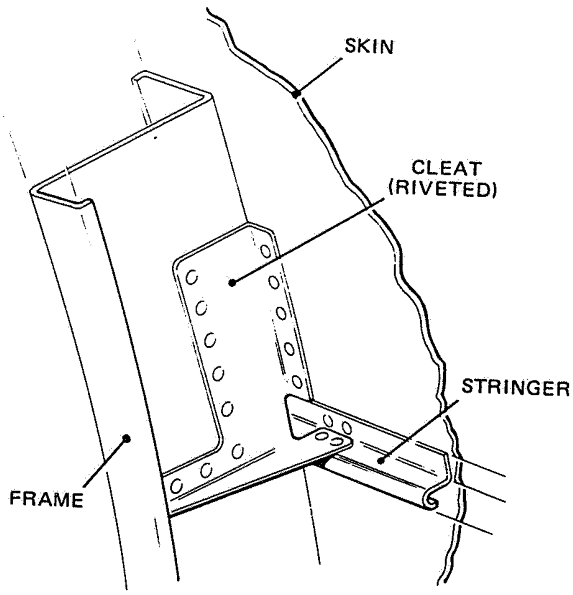


Figure 6 CLEATED CONSTRUCTION

3.5 The helicopter fuselage is built on the same principles as the fuselage for an aeroplane but the loads carried are of a different nature and in different directions. The main structural members in the fuselage illustrated in Figure 7 are the two large I-section floor beams. These beams, tapering at the front and rear, are made up from sheet metal webs with back-to-back extruded angles forming the flanges. The lift forces from the rotor are transmitted through the main gearbox casing and a single lift link into the lift beam. This beam forms the forward face of a vertical box structure which is tied into the floor beams. The side panels of this box structure are removable but are in fact stressed panels forming an essential part of the structure. The tailboom is attached to the rear frame by means of high-strength bolts. The roof structure carries relatively little stress and is made of lighter gauge materials. A helicopter tailboom is illustrated in Figure 8 and is constructed from the same basic components that have been previously described.

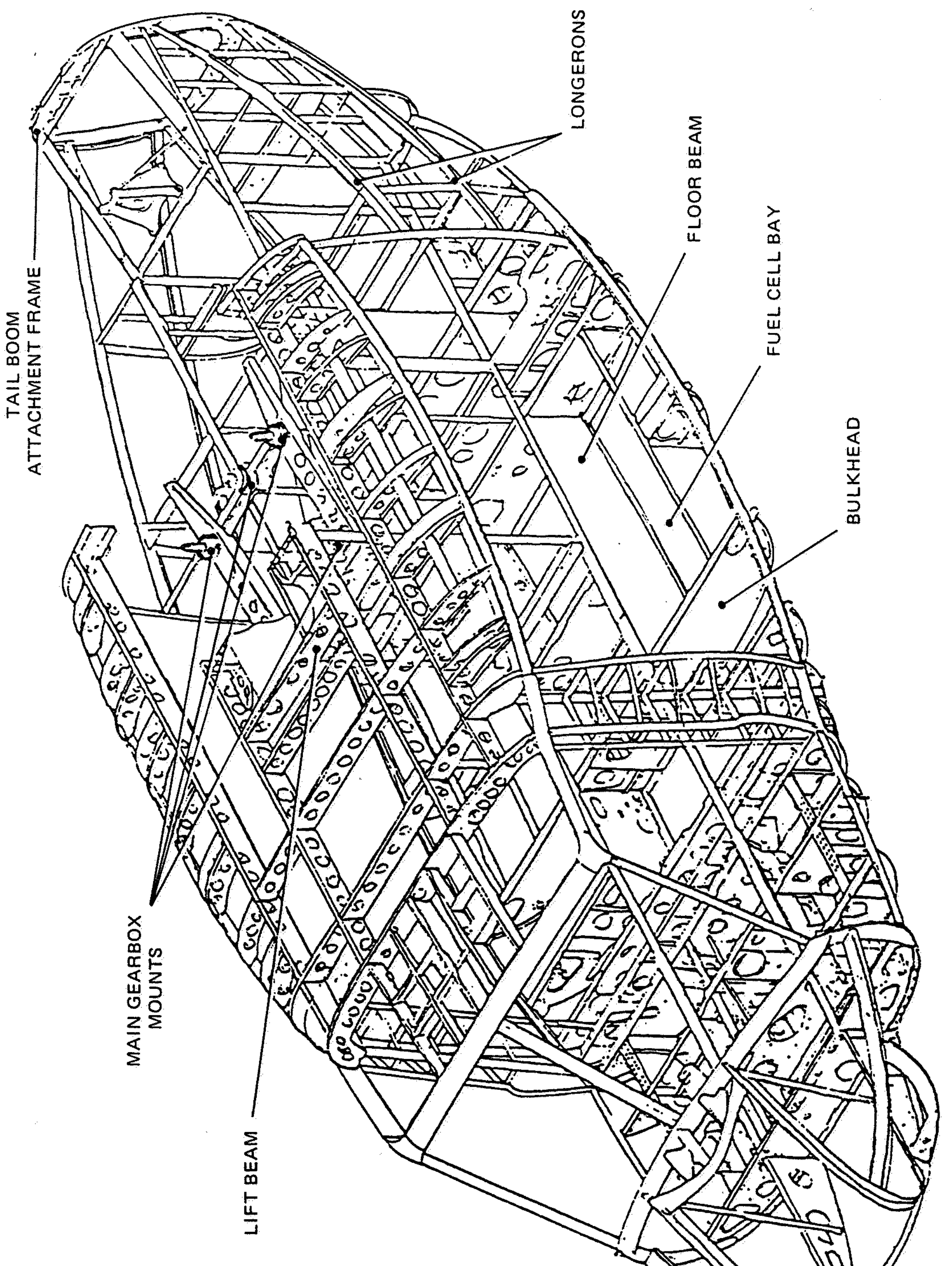


Figure 7 HELICOPTER FUSELAGE STRUCTURE

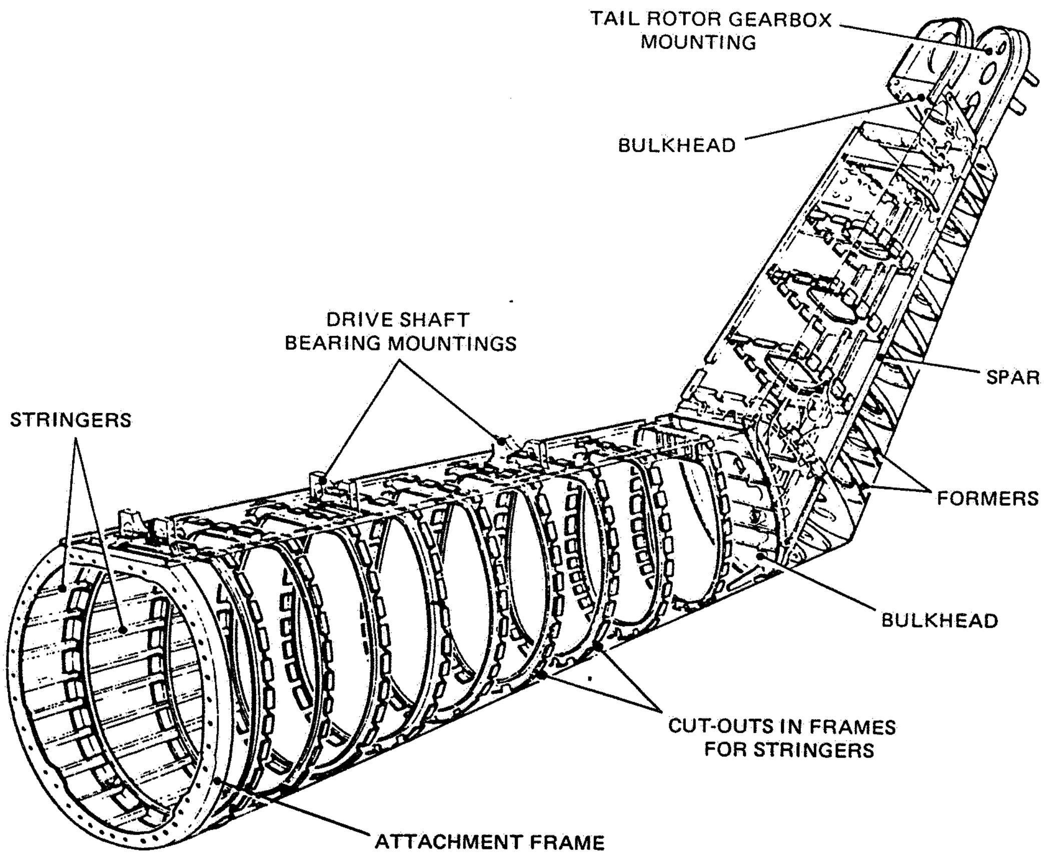


Figure 8 HELICOPTER TAILBOOM STRUCTURE

3.6 Any component of a structure is liable to collect moisture due to spillages, condensation and ingress of atmospheric moisture. This is particularly true of a pressurised cabin, partly due to the pressurisation of the air and partly due to the lower outside air temperatures experienced at the operating altitudes of pressurised aircraft. This being the case it is important that provision is made for adequate drainage. Design for drainage ensures that the open side of horizontal stringers faces downwards and that drain holes are provided at the lowest point of each bay to permit accumulations of moisture to drain to some other compartment and then overboard. Unpressurised aircraft simply use open holes at the lowest points of the structure when in the ground attitude to provide overboard drainage but this is not possible in pressurised areas of the structure. In such areas drain valves are provided that are open when the compartment is unpressurised and closed when pressurised. In their simplest form a rubber diaphram provides both the seal and the means of operation (Figure 9).

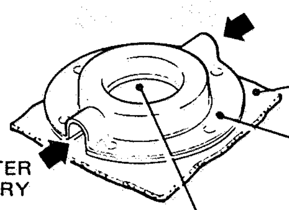


Figure 9 DRAIN VALVE

3.7 **Pressurised Cabin Sealing.** Where an aircraft design embodies a pressurised cabin it is necessary for it to be completely sealed to prevent unintentional escape of the pressurising air. All permanent riveted and bolted joints are sealed on assembly with appropriate sealants on the faying surfaces, and many other parts are sealed with a fillet or bead of sealant along their edges. Fasteners penetrating the pressurised cabin are assembled wet (i.e. dipped in sealant before assembly) and then over-coated on the inside after fastening is complete. Electrical cables passing through a pressure bulkhead are either sealed by specially designed cable connectors or they pass through a nylon collar which is filled with sealant under pressure.

3.8 Cabin doors and emergency exits are normally sealed by inflatable rubber seals, the simplest deriving the inflation air from the cabin through holes in the hollow seal (Figure 10). In a more sophisticated arrangement the seal is pressurised by an independent air supply from the engine air bleeds via a pressure regulator.

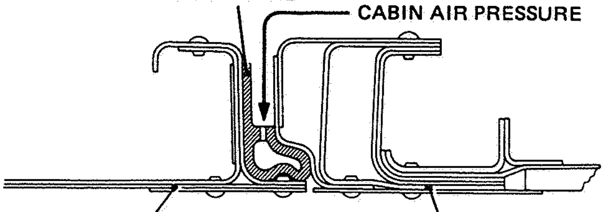


Figure 10 CABIN DOOR SEAL INSTALLATION

3.9 Flying control cables exit the pressurised area through rubber labyrinth seals that are installed in the manner shown in Figure 11. To reduce cable and seal wear, the assembly is packed with grease and it is very important that only the correct grease is used. Some greases contain synthetic products that are not compatible with all seal materials. Where rods are used for operating controls or landing gear, the seals take the form of a convoluted boot attached to the bulkhead and sealed to the rod with a hose clip.

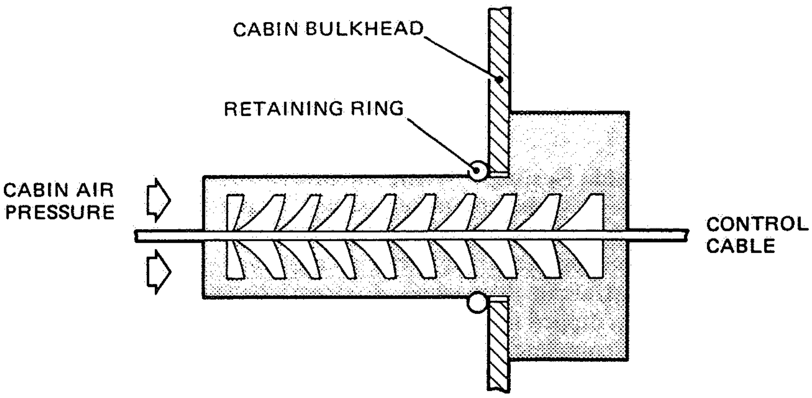


Figure 11 LABYRINTH CABLE SEAL

3.10 It is important to provide adequate access into the various parts of a structure both for inspection purposes and for the maintenance of systems and components contained inside the structure. Panels which are designed for frequent removal are usually fitted with quick-release fasteners and are simple unstressed panels. They are provided with a soft rubber seal to prevent the ingress of moisture. However, many panels used in the aircraft are removed at infrequent intervals and are designed to carry part of the structural load. Such panels will be retained by bolts or high-strength machine screws. Since such panels are structural parts they should not be removed without first ascertaining if the surrounding structure must be supported or if there are limitations on moving the aircraft with them removed. Some may require special sealing techniques on refitting.

3.11 Cabin and freight bay floors may take a variety of forms ranging from a simple reinforced light alloy sheet to fully composite panels. The majority of composite flooring panels are made from a polyimide honeycomb core dipped in phenolic resin and bonded to two glassfibre skins and are able to resist all forms of impact loading and corrosive fluids.

3.12 In wide-bodied aircraft it has been found necessary to provide a floor venting system to equalise pressures rapidly above and below the floor in the event of the loss of a cabin or a cargo compartment door. Without such a venting system major structural distortion can occur leading to disruption of controls and essential services.

4 AEROFOIL STRUCTURES In both fixed and rotary wing aircraft the purpose of the aerofoils is to provide the lift that makes flight possible. This is also true for auxiliary aerofoils such as tailplanes and synchronised elevators although the lift developed is used for control and stability purposes rather than supporting the weight of the aircraft. It is thus clear that the aerodynamic shape is of paramount importance. But the typical aerofoil is also a cantilever beam and therefore must be designed to support the loads imposed on it taking due consideration of the distribution illustrated in Figure 1(B). In addition to the basic loading produced by the lift developed, there is the dynamic loading produced by gusts, manoeuvres and ground loads such as landing and taxying. The aeroplane wing also provides a convenient place to attach engines and landing gear and an area in which to store fuel. Each of these items has its own effect on the loading of the beam and must be taken into account in the design, the result being a compromise between aerodynamic requirement and structural possibility.

4.1 **Aeroplane Wing Construction.** The cantilever wing of a typical light aircraft illustrated in Figure 12 reveals many of the points mentioned previously. The shear stress being approximately constant along the span, the spars are of constant depth but because the bending moment varies along the span the structure is heavier and stronger at the inboard end. It will be noticed that the ribs are closer together inboard of the engine mounting and become progressively wider apart towards the wing tip. The shaded integral fuel tank area is completely sealed to provide the storage capacity. The use of the wing as a fuel tank has advantages in that it will provide relief of the bending moments to some degree and this is the reason for some aircraft having their main tankage in the wing tips.

4.2 The spars are built up from sheet metal webs and a T-section cap strip. The web is stiffened with vertical angle sections to provide additional resistance to buckling in the space between the ribs. At the inboard end the web is increased in thickness with tapered doublers where the stresses are highest. The basic shape of the wing is controlled by the ribs and in the example shown these are made up of a number of parts riveted to the spars and other members. As in a fuselage, stringers are provided along the span of the structure and are riveted or bonded to the skin in order to stiffen it. The ribs are cut out as necessary in order to provide clearance for the stringers. The skin is riveted to the spars, ribs and stringers and, in addition to closing the structure, it braces the structure to absorb the drag loads imposed on the assembly. The thickness of the wing skin is increased towards the root end to cater for the increased loads. At the rear of the wing additional members provide the attachment points for the flap and aileron hinges. Other strong points provide attachments for the engine and landing gear and for attachment to the fuselage.

4.3 **Auxiliary Aerofoils.** The construction of tailplanes and fins is similar to that of the wing but is of lighter construction since the loads involved are smaller.

4.4 **Helicopter Rotor Blades.** The helicopter main rotor blade, as a lifting aerofoil, has much in common with the aeroplane wing and is subject to a similar pattern of bending and shear forces. However, because the whole assembly is rotating, the structure is also subject to centrifugal force in an outward direction, the value of the force depending upon the radius of rotation at which it is considered (assuming a constant speed of rotation). In a large helicopter this force will be many tons and is constantly superimposed upon the bending and shear forces and the fluctuations in them produced by manoeuvres and wind variations.

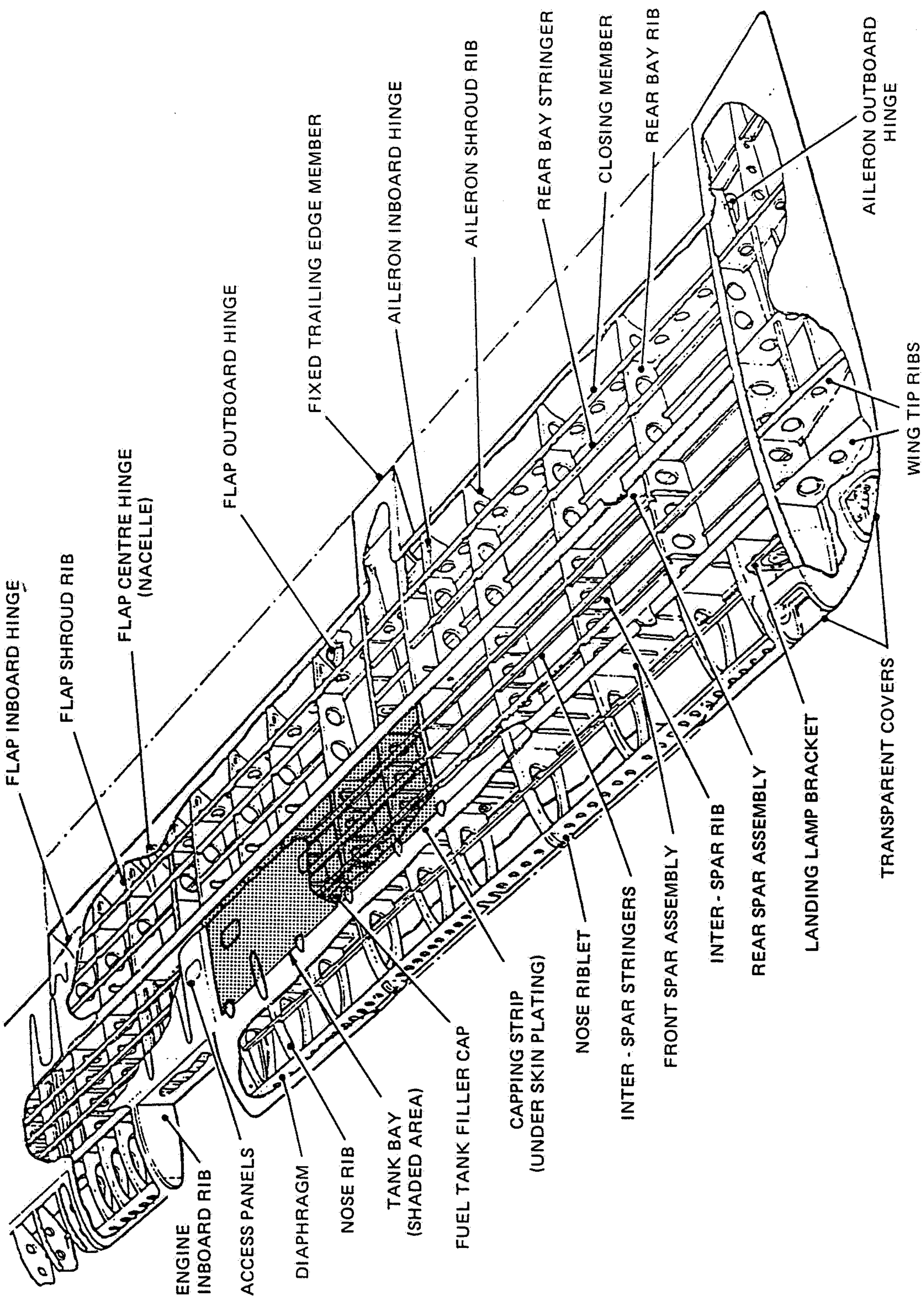


Figure 12 WING STRUCTURE

4.5 **Rotor Blade Construction.** Rotor blades are constructed on the base of a spar which may be of either composite or metal construction. Typically a composite spar is made up of glassfibre rovings running continuously from the tip to the root of the blade, round the root end attachment bush, or bushes, and out to the tip again (Figure 13). These straps provide the main strength of the spar to accept the centrifugal loading. Crossplied laminations provide a core for the spar, and the straps and the core are covered by a further crossplied lamination taking the torsion loads in the blade. The whole assembly is laid up with a suitable resin and cured under heat and pressure in the desired shape. Bonded to the aft side of the spar is a fairing to complete the aerodynamic shape of the blade. This fairing consists of a honeycomb core covered with a skin of crossplied glassfibre laminate and reinforced at the trailing edge with uni-directional glassfibre or carbon fibre filaments or strips. The leading edge is protected by a titanium nose cap bonded to the spar and the outer portion of this is protected by a nickel erosion strip.

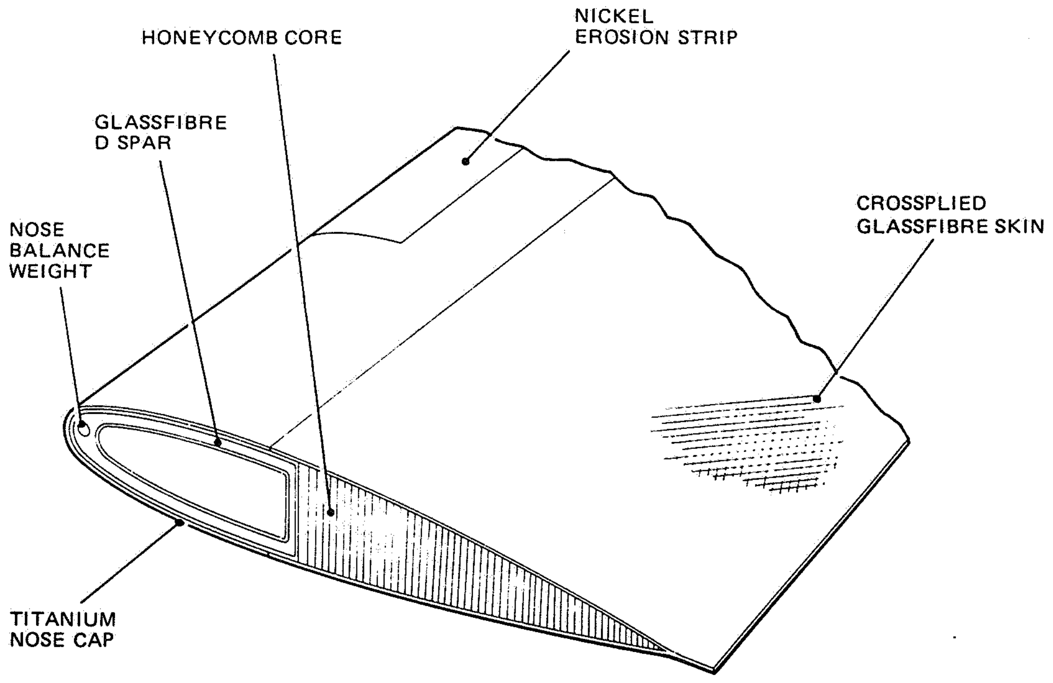
4.6 A typical metal rotor blade is constructed upon a tubular metal spar formed to the approximate section of the blade. The metal skins are supported by an aluminium honeycomb and the whole assembly is bonded together. Some metal blades use individual 'pockets' made from sheet metal and attached to the rear side of the spar. Some 20 or more of these form the aerodynamic section of the blade aft of the spar. Tail rotor blades follow the constructional techniques of the larger main rotor blades but, since the forces involved are smaller, a lighter structure can be used.

5 CONTROL SURFACE STRUCTURES The term control surface is taken to include the primary flying controls of ailerons, elevators and rudder; the secondary flying controls of trim tabs, servotabs and balance tabs; and lift control devices such as flaps, slats and spoilers. The structural requirements of each of these surfaces are different due to the fact that they are operated under different conditions in different parts of the flight envelope.

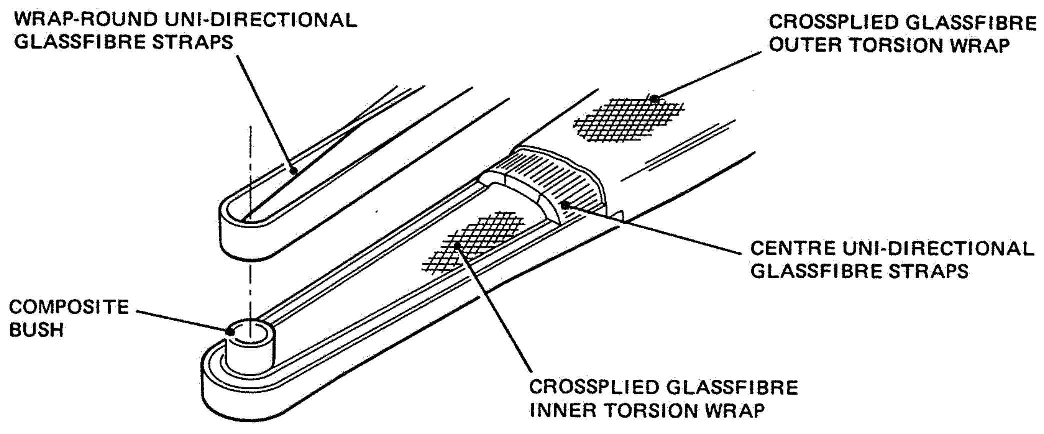
5.1 **Primary Flight Controls.** Whilst the aerofoil section of each control differs, the structure is essentially similar, being relatively light when compared with the main surface to which they are attached.

5.2 The example of an aileron shown in Figure 14 is typical of the design used on smaller twin-engined aircraft. The main structural element of the aileron is a torsion box consisting of the main and rear spars and the upper and lower skins. Inter spar ribs brace the structure. A second torsion box is formed by the leading edge skin and the main spar and this is reinforced with nose ribs, particularly at the cut-outs for the hinge points. The trailing edge skin is fluted in order to stiffen it and prevent buckling, thus obviating the need for stringers. The same principles of construction apply to the ailerons of larger aircraft except that the structural details are commensurate with the larger size and operating loads involved. Elevators and rudders are constructed along similar lines.

5.3 **Control Surface Balance.** It will be noticed that an external mass balance weight is fitted to the aileron illustrated in Figure 14. The purpose of the weight is to statically balance the control surface in order to prevent flutter. Flutter is a rapid oscillation of the control surface about its hinge that is excited by changes in the airflow under certain flight conditions. Primary control surfaces are always balanced but trim tabs are rarely balanced, depending upon their low mass to avoid the problem. It is also very important that backlash in the tab operating system should be kept to a minimum in order to reduce the likelihood of flutter. In the absence of any data from the manufacturer, the free play at the trailing edge of the trim tab should not exceed 2·5% of the maximum chord of the tab. Should it be necessary to repair or re-finish a control surface at any time, it is essential that the balance is checked against the manufacturer's limits and adjusted if necessary.



(A) BLADE CROSS-SECTION



(B) BLADE ROOT CONSTRUCTION

Figure 13 COMPOSITE ROTOR BLADE CONSTRUCTION

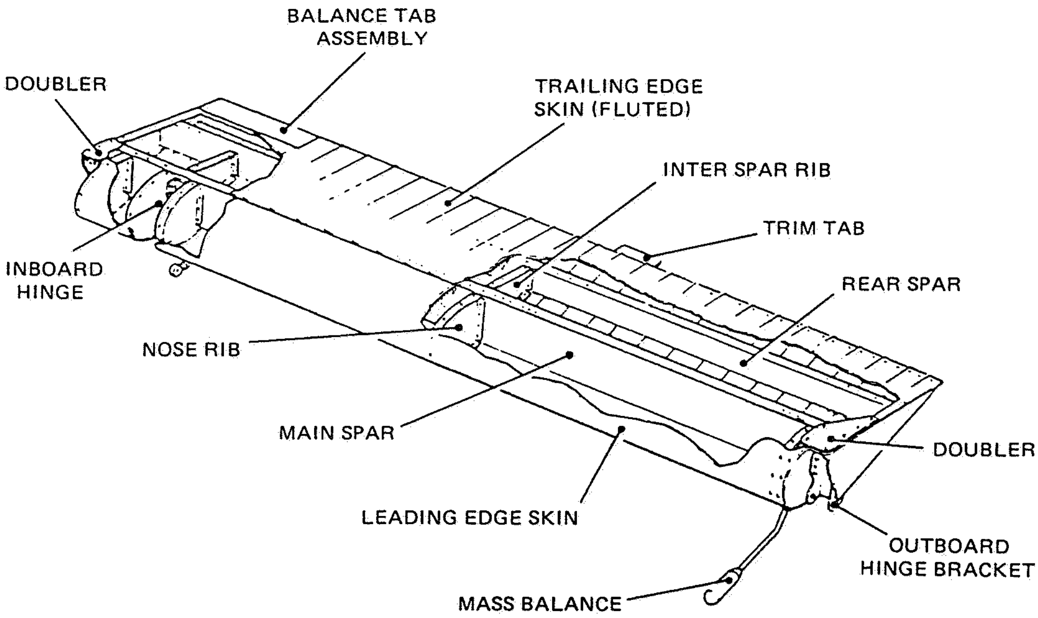


Figure 14 AILERON CONSTRUCTION

6 AIRFRAME LOCATIONS Leaflet **AL/7-12** gives guidance as to the placing of an airframe in the rigging position, that is longitudinally and laterally level. This is the basic position used when making dimensional checks on an airframe. Whilst this enables basic angular and linear measurements to be made it does not necessarily enable a specific point on the airframe to be defined. A system of planes is used that enables a point to be defined in relation to the three axes of the aircraft. A fixed wing aircraft is taken as the example in Figure 15.

6.1 Points along the longitudinal axis are termed Fuselage Stations and these are measured from a datum plane transverse to the longitudinal axis. The datum is fuselage station zero, more usually expressed as FS.0. The figures shown on the diagram indicate the number of inches of a point from the datum but any other unit may be used. Conventionally, stations forward of the datum are negative and stations aft of the datum are positive. In many aircraft the datum is a plane in space forward of the nose of the aircraft in order to make all the fuselage stations positive thus simplifying weight and balance calculations.

6.2 Horizontal planes through the aircraft transverse to the normal (vertical) axis are termed water lines. Lines above the datum are positive and lines below the datum are negative. Vertical planes transverse to the lateral axis are termed buttock (butt) lines or wing stations, the datum being the centre line of the fuselage, that is the longitudinal axis. To indicate whether the station is to the left or right of the datum the suffix letters L or R are added to the number as appropriate.

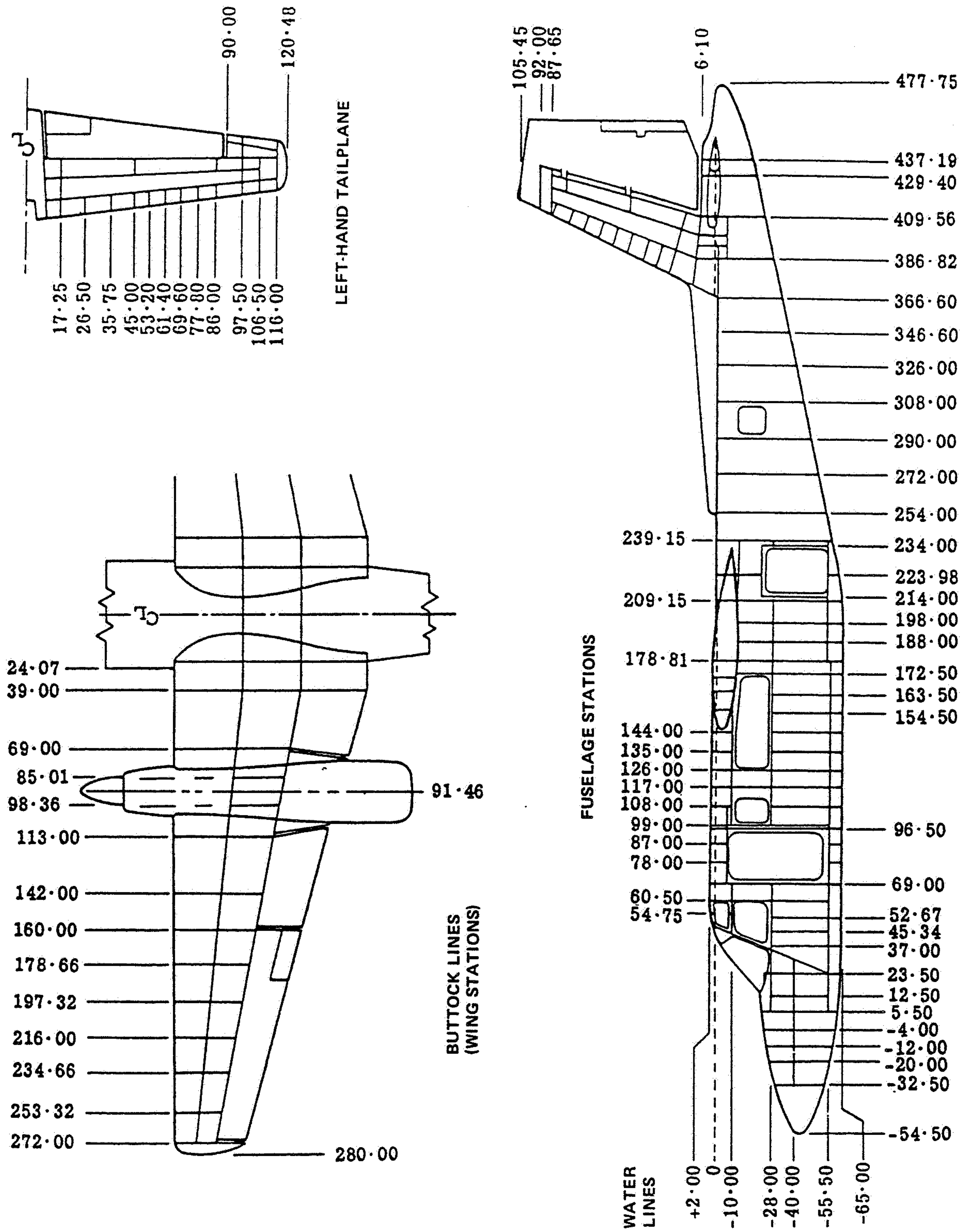


Figure 15 STATION DIAGRAM

7 MACHINED COMPONENTS The structural details described previously have comprised components manufactured from sheet metal and standard extrusions. The individual items have been commonly assembled by riveting. In recent years there has been a growing trend with large aircraft to employ structural components that are machined from a solid billet, examples being ribs, spars and skins with integral stringers. The adoption of this type of construction reduces the number of parts and hence the number of joints in the structure. Since each joint is a discontinuity in the load path and a possible stress raiser the abolition of as many joints as possible should result in a more reliable structure. It also makes the task of inspection easier although repair becomes more difficult. Figure 16 illustrates typical structure using machined detail parts.

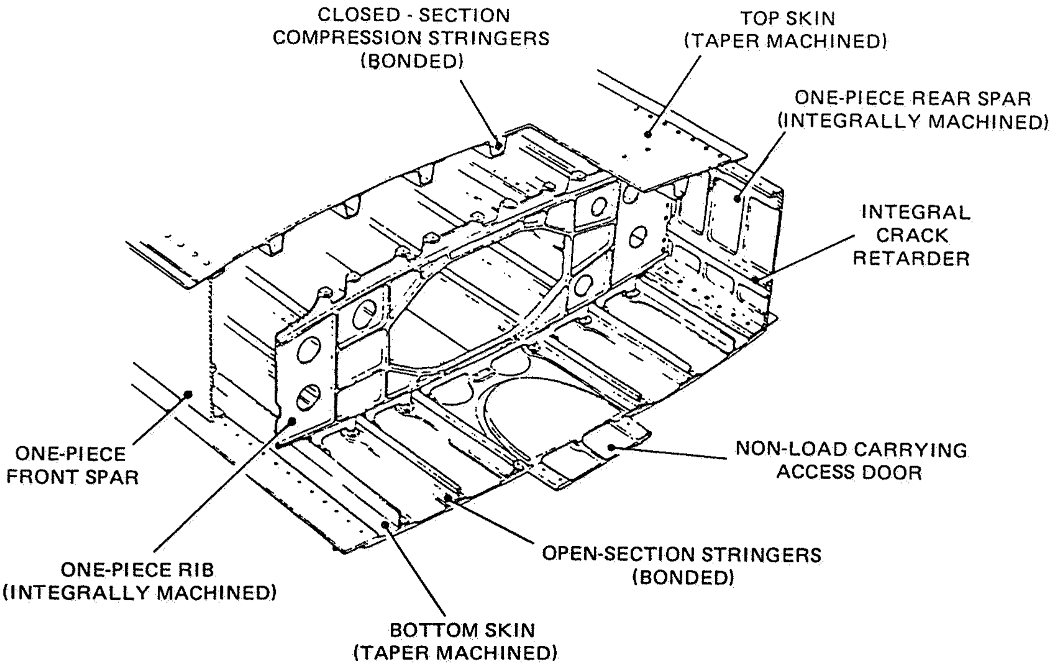


Figure 16
MACHINED STRUCTURAL COMPONENTS OF MAIN WING BOX STRUCTURE

AL/7–4

Issue 3

June, 1984

AIRCRAFT

STRUCTURES

TRANSPARENT ACRYLIC PANELS

1 INTRODUCTION This Leaflet gives guidance on the fitting and maintenance of transparent acrylic panels, but does not include detailed information on specialised workshop processes, such as the moulding of panels from the plasticised state.

1.1 The types of panels used vary considerably with different aircraft, therefore this Leaflet should be read in conjunction with the relevant aircraft Maintenance Manual and the Approved Repair Manual for the aircraft concerned.

1.2 Information on windscreen assemblies is given in Leaflet **AL/7-10**, and on the fabrication of acrylic panels and shapings in Specification DTD 925.

2 MATERIAL The material used for the manufacture of transparent acrylic panels is unplasticised polymethyl methacrylate sheet, which, like all acrylic materials, is little affected by prolonged exposure to atmospheric conditions. At normal temperatures acrylic sheet is rigid but rigidity decreases with increase of temperature. This change starts between temperatures of 80°C and 120°C, and at temperatures of 120°C and above the material is soft and rubber-like. In this state the material can be shaped under low pressure and, if cooled with the shaping pressure maintained, a rigid shape which is stable over a wide range of temperatures can be obtained. However, the shape starts to 'de-mould' at raised temperatures, and at 150°C returns rapidly to its original cast shape. The material is normally supplied either in the 'stretched' condition for applications where prolonged and/or high frequency of cyclic loading will be applied, or 'as-cast' for low fatigue applications.

2.1 Acrylic sheet can be machined, heat-shaped and cemented easily, has clarity and light stability, has a high strength-to-weight ratio and has good dimensional stability, although the coefficient of linear expansion is about eight times that of steel, i.e. approximately 80 to 100 x 10^{-6} per °C.

2.2 The material is not highly flammable, its burning characteristics being comparable to medium density wood. Although tough, it is soft, its resistance to scratching being comparable to aluminium; in many instances damage caused by scratches can be removed by polishing (see paragraph 7).

2.3 In general, acrylic sheet is resistant to inorganic chemicals and to some organic compounds, such as aliphatic (paraffin or fatty) hydrocarbons, hydrogenated aromatic compounds, fats and oils, but is attacked and weakened by aromatic hydrocarbons (e.g. benzene), esters (generally in the form of solvents, and some de-icing fluids), ketones (e.g. acetone), chlorinated hydrocarbons, etc. Some hydraulic fluids are also very detrimental to acrylic material, which also has low water absorption qualities. (See Airworthiness Notice No. 12 Appendix No. 22.)

2.4 **Acrylic Sheet for Aircraft Glazing.** Acrylic sheet complying with Specification DTD 5592 is available in two grades, one of which provides special freedom from defects for use where the highest optical qualities are required, and the other which can be used for all other forms of aircraft glazing. On some 'sandwich' type windscreens an acrylic sheet is used in conjunction with a toughened glass outer panel, usually with a rubber interspacer ring (see Leaflet **AL/7-10**).

3 MACHINING AND TRIMMING Tools similar to those used for light metal working or, in some instances, woodworking, can be used for machining acrylic sheet. All tools should be kept clean and well sharpened. Tools should be prevented from overheating, since the swarf produced under such conditions may bond itself to the panel. A convenient method of cooling is by the use of compressed air.

NOTE: Care must be taken to avoid excessive overheating of the material, since this may introduce local stresses which, in turn, may cause cracks, especially near the edge of the panel, and may cause crazing in service.

3.1 **Cutting.** Sawing with high-speed band saws or circular saws is the generally accepted method for cutting acrylic material, which should be slowly fed into the machine. Hand sawing with fret saws or hack saws is possible for small pieces, but the process is slow and the saw tends to stick due to overheating, resulting in frequent breakages. Another method of cutting small or awkwardly shaped pieces is to use a small tapered reamer as a cutting tool in an air or electric drill and using gentle side pressure on the reamer. This method is reasonably quick and minimises the tendency to cracking due to local overheating as in hand sawing.

3.1.1 Band saw blades having a tooth pitch of 2·5 mm to 5 mm (10 to 20 teeth per in) and running at a speed of 1500 m (5000 ft) or more per minute are suitable. Circular saws should be hollow-ground or should have a slight 'set' to prevent binding and overheating; the most suitable tooth pitch varies according to the thickness of the material to be cut, but the peripheral speed of the saw should be about 3000 m (10,000 ft) per minute.

3.1.2 Thin sheet of 2·5 mm (0·1 in) or less can be scribed and snapped along the scribed line. Even pressure, continuous support on the under-side and adequate clamping are essential for this process.

3.2 **Drilling.** It is recommended that special multi-stepped drills having small incremental increases in diameter are used. These drills are capable of cutting good smooth holes with no stress cracks around the edges. Standard twist drills can be used for drilling holes provided the cutting angle is reduced by grinding the point sufficiently flat to avoid splitting the sheet when the drill breaks through. Drills with a slow spiral and a wide polished flute are also suitable. A slow cutting-speed should be used and a hand feed is recommended, so that the swarf can be cleared frequently to prevent binding and overheating. Adequate support on the underside of the sheet is essential. Coolant, such as soluble oil or water, will help to produce accurate, strain-free holes; when used, it must be ensured that it reaches the tip of the drill.

3.3 **Routing and Spindling.** Standard high-speed wood-working machines can be used for these operations. High speed is necessary for good results and, as with other machining operations on acrylic materials, sharp tools are essential. Routing and spindling operations are usually done without lubricants. In the case of routing, it is an advantage to remove the swarf and cool the cutter with a compressed air jet.

3.4 **Hand Shaping.** A number of hand woodworking tools may be used, including planes, providing very light cuts are taken. Spokeshaves and chisels for forming curves and wood scrapers for edge cleaning may also be used, as may coarse files, providing very light cuts are taken.

3.5 **General.** It should be ensured that the protective paper is left in position during machining operations, with local removal to provide a margin on either side of the machining lines to prevent swarf collecting under the paper. The material may become electrostatically charged during machining operations and swarf may adhere to the edges; although difficult to remove at once, it can be shaken off after a short while.

3.5.1 After machining, all sharp edges and burrs should be removed by means of a planing machine, sanding machine or by the use of an abrasive cloth or scraper. The edges of the material and the periphery of the holes should be polished and slightly chamfered. It is general practice to stress relieve the material after any form of working by annealing in accordance with DTD 925.

3.5.2 After all mechanical work has been completed, the protective covering should be removed, the material washed and then re-protected (see paragraph 10) if it is not required for use and is to be stored.

4 FITTING PANELS The coefficients of linear expansion of transparent acrylic panels (see paragraph 2.1) and metal mounting frames differ considerably; therefore, in all mountings, provision must be made for the relative movement of the panel to the frame. In this respect, all dimensions of panels and fixing details must be in accordance with approved Maintenance Manuals, drawings and/or any associated installation instructions.

4.1 Acrylic sheet is notch-sensitive and if small cracks or inequalities occur at the end of the panel or at holes then, under quite light stresses, cracks may be propagated through the material. This is particularly important when bolting directly through the panel and in all such cases the holes should be polished and radiused. The holes must be oversize to allow for contraction and expansion and a flexible rubber grommet, manufactured of a material compatible with acrylic sheet, must be inserted between the bolt and the panel. Bolting directly in this manner is used only where very light loads are taken by the panel.

4.2 On pressurised aircraft, or where the loads are at all considerable, the panels are held in a suitably shaped mounting frame, the expansion differences being taken up by rubber mouldings or strips, any bolts, e.g. for securing glazing strips, being positioned in the frame outside the perimeter of the panel. For such an assembly the edge of the panel must be smooth and polished.

4.3 When a panel or moulding is fitted to its mounting frame, the material must not be strained in any way in order to make it fit; if straining appears necessary, the panel should be removed and checked to ensure that it is dimensionally correct. Because of relative movement the specified clearances must be observed.

4.4 After installation the panel should be carefully checked for any damage which might have occurred during installation. A check should also be made to ensure that the edges of the panel extend the correct amount under the glazing strips; inspection holes for this purpose are usually provided. It is also important to ensure that the rubber moulding or beading has not been displaced during assembly, and that the panel is not in direct contact with the metal frame. A gap is usually specified between the edge of any raised portion of the panel and the glazing strip, as shown in Figure 1, sufficient to allow for any differential expansion which may occur (see paragraph 2.1).

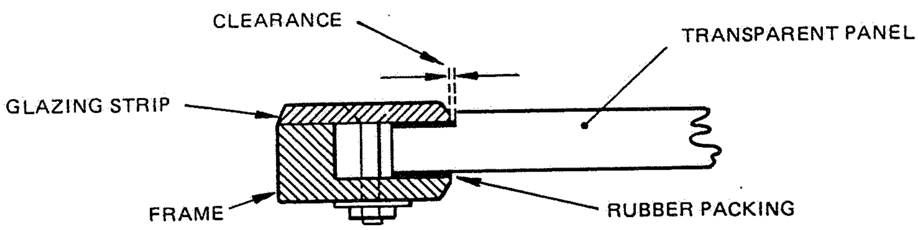


Figure 1 PANEL MOUNTING

4.5 It is important to ensure that any glazing or sealing compound used is that specified in the Maintenance Manual and that it is only used where specified.

5 PROTECTIVE COVERINGS Acrylic sheets are usually supplied with protective paper coverings or a suitable lacquer (see paragraph 10.2) to prevent damage during handling and storage; these protectives should be left in position for as long as possible. Paper coverings on flat sheets can often be used for marking out, but when the material is to be shaped all protectives must be removed and the sheet cleaned prior to heating, otherwise staining of the panel may occur.

5.1 Where paper protective is concerned, a gelatine adhesive is normally used, and the paper can generally be peeled off by easing one corner off the sheet and pulling. Any trace of gelatine adhesive remaining on the surface must be removed in accordance with the instructions contained in the relevant Maintenance Manual. In the absence of any specific instructions the panel should be thoroughly washed with warm water and soap and then gently wiped with a soft cloth or pad of cotton wool. After rinsing in clean water, the panel should be wiped with a soft cloth or chamois leather. Harsh fabrics should never be used and care should be taken to avoid picking up grit on the cleaning cloths.

5.2 If panels are not properly protected by covering they will be detrimentally affected by certain chemicals or, in some cases, their vapours (see paragraph 2.3). These chemicals (or their vapours) will cause a 'crazing' or 'frosting' effect on the panel surfaces which, apart from affecting visibility, will considerably weaken the panel. It should be noted that when an aircraft is being sprayed the vapours may affect other aircraft nearby.

5.3 To mask panels during spraying, etc., soft soap, covered by paper may be used. When adhesive masking tape is used, care should be taken in selecting the tape, as some adhesive tapes contain solvents which would cause crazing.

6 CLEANING Transparent acrylic panels should be maintained in a clean condition and any slight scratch or slight crazing should be removed by cleaning and polishing (see paragraph 7). Panels should never be left in a dirty state, since this will affect their optical qualities.

6.1 Warm water (40°C maximum temperature) and soap is recommended for cleaning, using a soft clean cloth or cotton wool pad; after washing, the panels should be rinsed and dried with a clean chamois leather. Some aircraft manufacturers recommend a proprietary detergent which is also suitable for the surrounding aircraft structures and therefore to some extent simplifies cleaning operations; it is important to ensure that only the detergent specified is used and that the proportion of detergent to water is observed.

6.2 Grit or dirt should, at regular intervals, be removed from recesses, such as where, for example, the panel joins the frame, to prevent its being picked up by the polishing cloth. The accumulation of cleaning and polishing materials in recesses must be avoided.

7 POLISHING Various proprietary polishing kits are available which usually consist of a jar of cleaning compound, a jar of polishing compound, polishing cloths and application cloths. Material to Specifications DTD 770 (polish) and DTD 763 (polishing cloths) should be used unless otherwise specified by the manufacturers.

7.1 Polishing cloths and application cloths must be kept separate. Polishing cloths may be used until soiled but application cloths should be discarded after use.

7.2 When using cloths that are not specifically obtained for cleaning or polishing transparent material, it is essential to ensure that the cloth is of soft texture and clean.

7.3 Scratches can usually be removed by polishing, the depth of the scratch being the controlling factor. The repair manual of the aircraft concerned should be consulted to ascertain the extent, depth and location of any scratches or damage that may be removed, since apart from the amount of material that may be removed, the optical qualities of the panel may be affected.

NOTE: A dry cloth should never be used to remove dust or dirt.

7.4 **Static Charges.** Because of the high surface and volume resistivities of acrylic sheet, a static charge is built up when it is rubbed with a dry cloth. Treating the surface with an anti-static polish approved for use on acrylic will help to prevent this static charge and reduce the resultant accumulation of dust.

7.4.1 A small quantity of the specified type polish (which may be thinned down with water if desired) should be applied to the sheet and spread evenly, using a soft cloth. Finally, the panel should be rubbed with a clean soft cloth until a bright polish is obtained.

7.4.2 This treatment helps to eliminate the static charge and so reduce dust collection for approximately two months under normal dry indoor conditions. Frequent polishing with a dry cloth does not impair the efficiency of the treatment, but washing destroys the anti-static effects and polish must be re-applied.

NOTE: It is important to ensure that all surfaces are treated.

8 INSPECTION When inspecting transparent acrylic panels, the following points should be borne in mind.

8.1 The optical standard and the standard of cleanliness of cockpit panels can have a direct effect on the flying of the aircraft especially in conditions of poor visibility. A hazy panel blurs the details, reduces black to grey and dims outlines. Dirt or slight scratching scatters the light and makes it impossible for the pilot to see against the sun.

8.2 The soft nature of acrylic panels (compared with glass) makes them very susceptible to scratching. Some of the common causes of scratches are as follows:

(a) Protective paper covering, which has slipped.

(b) Cloths of a rough texture used for cleaning or polishing.

(c) Dirty cloths used for cleaning or polishing.

(d) Dirty hands.

(e) Contact with any hard object.

8.3 During maintenance, the following precautions should be taken:

(a) Panels should be cleaned as detailed in the aircraft Maintenance Manual, and only approved polishes and soft, clean polishing cloths should be used.

(b) Panels should not be covered with rough canvas covers. In frosty or changeable weather, covers especially designed for the purpose should be used. In damp weather, prolonged rain or fog, the panels should be left uncovered.

(c) Personnel should not touch panels with bare hands.

(d) Fuel should never come in contact with panels.

(e) Any damage to the panel should be carefully checked in accordance with the requirements of the aircraft Maintenance Manual.

(f) Because of the adverse reaction of acrylic material to various chemical vapours, the cockpit and cabin should be well ventilated during maintenance.

8.4 **Crazing.** Stress crazing is caused if the surface tensile stress of a panel exceeds a critical value. Crazing consists of multiple hairline surface cracks which, being very narrow, relatively deep and sharp at the bottom, act as notches and may cause a serious drop in strength. The depth of the crack may increase with time if the formation of the surface cracks does not relieve the stress, and so could ultimately penetrate through the sheet. Stress crazing is a time-dependent phenomenon and, therefore, it may occur at lower stresses after longer periods of loading.

8.4.1 Stress crazing is not usually dangerous because the loss of strength in the presence of such crazing is small and in any case the window would be changed because of appearance long before it became too weak. However, crazing caused by solvents can be much more serious in that the window can suffer appreciable loss of strength. It is impossible to distinguish between the causes of crazing, hence the necessity of keeping harmful solvents away from panels, both in storage and in service.

8.4.2 Crazing usually occurs in the vicinity of a joint and, when the panel is held up to the light, the faulty area appears sparkling and iridescent. It should noted that hot sun will further aggravate craze-prone areas.

9 REPAIRS Only the repairs detailed in the aircraft repair manual or on approved repair drawings may be made. On load carrying panels, the repairs permitted are usually confined to the removal of scratches by polishing, and the amount of material removed, as well as the location of the repair, will be carefully defined.

9.1 On some aircraft, where the panels are not considered load carrying, some repairs are permissible, but irrespective of the aircraft, all repaired transparent acrylic panels should, whenever possible, be renewed, since it is impossible to restore the full strength of the panel by repair methods.

9.2 **Patches.** Repairs by patching may be grouped in two categories, i.e. inlay patches secured at the edges by adhesive cement, and lap joints secured by adhesive cement (a typical method of holding patches in position while the cement is drying is illustrated in Figure 2). Where the clarity of vision is essential and the use of a patch will impair the transparency, the panel must be renewed.

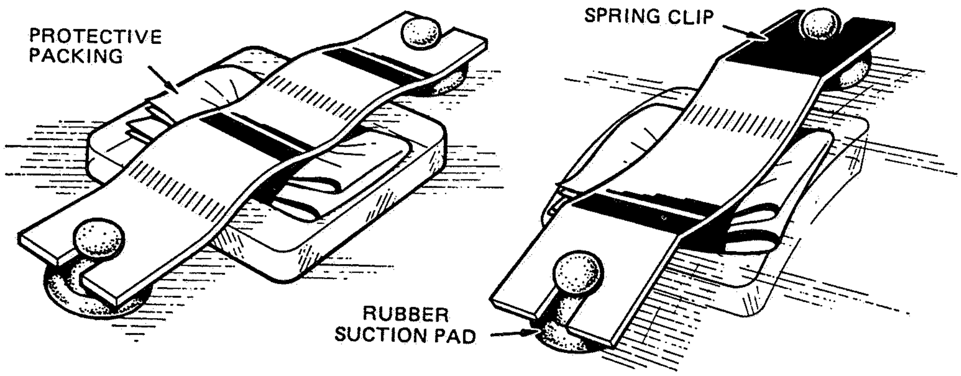


Figure 2 METHOD OF SECURING PATCHES

9.2.1 Inlay patches call for a high degree of skill when fitting; good results can only be obtained if the edges to be joined mate perfectly, otherwise air bubbles will cause weaknesses in the joint and transparency will be impaired.

9.2.2 The surfaces of lap joints should be perfectly clean and the use of clamps should be avoided. Undue pressure during the application of the adhesive may lead to crazing; the adhesive itself also tends to produce a minute crazing effect.

9.2.3 For the purpose of making patches only, acrylic sheet may be remoulded by the application of heat and light pressure. The temperature must be closely controlled (see Specification DTD 925).

NOTE: Over 130°C (i.e. above softening point), materials will permanently shrink 2%, but any subsequent application of temperature will cause the material to expand and then contract back to its reduced length.

9.3 **Cracks.** Cracks should be prevented from spreading by drilling, but, owing to the brittle nature of the material, it should only be drilled when the hole is to be filled with a cemented patch.

9.3.1 Cracks which start at the edge of a panel should be arrested (drilled) and then opened up by inserting a sharp instrument (a razor blade is often suitable) as near to the edge of the panel as possible. The surface of the panel immediately adjoining the crack should then be painted with adhesive cement, using a fine clean brush (preferably sable or camel hair), and the adhesive should be allowed to run into the crack. When the adhesive becomes tacky, the instrument should be withdrawn to allow the faces of the crack to come together; surplus adhesive should then be wiped off and the repair allowed to dry.

9.3.2 The adhesive cements (i.e. DTD 900, AN 4142 and 4143) used for repair work are highly flammable and the fumes are poisonous. Therefore, naked lights must be avoided and good ventilation is essential.

10 STORAGE Acrylic sheets are best stored on edge, with the protective paper left in position; this will help to prevent particles of grit, etc., becoming embedded in the surfaces of the sheets. When this is not possible, the sheets should be stored on solid shelves, and soft packing, such as cotton wool, should be placed between each sheet. The pile of sheets should be kept to a minimum and should never exceed 12 sheets.

10.1 Curved panels should be stored singly with their edges supported by stops to prevent 'spreading'.

10.2 There are several proprietary lacquers available for the protection of acrylic panels and shapings during handling and storage, including those complying with Specifications DTD 900/4051, DTD 900/4294 and DTD 900/4356. Protective paper may also be used, but to prevent deterioration of the adhesive between the protective paper and the sheet, store rooms should be well ventilated, cool and dry. The material should not be placed near steam pipes or radiators, as hot conditions will cause the adhesive to harden and make the subsequent removal of the paper difficult.

10.3 Acrylic sheets or panels in storage should not be exposed to strong sunlight, particularly when light shines through a glass window which might cause a 'lens' formation, as this may result in local overheating and be detrimental. (See also Leaflet **BL/1-7**.)

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STRUCTURES

REPAIR OF LAMINATED AND HONEYCOMB STRUCTURES

1 INTRODUCTION This Leaflet gives guidance on the repair of laminated and honeycomb structures made from or containing metallic or reinforced plastics material, with particular reference to aluminium alloy and glass-fibre. Repairs to similar structures made from other materials may require special procedures, and reference should be made to the relevant manufacturer's manuals.

2 GENERAL Many components in modern aircraft are manufactured from reinforced plastics or honeycomb sandwich structures, including external parts such as fillets, leading edges, wing tips, control surfaces, engine cowlings and radomes, and internal parts such as tanks, heater ducts, cable ducts, floors and furnishings. The materials used in the construction of a particular component depend on many factors, such as aerodynamic shape, strength, stiffness, heat resistance, chemical resistance and dielectric properties required, and the materials used in a repair must be identical to the original materials, or be alternatives having the same properties and approved for such use by the aircraft manufacturer. The repair of reinforced plastics may be more difficult than the original manufacture, and the type and extent of repairs carried out must, therefore, be strictly in accordance with the relevant aircraft manual or be specifically approved by the design authority. Personnel carrying out these repairs must have the skill and knowledge necessary for working with these materials, and should preferably have undertaken suitable training.

2.1 The following topics are discussed in this Leaflet:

Para.	**Topic**	**Para.**	**Topic**
3	Materials	7	Repairs to glass-fibre laminates
4	Preparation and curing of resins	8	Repairs to glass-fibre honeycomb
5	Assessment of damage to glass-fibre components	9	Repairs to aluminium honeycomb
6	General repair considerations	10	Radomes and dielectric panels

3 MATERIALS Laminated or reinforced plastics material is generally made from resin-bonded glass-fibre cloth or uni-directional glass fibres, but nylon cloth or carbon fibres may be used in some components. Sandwich material may have a solid core of end-grain balsa wood or a honeycomb core of glass-fibre, nylon paper or aluminium foil, and is usually faced with aluminium or laminated glass-fibre, which is bonded to the core with a resin adhesive. The core material on some radomes, however, may be of expanded polyvinyl chloride or similar low-density product.

3.1 **Glass-fibre Cloth.** This is the reinforcing material in the laminate, and it is manufactured in various thicknesses and types of weave, usually in accordance with British Standard (BS) 3396 or U.S. Military Standard MIL-C-9084. Twisted glass-fibre strands may also be used for local stiffening, and chopped glass-fibres may be used for moulding or repair work. Glass-fibre cloth is also supplied pre-impregnated with resin, to facilitate manufacture and repair.

3.2 **Resin.** Polyester or epoxy resin is used both for bonding laminated glass-fibre parts and as an adhesive for glass-fibre-to-metal and metal-to-metal joints. These resins are formulated to provide specific properties such as heat-resistance and flame-proofing, although in some cases an additive is used to impart these properties, and pigments may also be used. The type of resin to use is, therefore, most important, since a particular type will have been chosen at the design stage to provide the necessary properties in a particular component and may not be suitable for carrying out repairs in different locations. Resin is usually in liquid form, but for metal-to-metal joints is also supplied in the form of a dry film adhesive with a strippable protective sheet on each side.

3.3 **Additives.** Resins will not harden on their own, and must usually be mixed with one or more additives, which provide a chemical cure. Polyester resins generally require the addition of a catalyst and an accelerator, while epoxy resins generally only require the addition of a hardener or activator. Either type of resin may be cold cured at room temperature (not below 20°C) or heat cured (by the use of infra-red lamps or electric heaters), but the temperature of the resin should not be allowed to exceed the maximum specified for the material. Cold curing of a resin may be accelerated by adding heat after it has gelled, or by varying the quantities of the additives within specified limits.

3.3.1 In addition to the chemicals added for curing purposes, mica powder or other proprietary material may be used to add flame retarding properties, while fillers such as plastics micro-balloons or chopped glass-fibre may be added for filling gaps or voids in the structure.

3.4 **Core Materials.** Many core materials are made in a honeycomb pattern from glass-fibre cloth, nylon paper or aluminium foil of various thicknesses, and this is bonded to the inner and outer skins. The strength of the honeycomb structure is chosen during design, and when permanent repairs are carried out an identical core material or an approved alternative must be used. The direction of the honeycomb strips may also be important, and new core materials should be assembled in the same direction as the original core. Radomes and dielectric panels may have glass-fibre honeycomb, expanded nitrile ebonite or expanded PVC cores, to provide structural strength and rigidity, and suitable dielectric properties. Replacement of the correct core and skin material, and maintenance of the original cross-section and contour is, therefore, especially important when carrying out repairs to these components.

4 PREPARATION AND CURING OF RESINS Extreme care is necessary when preparing a resin mixture for use, firstly because the chemicals could damage the eyes or cause dermatitis, and also because an explosion could result from mixing an accelerator with a free catalyst. Safety goggles and rubber gloves should be worn when handling these materials, adequate ventilation should be provided, and the manufacturer's instructions regarding the mixing of the various ingredients should be carefully followed. If the chemicals do come into contact with the skin, they should be washed off immediately with soap and warm water. If the eyes are affected they should be irrigated with water, and medical attention should be sought.

4.1 **Mixing.** The ingredients of the resin mixture are usually stored in a cool place (less than 10°C for maximum storage life), and should be allowed to assume room temperature before use. Powder and solid additives must be free from dirt or grease and thoroughly dry, and all utensils used for measuring and mixing the materials must be scrupulously clean. The resin and additives should be carefully measured into glass or non-absorbent cardboard containers, in the proportions required for the particular application; these proportions are usually specified as percentages, by weight, of the quantity of resin required for the task in hand. The catalyst should be thoroughly mixed with the resin before adding the accelerator, then any additional material, such as filler, chopped glass-fibre or micro-balloons should be added, and stirred until thoroughly mixed.

4.2 **Pot Life.** Once mixed, the resin begins to cure and has a limited life (pot life) before it has gelled to such an extent as to become unworkable. The pot life varies from a minimum of five minutes to several hours, depending on the formulation of the ingredients and the ambient temperature. All operations should be performed within the pot life of the mixed resin for the results to be satisfactory, and, to prevent waste, only the quantity of resin known by experience to be necessary, should be prepared for use.

4.3 **Curing.** Most resins used on aircraft structures will cure at room temperature (normally 20°C or above), but although they may solidify in a few hours, complete curing may take several days. It is often necessary therefore, to accelerate the cure by heating the resin to a specified temperature after it has gelled. Those resins which will not fully cure at room temperature must be heated throughout the curing period. The times and temperatures required to effect a cure on a particular component are specified in the relevant Maintenance or Repair Manual, and these recommendations should always be followed.

4.4 **Film Adhesives.** Film adhesives are generally easier to use than liquids, since the ingredients are already mixed in the correct proportions, and the amount required is simply cut from the sheet so as to overlap the repair area by approximately 3 mm (0·125 in). Care is necessary during handling, however, and the film should not be stretched, creased or folded in use. Once the protective sheets have been removed, the adhesive film should not be touched with the bare hands, since this will impair the adhesive qualities, and the repair should be assembled and cured as soon as possible.

4.5 **Heating.** Heat is usually applied by means of an infra-red lamp, an electric heater, or, in the case of components which have been removed for repair, in an oven of suitable size. An oven is the most satisfactory heating method since the temperature can be accurately controlled, but the other methods are more generally used, and temperature is checked by use of temperature indicating lacquer or pencils (such as 'Tempilaq' and 'Tempilstick'). Marks made by these methods, adjacent to a repair, will melt at a predetermined temperature. Manufacturers may specify a maximum curing temperature, and if this is exceeded damage to the resin or buckling of the repair may result.

5 ASSESSMENT OF DAMAGE TO GLASS-FIBRE COMPONENTS Damage to glass-fibre components can result from a number of causes, such as rain or hail erosion, lightning strikes or static discharges, and bird strikes or other impacts. Radomes are protected from erosion by either fitting neoprene overshoes over the nose area and cementing them in position, or by applying a coating of neoprene or polyurethane. Other glass-fibre parts are given a 'gel' coat of resin, and are painted in accordance with the aircraft paint scheme.

5.1 Physical damage may be hard to detect, since the surface will often spring back to its original shape after impact, and may only be visible as cracks, crazing, stains, or scuffs on the paintwork or overshoe. Any such marks must be investigated, to ascertain whether damage to the glass-fibre has actually occurred, and the structure should be examined for secondary damage such as may occur at attachments and fittings, and where the shock may have been transmitted to adjacent parts. Damage may also result from chafing against internal or mating structure, pipes, cables, etc., and if this occurs, consideration should be given to trimming, clamping or re-routeing these parts to prevent a recurrence of the damage.

5.2 Any damage to the surface of a glass-fibre laminate or honeycomb will allow moisture to enter the structure and cause damage to the bond between the glass-fibre and the resin, and, once moisture has entered, the repeated cycle of freezing and thawing may eventually destroy the bond between the glass-fibre laminations and between the honeycomb core and skins, thus extending the damage over a wide area. When it is suspected that moisture has entered the structure through a rupture in the surface, an investigation should be carried out to check the extent of the moisture absorption, and on radomes it is often recommended that a 'moisture meter' should be used. Prior to scanning, the surface of the radome must be dry, and scanning should be carried out on the inner surface, care being taken when probing the surface to avoid scratching or denting the resin. Where the use of a moisture meter is impractical, X-ray methods may be helpful in assessing moisture quantity.

5.2.1 Moisture must be removed before carrying out a repair, and this is usually done by the application of heat, either by placing the component in an oven or by the use of a warm air jet. With honeycomb components it may be recommended that an outlet path should be provided for the moisture by drilling holes into the affected cells before heat is applied.

5.3 Delamination may be caused by moisture absorption or by impact damage, and when either is known to exist the area surrounding the visible damage should be checked to ensure the structural integrity of the laminations. This can be determined by tapping the skin with a small metallic object such as a coin, which should produce a live resonant tone if the bonding is sound, but if delamination has occurred a flat, dead response will be obtained.

5.4 Since glass-fibre structures are often located at the aircraft nose or wing tips, where lightning strikes and static discharges are most likely to occur, lightning diverter strips are often fitted to a radome and bonding strips or cages are often fitted to other glass-fibre components, and these are electrically bonded to the adjacent metallic structure. The electrical bonding of these components should be checked after removal and replacement, and at other times specified in the relevant Maintenance Schedule (see Leaflet **EEL/1-6**). It is also important to check that the strips are securely attached to the glass-fibre component.

5.5 Electrical discharge damage on the outer surface of a radome may be difficult to locate, and an air pressure test may help to pinpoint the position of the damage. The radome should be removed from the aircraft, and the position of the internal damage should be noted. The overshoe should be removed from the nose of the radome (when necessary), and the paint should be removed from a small area of the outer surface opposite to the internal damage. A film of uncured resin should then be applied over this area, and an air pressure of 20·7 kN/m^2 (3 lbf/in^2) applied to the inside surface by means of a flexible funnel located over the internal damage. Bubbles in the uncured resin will indicate the position of the external damage.

5.6 The extremities of any damage found in a glass-fibre structure should be marked, and the maximum area and depth of damage should be assessed in order to determine whether a repair is required, and if so, the type of repair which should be carried out. The limits of the various standard repairs which can be carried out are defined in the relevant Maintenance Manual or Repair Manual for the aircraft concerned, and may vary considerably, depending on the type of structure and its location. It must be emphasized that repairs may only be made in accordance with the manufacturer's instructions, and that repairs may be prohibited in certain areas In some instances repairs may not be permitted within a specified distance from the edge of a panel, while in other instances temporary repairs may be permitted, but these must usually be replaced by a permanent repair within a specified time period. It should also be noted that, although extensive repairs to radomes and dielectric panels are permitted on most aircraft, some manufacturers do not recommend repair of these components, because of the possible effect on radar performance.

6 GENERAL REPAIR CONSIDERATIONS When a large repair is being carried out it may be necessary to support the adjacent structure, so as to prevent bow, twist and distortion. The supports should be secured before commencing the repair and left in position until the repair has cured. A repair must be of the correct profile, and, if it is likely to be thicker than the original material, a check may have to be carried out to ensure that there will be no interference between the repair and adjacent moving parts; clearance from, or satisfactory contact with, adjacent or mating parts, as appropriate, should also be checked. Repaired components which move during operation should be checked for correct functioning and freedom from chafing or binding through their complete range of movement, and the balance of control surfaces should be checked and adjusted as necessary.

6.1 **Materials.** Glass-fibre materials and resins should be mixed and applied in a warm, dry atmosphere, and it is obviously preferable that a component should be removed from an aircraft and repaired in a specially-prepared workshop. When this is not possible, the repair area and local surroundings should be kept at a temperature of at least 20°C while effecting the repair and curing the resin.

6.1.1 Materials should normally be stored in a cool, dry place, the catalyst and accelerator being stored separately to prevent inadvertent contact. Resins have a shelf life of up to 12 months, depending on their type, after which time they should be discarded. Before use, careful note should be taken of the life expiry date marked on the container. When required for use, the resin should be removed from storage and kept at room temperature for at least 24 hours before being mixed. Resin which has absorbed moisture and become cloudy should normally be discarded, but, when permitted, it may sometimes be recovered by heating to 120°C; if the resin becomes clear on cooling down it may be used, but if it remains cloudy then it must be rejected. Glass-fibre materials should be stored in their original wrappings, and must be kept dry and free from dust, oil or other contaminants.

6.2 **Cleaning.** It is most important that an area being repaired should be thoroughly clean, and once cleaned it should not be touched with the bare hands. All paint in the vicinity of the damage should be removed by sanding (paint remover could have an adverse effect on a bonding adhesive and should not be used unless specifically recommended), care being taken not to damage any glass-fibre material not included in the repair. The area should then be washed with acetone or methyl ethyl ketone (MEK) to remove any dust or residue, and allowed to dry before commencing the repair.

6.3 **Use of Pressure.** Manufacturers often recommend that pressure should be applied to a repair while it is being cured, since this helps to effect a satisfactory bond and to maintain the correct profile. Pressure may be applied by means of a vacuum bag, or by clamps or weights. A sheet of cellophane or polyvinyl chloride (PVC) should be placed over the repair area before applying pressure, as this will prevent the resin from sticking to the bag, clamp or weight.

6.4 **Moulds.** A repair to damage which includes all plies of a laminated skin will usually require supporting in its desired shape while carrying out the repair and during the curing period, particularly if pressure is being applied to the surface. The support for components which are flat or have a single curvature may often be provided by a wooden block or aluminium alloy plate, or, for a small area, by means of a cellophane sheet taped to the surface, but parts with a complicated curvature may require the use of a specially-made mould.

6.4.1 A mould is generally made from laminated glass-fibre cloth, plaster of Paris, wood or metal. It can be made on the damaged surface, on the surface of an identical component, or, as is often the case with a symmetrical component such as a radome, in an identically shaped area on the same component.

6.4.2 When making a glass-fibre/resin mould, the area from which the shape is being taken must be covered with a release agent such as cellophane or wax, to prevent it sticking to the mould. Before using a plaster of Paris mould, it must be thoroughly dried and the pores must be filled with wax.

6.4.3 Whichever type of mould is to be used, a release agent must be applied to the surface abutting the repair area.

6.5 **Health Hazards.** Mention has already been made (paragraph 4) of the health hazards which may result from mixing and using resin, and it should also be noted that the fine dust produced by sanding glass-fibre can cause skin and respiratory irritation. Suitable protective clothing should be worn when carrying out these operations, and adequate ventilation should be provided.

6.6 **Care of Tools.** Brushes and tools used for mixing and applying resin must be cleaned in acetone before the resin has set. Once resin has hardened it is almost impossible to remove.

7 REPAIRS TO GLASS-FIBRE LAMINATES The repairs outlined in this paragraph may, when authorized in the relevant Repair Manual or approved by the design authority, be applied to single-skin laminated structures such as are used for some fillets, ducts, wing tips and panels, and may also be applied to the glass-fibre skins of sandwich structures. Any dimensions quoted are typical values, but may not be applicable in all cases.

7.1 **Temporary Repairs.** In some instances, where the proper repair materials are not available, a temporary repair to a glass-fibre laminate may be permitted. This may be effected by means of doped-on fabric patches, or by a bolted aluminium alloy plate. The patches or plate should overlap the damage by at least 50 mm (2 in), and in the case of the aluminium plate, large plain washers should be used under the nuts to prevent them pulling through the glass-fibre. Temporary repairs should be replaced by permanent repairs at the earliest opportunity.

7.2 **Scratches, Pits and Dents.** Scratches, pits and dents which do not penetrate the glass cloth are considered to be minor damage, and should be repaired as follows:

(a) Clean the area surrounding the damage (paragraph 6.2).

(b) Mix a small quantity of resin and hardener and fill all scratches, pits and dents to restore the original profile.

(c) Allow the resin to cure, then sand any irregularity in the surface of the repair.

(d) Wash-off any residue and repaint the repair to the original standard.

7.3 **Small Blisters and Delamination.** The extent of any blisters or delamination of edges should be checked in order to determine whether the damage is within the limits for this type of repair (normally less than 25 mm (1 in) diameter or length). Repairs should be carried out as follows:

(a) Blisters should have at least two small holes 0·7937 mm (0·03125 in) diameter drilled through the separated layer close to the edge, and mixed resin should be injected, by means of a hypodermic syringe, into one of the holes, until it completely fills the void. Pressure should then be applied to flatten the blister and remove excess resin, and this pressure should be maintained until the resin has cured. Surplus resin should then be sanded off, and the paint renewed as necessary.

(b) Edge delamination should be thoroughly cleaned (paragraph 6.2) and mixed resin should be forced between the separated plies so as to fill the voids. Pressure should then be applied to the damaged area, care being taken to maintain the original edge profile. When the resin has cured, the excess resin should be sanded off and the paintwork renewed.

7.4 **Small Holes.** Holes which pass completely through the skin and are less than 9·5 mm (0·375 in) diameter may be repaired as indicated in Figure 1.

(a) One glass-fibre ply should be removed from each side of the laminate, in a circular area extending at least 12 mm (0·5 in) from the edge of the damage. This operation must be performed very carefully, so as not to cut into the fibres of the inner plies. A sharp knife or disc cutter should be used to cut round the outside of the cut-out, and a radial cut should be made into the damaged area. A knife can then be used to pry up and peel off the damaged layer, commencing at the inner part of the radial cut.

(b) The area should then be cleaned (paragraph 6.2) and any loose fibres should be removed.

(c) Two pieces of glass-fibre cloth, of identical thickness and weave to the original cloth, should be cut to fit exactly into the places from which the damaged plies were cut.

(d) The resin should be mixed and separated into two parts, one part being mixed with chopped glass-fibres (in the proportions specified in the relevant Repair Manual) to plug the hole, and the other part being used to impregnate the glass-fibre cloth.

(e) The hole through the inner plies should be plugged with the resin/glass-fibre mixture, and the repair plies should be placed on each side of the damaged area, with their weave running in the same direction as the original plies.

(f) The second part of the resin mixture (without the chopped glass fibres) should be brushed into the repair plies, to thoroughly impregnate them and to leave a layer of resin on the surface. It may often be necessary to support the area while carrying out the repair and while the resin is curing (paragraph 6.4).

(g) The resin should be left to cure, and when hard should be sanded to the contour of the surrounding laminate. If any glass fibres become exposed during the sanding, a thin coating of catalysed resin should be brushed over the repair and, when it has cured, the paint should be re-applied as appropriate.

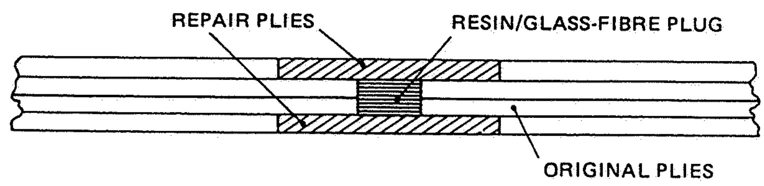

Figure 1 SMALL-HOLE REPAIR

7.5 **Multiple Lamination Repairs.** The type of repair permitted when a number of plies have been damaged, or when a hole larger than that covered by a 'small hole' repair, has been made in a laminate, will depend on the structural importance of the component and requirements such as aerodynamic cleanliness. Figure 2 illustrates several repairs of this type, but the method used for a particular repair must be in accordance with the relevant Repair Manual, in order to ensure that the properties designed into the original structure are maintained.

7.5.1 The overlay repair illustrated in Figure 2(A) would be applied, for example, to an air duct, for which the main concern would be the prevention of leaks. This type of repair would be carried out in the following way:

(a) Remove any loose material from the damaged area and press the surrounding material back into shape. Where possible insert a support, covered with a release agent, into the duct, to support the area while carrying out the repair.

(b) Sand the duct outer surface in an area extending 12 mm (0·5 in) x number of plies from the edge of the damage, taking care not to damage the sound glass-fibre material. Wipe off the dust produced by sanding with a cloth moistened with MEK.

(c) Cut new pieces of glass-fibre cloth of the same type as the original, to cover the repair as shown in Figure 2(A). The same number of plies as in the original laminate should be used.

(d) Mix a quantity of the specified resin and brush this over the sanded area. Place the largest repair ply in position over the damaged area, and brush in resin to completely impregnate the fibres. Cover the area with a sheet of cellophane, and sweep out excess resin and air bubbles with a squeegee made from rubber or plastics. Remove the cellophane and wipe excess resin from the outside of the repair.

(e) Place the next repair ply in position, impregnate the fibres, then remove excess resin and bubbles as outlined in paragraph (d).

(f) Repeat paragraph (e) for each of the remaining repair plies.

(g) Cover the repair with a sheet of cellophane, apply pressure if required, and allow the resin to cure. Remove the cellophane and the support.

(h) Further finishing is not normally necessary with this type of repair.

7.5.2 **Scarfed Repair.** This type of repair (Figure 2(B)), and the stepped repair described in paragraph 7.5.3 (Figure 2(C)), are used for the repair of components which must have a smooth outer surface, such as fairings, leading edges and nose cones. The scarfed repair is carried out as follows:

(a) Remove damaged fibres, and carefully cut back the lowest damaged ply to sound material, in a circular or oval shape.

(b) Scarf the area surrounding the damage by sanding, and also sand the outer surface for at least 25 mm (1 in) outside the repair area; care must be taken not to damage sound fibres when sanding. The slope of the scarf should not exceed 1 in 10, but may be as low as 1 in 100 if the laminations are thin. After sanding, wipe the area with a cloth moistened with MEK.

(c) Cut repair plies from glass-fibre cloth which is identical to the original cloth, in such a way that the weave of each ply corresponds to the weave of the ply it replaces. The largest repair ply should be 12 mm (0·5 in) larger all round than the repair area, and subsequent plies should be 12 mm (0·5 in) smaller all round than the underlying ply.

(d) Mix the appropriate resin, and brush a coat over the whole of the sanded area.

(e) Apply the largest repair ply and thoroughly impregnate with resin. Place a sheet

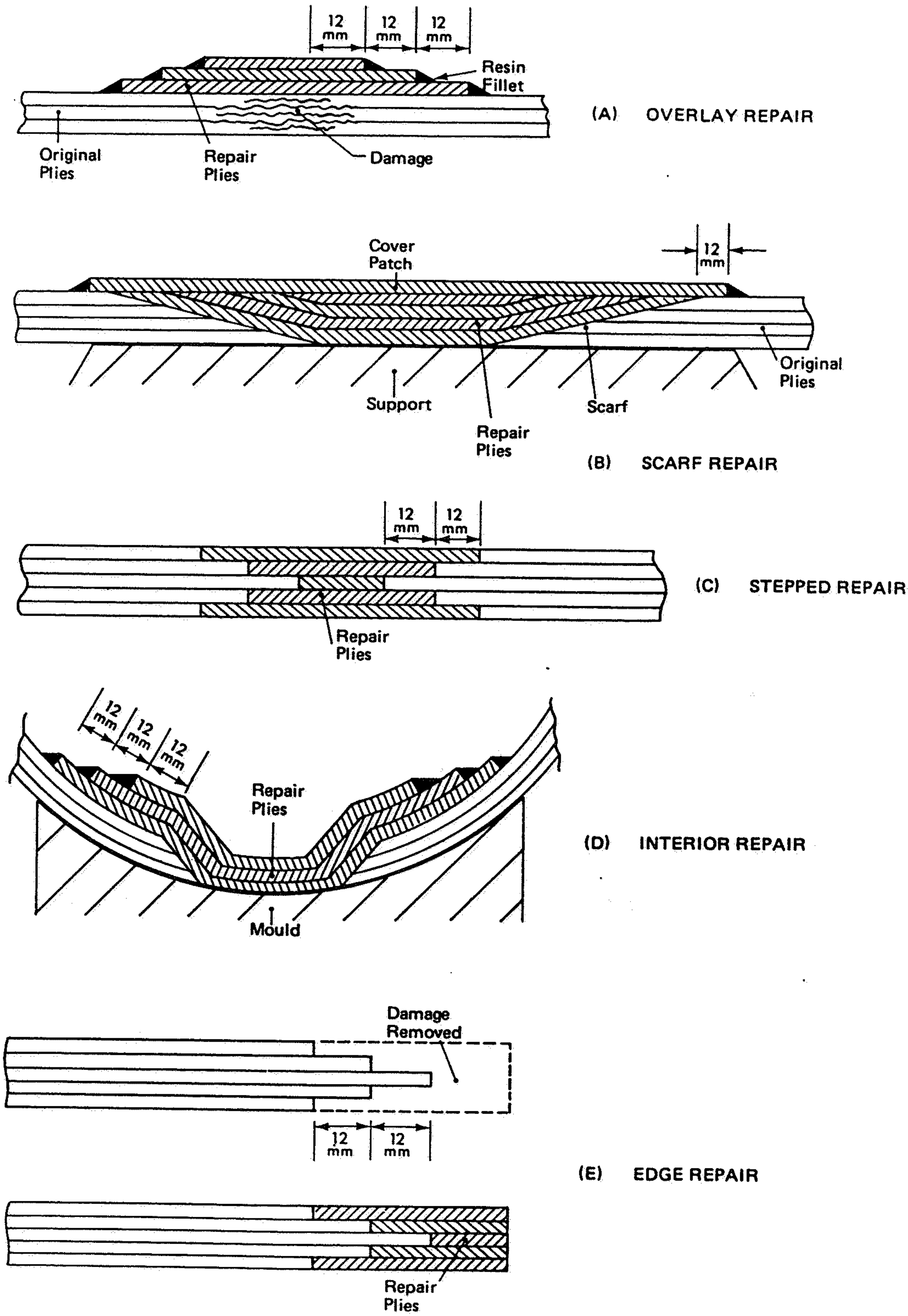

Figure 2 LAMINATE REPAIRS

of cellophane over the ply and sweep out all bubbles and excess resin using a roller or squeegee. Remove the cellophane and wipe off excess resin from the outside of the ply.

(f) Repeat paragraph (e) for each repair ply, until the repair has been built up to the original contour.

(g) Cover the repair with cellophane, and allow to cure, using supports and pressure as required.

(h) When the resin has cured, sand the outer surface to the original contour. If a cover patch is specified for the repair (Figure 2(B)), cut a piece of glass-fibre cloth as shown, and apply as indicated in paragraph (e). Sand this patch smooth when cured, leaving a resin fillet as shown in the illustration.

(j) Paint the repair to the prescribed scheme.

NOTE: Figure 2(D) illustrates a repair which is carried out from the inside. A mould is used to obtain the required shape of the outer surface, and when the repair has cured, this surface is sanded smooth and painted. The inside of the repair is left as shown.

7.5.3 **Stepped Repair.** A stepped repair (Figure 2(C)) is specified for many components, and serves the same purpose as a scarfed repair; in practice, however, separation of the plies may prove to be very difficult. Damage extending through several plies of the laminate can be repaired from the damaged side, but damage affecting all plies should normally be repaired from both sides if practicable, as shown in the illustration. This type of repair is carried out as follows:

(a) Remove damaged fibres and carefully cut back the damaged area to sound material.

(b) Scribe a line on both surfaces, 12 mm (0·5 in) x number of plies to be replaced on that side, from the edge of the damaged area, in a circular or oval shape. Scribe a radial line from the circumference to the centre.

(c) Using a sharp knife, cut through the outer ply along the lines scribed on one surface, taking care not to cut into the lower plies.

(d) Commencing at the inner end of the radial line, pry up and peel off the outer ply within the area enclosed by the cut line.

(e) Scribe a second line, 12 mm (0·5 in) inside the previous line, and remove the second ply. Repeat for subsequent plies until the centre layer is reached.

(f) Turn the laminate over, and repeat operations in paragraphs (c), (d) and (e) on the other side of the laminate.

(g) Sand all exposed surfaces, and sand off all paint within 25 mm (1 in) of the repair, on both sides.

(h) Cut pieces of glass-fibre cloth to the same specification as the original, to fit exactly into the stepped areas, with the weave in the same direction as the corresponding original plies.

(j) Place a support (covered with a release agent) under the original centre ply, to prevent sagging while the first part of the repair is carried out.

(k) Place the smallest repair ply in position, impregnate it with catalysed resin, and remove surplus resin and bubbles as indicated in paragraph 7.5.2 (e).

(l) Position the remaining repair plies on that side, impregnating the cloth and sweeping off excess resin and bubbles before applying the next ply, until the laminate is built up to the original contour.

(m) Turn the component over, support the lower surface, and complete the repair in the same manner as indicated in paragraph (l).

(n) Cover the repair with a sheet of cellophane, apply pressure as required, and allow to cure.

(p) When cured, sand smooth on both sides, apply a thin coat of catalysed resin over any exposed fibres, and when this has cured, finish in accordance with the relevant paint scheme.

7.5.4 **Edge Repairs.** Damage to the edges of glass-fibre laminates frequently occurs through careless handling. Such damage should be rectified by means of a stepped repair such as that illustrated in Figure 2(E), and if the damage is closer than 25 mm (1 in) to a fastener, then the repair should be extended to include the fastener. New material is usually left protruding slightly past the required edge line, and is cut to shape when the repair has cured. It is also often specified that an extra ply of glass-fibre cloth should be overlayed on the outside of the repair, to ensure that the original strength is maintained. Similarly an extra ply may be specified at positions where fasteners are fitted. The repair should be carried out in the same way as the stepped repair explained in paragraph 7.5.3, and particular attention should be paid to sealing the edge of the panel with catalysed resin after it has been trimmed to shape.

7.5.5 **Blind Repairs.** Repairs may sometimes have to be carried out when only one side of the laminate is accessible. In these cases the damage should be removed in an oval shape, so that a backing plate can be inserted through the hole and fixed to the inaccessible side of the laminate. The backing plate should be fabricated from one or two layers of glass-fibre cloth, of sufficient size to overlap the damage by 25 mm (1 in) all round. The repair should be carried out as follows:

(a) Prepare the damaged area for a scarfed or stepped repair.

(b) Cut out two layers of glass-fibre cloth to form a backing plate.

(c) Lay a sheet of cellophane over a mould, or a component having the same contour as the inaccessible side of the damaged area, and impregnate the two layers of glass-fibre cloth onto this surface. Sweep off excess resin and bubbles and allow to cure.

(d) Sand the upper surface of the cured backing plate, and drill two small holes in its centre. Pass a wire through these holes so that the plate can be secured in position.

(e) Apply catalysed resin to the upper surface of the backing plate, insert it through the cut-out and secure it to a support frame as shown in Figure 3. When this resin has cured, remove the wire and support frame, and continue with the repair.

8 REPAIRS TO GLASS-FIBRE HONEYCOMB Damage to, or separation of, the laminated facings of a glass-fibre honeycomb sandwich structure should normally be repaired in the manner described in paragraph 7. Where damage extends into the core material or through the complete structure, however, the core material must also be replaced. Typical repairs are described in this paragraph.

8.1 **Temporary Repairs.** Temporary repairs may be permitted to some components made from glass-fibre honeycomb sandwich material, but permanent repairs should be effected as soon as possible.

8.1.1 **Repairs Using Glass-Fibre.** Loose material should be cut away from the damaged area, and paint should be removed from the surface (within 50 mm (2 in)

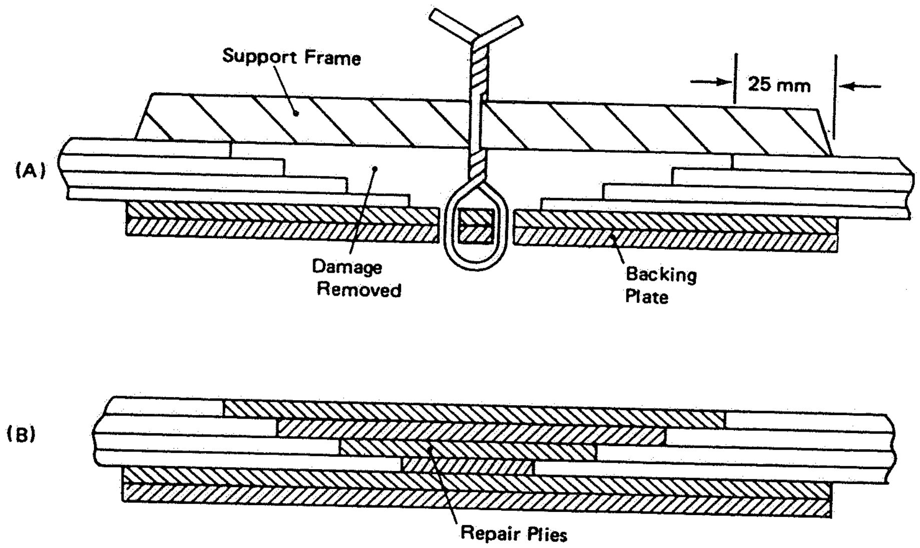

Figure 3 BLIND REPAIR

of the damage) by sanding. The voids in the exposed core material should be filled with catalysed resin (or resin and chopped glass-fibres), and two layers of glass-fibre cloth should be impregnated onto the sanded surface; the lower layer of cloth should overlap the damaged area by 25 mm (1 in) all round, and the upper layer of cloth should overlap the lower one by the same amount. When cured the repair should be sanded smooth.

8.1.2 **Repairs Using Sheet Metal.** Two pieces of thin aluminium alloy sheet (approximately 24 s.w.g.) should be cut and shaped to overlap the damage by at least 25 mm (1 in) all round. After cutting out all loose material, these repair plates should be bolted on each side of the sandwich structure, using distance pieces at the bolt positions to prevent crushing the sound material.

8.2 **Repairs to Core and One Facing.** When the core and one facing have been damaged by physical impact, delamination or water contamination, the core and facing must be cut back to sound material and a repair carried out as illustrated in Figure 4. The procedure is as follows:

(a) Cut out the damage to the facing and core, in the smallest circular or oval shape which will include all the damage. A suitable tool for cutting out the core is a hand-held drill with a circular cutter fitted into the chuck. The lower facing should be supported during this operation and the minimum of pressure should be used, so as to prevent separation of the bonding in the surrounding structure.

(b) Scarf or step the surface laminations to form a shallow depression with a taper of 12 mm (0·5 in) for each ply.

(c) Sand the exposed core and surface of the lower facing to allow the replacement core to seat properly. Sand the scarfed or stepped area, and the surface within 25 mm (1 in) of the perimeter of the repair.

(d) Clean the whole repair area with acetone or MEK.

(e) Cut a section of replacement core material to fit exactly into the cut-out, with the direction of the strips corresponding to the original material. Lightly sand the bottom and sides of the new core, and wash in acetone or MEK.

NOTE: Although the core material will usually be identical to the original honeycomb, in some cases a wood block filling may be permitted and in other cases the damaged core may be replaced by a mixture of resin and micro-balloons.

(f) Coat all mating surfaces of core and cut-out with catalysed resin, and press the core into position.

(g) Fit the repair plies as described in paragraphs 7.5.2 or 7.5.3 as appropriate, and finish in accordance with the relevant paint scheme.

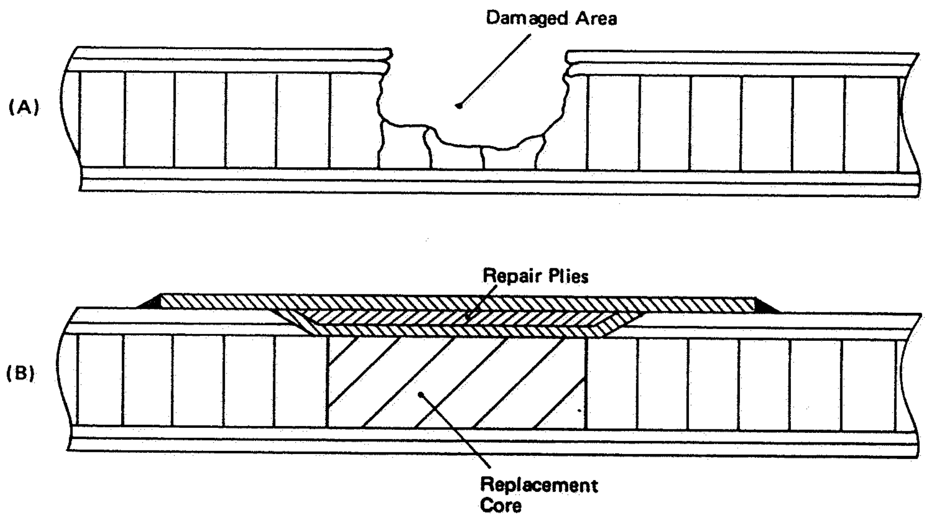

Figure 4 REPAIR TO CORE AND ONE FACING

8.3 **Repairs to Core and Both Facings.** When the damage extends through the whole structure, the repair procedure is similar to that described in paragraph 8.2, but is completed in two steps as follows:

(a) Cut out damaged areas of facings and core, in the smallest circular or oval shape that will remove all damage.

(b) Scarf or step the outer facing laminations to form a shallow depression with a taper of 12 mm (0·5 in) for each ply.

(c) Lightly sand the surfaces of the core cut-out, laminations, and the surface area within 25 mm (1 in) of the periphery of the repair.

(d) Prepare a mould to fit the contour of the inner facing, and cut a distance piece the thickness of the inner facing, which will fit exactly into the cut-out. Apply a release agent to the mould and distance piece, and assemble them to the structure as shown in Figure 5.

(e) Complete the repair to the core and outer facing as described in paragraph 8.2, and allow to cure.

(f) Remove the mould and distance piece, scarf or step the inner facing, and fit the repair plies as described in paragraphs 7.5.2 or 7.5.3 as appropriate.

(g) Allow repair to cure, sand smooth, and finish in accordance with the relevant paint scheme.

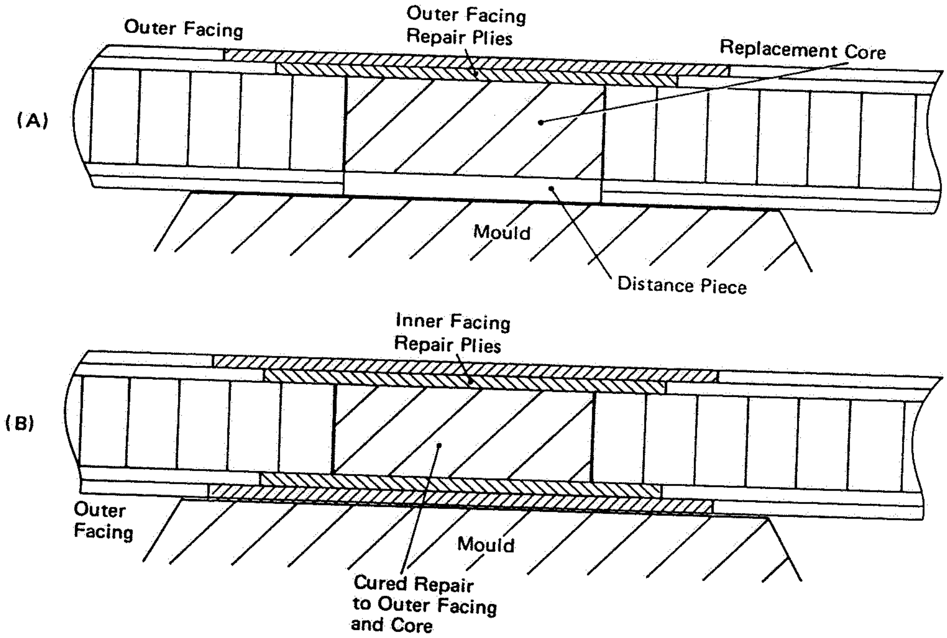

Figure 5 REPAIR TO CORE AND BOTH FACINGS

9 REPAIRS TO ALUMINIUM HONEYCOMB Many aircraft components, such as control surface panels, flap trailing edges, and floor panels, are made from aluminium alloy honeycomb sandwich; both glass-fibre and aluminium material may be used when effecting repairs. Repairs will usually be necessary for dents or other damage exceeding 100 mm (4 in) in any direction, and smaller areas of damage which contain cracks or cannot be sealed to prevent water contamination. Any damage assessed as allowable and not requiring repair should be inspected at frequent intervals to ensure that it is still within acceptable limits.

9.1 **Temporary Repairs.** Temporary repairs may often be permitted on minor damage to certain components, but a permanent repair must be carried out as soon as possible. Examples of temporary repairs are described in paragraphs 9.1.1 and 9.1.2, and illustrated in Figure 6.

9.1.1 Damage sustained, for example, by a wing trailing edge, which extends less than 75 mm (3 in) in any direction, may sometimes be repaired as follows:

(a) Cut out all damaged material, and trim all rough edges, as shown in Figure 6(A).

(b) Thoroughly clean all exposed surfaces with a solvent.

(c) Apply catalysed potting compound (a viscous resin) to all exposed surfaces, to seal the component against water penetration. Allow to cure.

9.1.2 Minor damage which cannot be repaired by the method described in paragraph 9.1.1, may sometimes be repaired by covering it with a riveted metal plate. This type of repair might be considered satisfactory for 100 hours of operation before a permanent repair need be made. The method of carrying out this repair is as follows:

(a) Trim the damaged skin to a regular outline.

(b) Cut and shape a repair patch as shown in Figure 6(B), from aluminium alloy sheet or clad sheet (approximately 22 s.w.g.). Drill pilot holes for rivets at the positions shown.

(c) Temporarily fit the repair patch over the damage and open out the pilot holes to the specified size (clearance holes for 3 mm (0·125 in) rivets are generally required).

(d) Remove repair patch and de-burr all holes.

(e) Clean mating surfaces with trichloroethylene or MEK.

(f) Catalyse potting compound and coat the surface of the component.

(g) Assemble the repair patch, secure with blind rivets, and allow to cure.

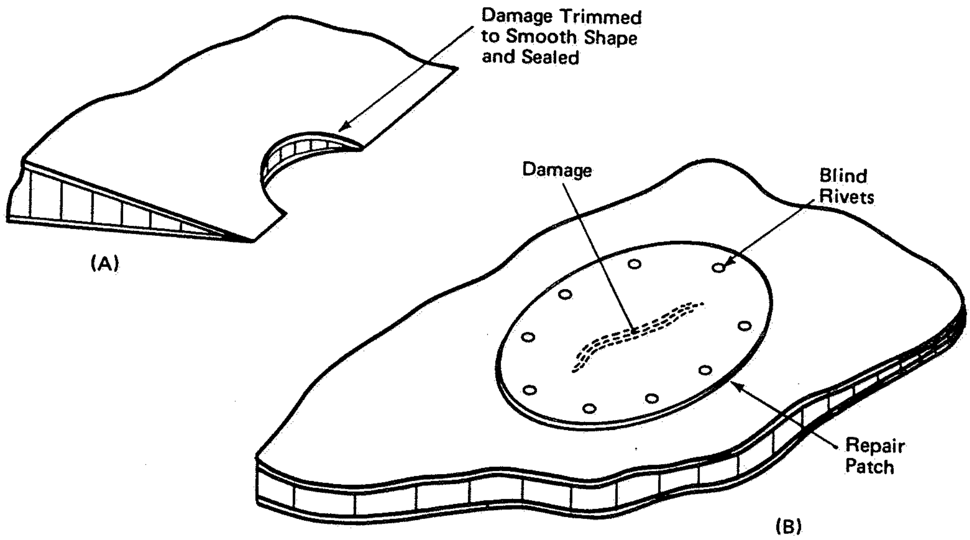

Figure 6 TEMPORARY REPAIRS

9.2 **Edge Delamination.** The delamination should be cleaned as far as possible with MEK. Catalysed cold-setting resin should then be forced into the delaminated area, and allowed to cure under pressure. Pressure may be applied to wedge-shaped edges by means of a clamp and tapered blocks; parts with flat edges may usually be secured by means of solid rivets, which should be closed with a squeeze riveter rather than by hammer blows.

9.3 **Repairs Using Glass-fibre.** Glass-fibre materials are used in many repairs to aluminium honeycomb structures, mainly because they are easier to shape and require no special tools. The resulting repairs may not completely restore the strength of the part, however, and some components may have to be repaired as described in paragraph 9.4. The following glass-fibre repairs are typical of those recommended for many aircraft.

9.3.1 **Skin Cracks.** Providing there is no delamination, cracks in a facing skin may be repaired as follows:

(a) Stop-drill the ends of the crack, using a 6 mm (0·250 in) drill.

(b) Remove all paint and other surface finish within 50 mm (2 in) of the crack by scrubbing with MEK or other approved solvent, then lightly sand to remove surface oxides, taking care not to penetrate the cladding. Paint stripper must not be used unless permitted by the manufacturer, since it could affect the bonding adhesive.

(c) Wipe off all residues with a cloth moistened with MEK or trichloroethylene, wiping off the solvent with a separate cloth before it dries.

NOTE: Trichloroethylene should not be used in enclosed areas.

(d) Apply adhesive primer to the cleaned surface in a thin continuous film and allow to dry.

(e) Cut two pieces of glass-fibre cloth to overlap the crack by 38 mm (1·5 in) all round.

(f) Impregnate the glass-fibre patches on a flat surface as follows:

(i) Cut two pieces of parting film (or cellophane) which will overlap the glass-fibre patches by 75 mm (3 in) all round.

(ii) Place one piece of parting film on a flat surface and brush on a layer of mixed adhesive.

(iii) Place one glass-fibre patch centrally on the adhesive, cover with the second piece of parting film, and work the adhesive into the glass-fibre patch, using a roller or squeegee.

(iv) Remove the upper parting film, spread a film of mixed adhesive over the impregnated patch, place the second glass-fibre patch in position and cover this with the parting film. Again sweep with a roller or squeegee, to impregnate the second patch and remove air bubbles.

(v) Remove patches and parting film together from the flat surface, and trim to the required shape.

(g) Apply a coat of prepared adhesive over the repair area, remove the lower parting film from the patches and place them centrally over the repair.

(h) Remove the upper parting film and replace it with a piece which overlaps the glass-fibre patches by 12 mm (0·5 in).

(j) Sweep out excess adhesive with a roller or squeegee, so that it forms a faired edge around the patches.

(k) Remove the parting film and wipe off excess adhesive; allow repair to cure.

(l) Repaint to the appropriate paint scheme.

9.3.2 **Repairs to Core and Skin.** These repairs are carried out in a similar way to the repairs described in paragraphs 8.2 and 8.3 for glass-fibre honeycomb structures.

(a) Remove damage in a circular or oval shape, using a hole saw or a router and template (paragraph 9.4.3(a) to (d)). If only the outer skin is damaged, the core should be removed down to the surface of the inner skin, but leaving the original adhesive intact.

(b) After removing the debris, sand the core edges with abrasive cloth and prepare the surface as described in paragraphs 9.3.1(b) to (d).

(c) Prepare the replacement core material to fit exactly into the cut-out, but be flush with the outer surface of the skin (Figure 7). A variety of replacement core materials may be used, depending on the purpose for which the structure is required, but glass-fibre honeycomb or mixed resin and micro-balloons are usually specified.

(d) Install replacement core as detailed in paragraphs 8.2(f) and (g).

(e) Fit surface patches of glass-fibre cloth as detailed in paragraphs 9.3.1(e) to (l).

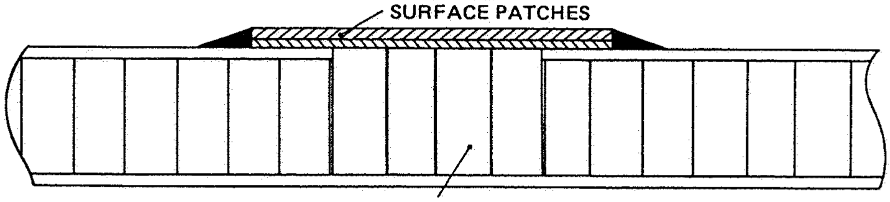

Figure 7 GLASS-FIBRE REPAIR OF METAL STRUCTURE

9.4 **Repairs with Aluminium Material.** When the maintenance of structural strength or the provision of a smooth aerodynamic surface is required, a repair using aluminium materials may be specified. These repairs are carried out in a similar way to repairs using glass-fibre materials, but particular methods of cleaning mating surfaces and the use of a primer to improve adhesion may be recommended; cover patches are often attached by a film adhesive, which is cured using both heat and pressure. A typical flush insert repair is described in paragraph 9.4.3 and illustrated in Figure 8, but the methods used are also applicable to other types of repair and should be used as appropriate.

9.4.1 **Cleaning.** The thorough cleaning of mating aluminium surfaces is particularly important. Some manufacturers require these surfaces to be chemically etched, but abrasive methods such as the use of aluminium oxide cloth, 'Scotch Brite', or a paste made from aluminium oxide powder and water, may also be suitable. Because of the nature of the chemicals used for etching, the manufacturer's instructions appertaining to the etching process must be strictly observed, and any warnings of hazards to health which may be presented, should be noted. Foam or liquid chemicals should be prevented from becoming trapped in inaccessible areas, and all traces should be washed off before continuing with the repair. Once the surfaces have been cleaned, washed and dried, they must be kept completely free from contamination, and the primer or adhesive should be applied as soon as possible.

NOTE: In some cases a 'water break test' may be specified to check the cleanliness of the metal surfaces before continuing with the repair.

9.4.2 **Machining of Aluminium Honeycomb Core.** When it is necessary to shape a piece of aluminium honeycomb for use in a repair, difficulty may be experienced in holding it while machining is carried out. This may be overcome by fixing the honeycomb to a flat metal plate in the following manner:

(a) Place a layer of powdered polyethylene glycol on a flat metal plate, and heat until it melts.

(b) Place core on the metal plate, remove heat, and apply light pressure on the core until the polyethylene glycol has solidified.

(c) If extensive sawing, sanding and machining are required, the honeycomb should be filled with melted polyethylene glycol after the core has been attached to the plate.

NOTE: Machining operations should be carried out without the use of oil or coolant, and care must be taken not to heat the core excessively.

(d) After the machining has been carried out, heat the plate to melt the polyethylene glycol, and hold the core in boiling water to clean it.

9.4.3 **Typical Insert Repair.** The repair described in this paragraph is a flush insert repair such as would be used for damage extending through the core and both skins. It uses material cut from a repair panel (a complete sandwich structure) in the form of a plug, and a fairing patch to provide a smooth exterior contour. Should the damage be confined to the core and one skin, the repair is identical to the flush repair, but, since the damage will usually be on the outside skin, the repair will be raised above the surrounding surface. When a separate core and skin are used the repair methods are similar, but a cover plate will have to be fitted to cover the core and surrounding surface. The repair should be carried out as follows:

(a) Mark the extent of the damage and select a hole saw or router template which will enclose this damage. Remove the damage in a circular or oval shape.

(b) Select and position a hole saw or router template to cut a path through the inner skin 12 mm (0·5 in) outside the cut-out, as shown in Figure 8(A).

(c) Peel off the inner skin between the cut-out and the routed path.

(d) Using a drill fitted with a grinding disc, remove the honeycomb core down to the bonded surface of the outer skin. Remove the remaining adhesive by lightly sanding with fine aluminium oxide paper, taking care not to damage the metal surface (Figure 8(B)).

(e) Prepare a repair insert from a repair panel of the same thickness and strength as the original, so that the ribbon direction matches the existing honeycomb; ideally the new honeycomb should be 1·5 mm (0·0625 in) smaller than the cut-out. Shape a fairing from material of the same type and thickness as the outer skin and, if a separate honeycomb core was used, also shape an inner patch and a cover plate (Figure 8(C)).

(f) Deburr all sharp edges, remove all paint in the area of the repair, and clean all mating surfaces. When the manufacturer does not specify chemical cleaning methods, the procedure outlined in paragraph 9.3.1 may be used.

(g) Mix the adhesive, and apply it to the exposed edges of the core and all mating surfaces of the repair parts and the original skins.

(h) Assemble the repair parts and cure with heat pressure as specified in the Repair Manual.

(j) When the method of applying pressure to the repair is as shown in Figure 8(D), the repair should first be assembled without the fairing. The bolt and pressure plate may then be removed, the bolt hole filled with adhesive, and the repair completed by fixing the fairing in position (Figure 8(E)).

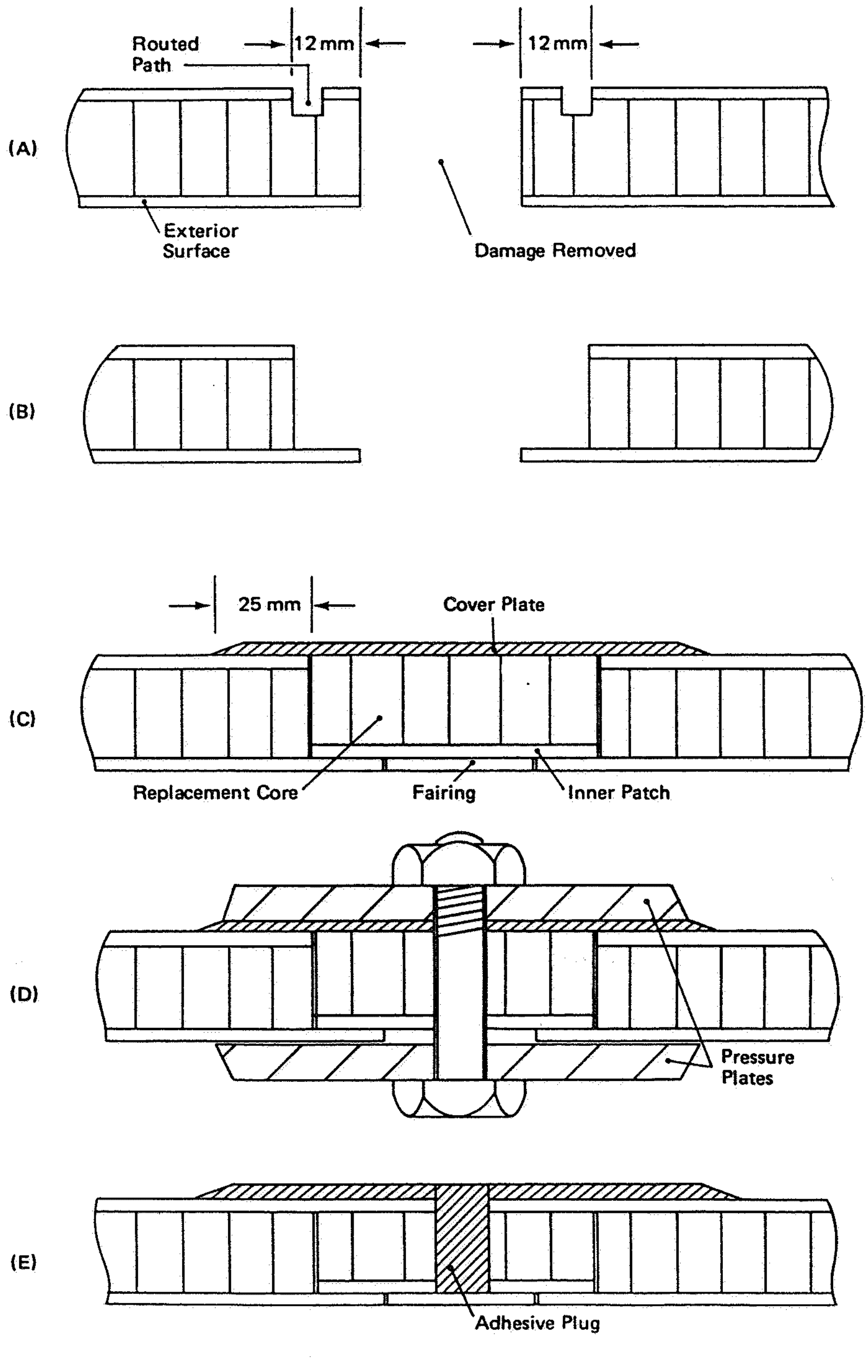

Figure 8 METAL REPAIR OF METAL STRUCTURE

10 RADOMES AND DIELECTRIC PANELS The construction and thickness of a radome or dielectric panel are determined by the structural strength required and the frequency of the signals transmitted by the equipment it houses. Any repairs carried out must, therefore, result in a structure with the same strength, contour, thickness and density as the original. Although in some cases repairs to a radome are not considered a satisfactory proposition, and are not recommended, in other cases quite extensive repairs are permitted, the main factor limiting the size of the repair being the ability to maintain an accurate profile and thickness. It follows, therefore, that particular care must be taken when carrying out repairs to these components, that accurate moulds must be prepared, and that satisfactory means of measuring the thickness of the repair must be available.

10.1 **Repair Limits.** Electrical discharge damage less than 25 mm (1 in) in diameter, and other damage less than 100 mm (4 in) in diameter, may usually be repaired without special electrical tests to check the satisfactory transmission of signals through the radome; a number of these repairs, covering up to 10% of the surface area of the radome may be permitted provided that a specified minimum distance between repairs is maintained. Repairs to larger areas of damage require tests to be made to verify the satisfactory operation of the radome, and if the necessary test equipment is not available the radome should normally be returned to the manufacturer or to an approved repair organization. The tests which must be carried out after a repair has been completed are described in Leaflet **RL/2-5**.

10.2 **Temporary Repairs.** Damage up to approximately 25 mm (1 in) in diameter may often be repaired on a one-flight basis, to enable the aircraft to be flown to a base where permanent repairs can be carried out. It must be appreciated, however, that operation of the radar may be impaired.

10.2.1 Loose debris should be removed, and the damage should be cleaned out to a smooth finish. The hole may be filled with sealant or by a plug made from wood or other suitable material, and a neoprene patch, overlapping the damage by at least 12 mm (0·5 in) all round, should be fixed over the damaged area with a suitable adhesive.

10.3 **Permanent Repairs.** Repairs to a damaged radome or dielectric panel are the same as repairs carried out to other parts of similar construction, but special care must be taken to ensure that the final thickness over the repair area is as near as possible to the original thickness. In some cases the dimensional limits for different areas on the radome are specified in the relevant Repair Manual, and, if the final thickness of the repair is outside these limits, electrical tests must be carried out. If the repair does not have a flat inner and outer surface (Figure 9), measurement of the thickness is essential, and eddy current instruments are often used; repairs with surfaces conforming to the original contour (Figure 10) may often be performed using a mould for the inner surface and templates for the outer surface.

10.3.1 **Scarfed Repair.** This repair should be carried out as described in paragraphs 8.2 or 8.3 as appropriate, but the core material must be to the same specification as the original core, no alternative generally being permitted. In addition, the repair of the inner-facing laminations is made larger than that on the outer-facing laminations, so as to minimize the increase in thickness which could result from facing repairs of the same size. The repair is illustrated in Figure 9.

10.3.2 **Stepped Repair.** A stepped repair is also carried out in a similar way to that described in paragraphs 8.2 or 8.3 as appropriate, but the edges of the inner-facing repair plies should be staggered between those of the outer-facing plies (Figure 10). In addition, the edges of the original plies should be chamfered and the edges of the repair plies should be frayed, so as not to produce an abrupt change of section in the repair.

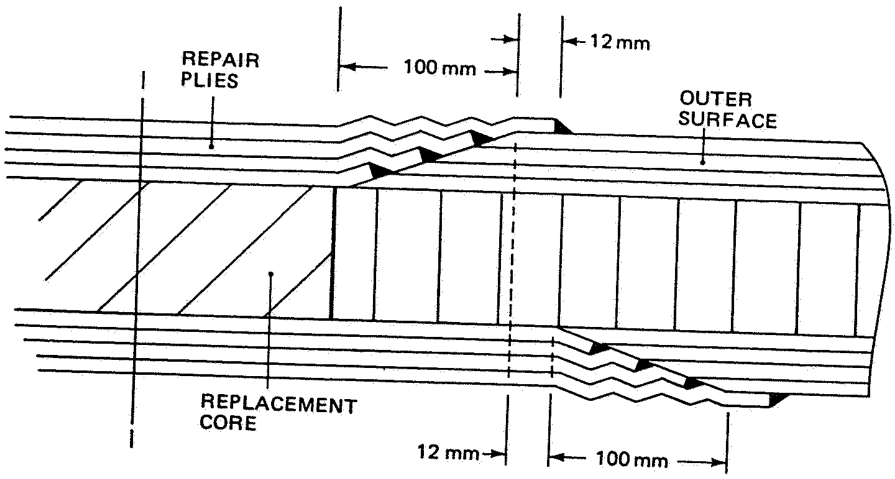

Figure 9 SCARFED RADOME REPAIR

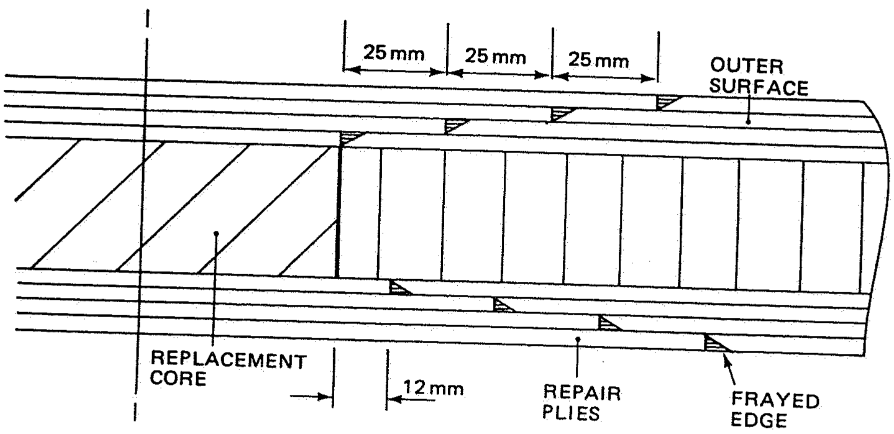

Figure 10 STEPPED RADOME REPAIR

10.3.3 Although it is generally recommended that a repair should be circular or oval in shape, some manufacturers suggest that a better fit may be obtained by shaping a square or rectangular replacement core, and permit this type of repair. The facing plies should also be removed in a square or rectangular outline, with the sides parallel to the weft and warp of the original glass-fibre cloth, but with rounded corners of at least 25 mm (1 in) radius.

AL/7-8

Issue 4

September, 1988

AIRCRAFT

STRUCTURES

ASSEMBLY AND MAINTENANCE OF CRITICAL BOLTED JOINTS

1 INTRODUCTION

1.1 In the context of this Leaflet the term 'critical bolted joint' is used to describe any bolted joint or attachment where stress levels are high and where inadequate assembly techniques could result in fatigue failure. Examples of critical bolted joints are spar joints, tailplane attachments, wing attachments, and engine mounting structure.

1.2 This Leaflet gives guidance on the recommended assembly procedure for critical bolted joints and on the extent to which inspection can verify that design requirements have been met. Guidance is also given on the inspections necessary during maintenance and overhaul to ensure the continued effectiveness of the joint.

1.3 Where specialised procedures or techniques are specified for the preparation or assembly of a critical bolted joint, the manufacturer's published procedures should be referred to and their recommendations observed.

1.4 Related CAIP Leaflets:—

BL/4-1 Corrosion — Its Nature and Control
BL/4-2 Corrosion — Removal and Rectification
BL/4-3 Corrosion — Methods of Protection
BL/6-30 Torque Loadings
BL/8-5 Magnetic Flow Detection

1.5 The subject headings are as follows:—

2 ASSEMBLY PROCEDURE

2.1 During the initial assembly of a joint, checks should be made to ensure that the component parts are protected against corrosion, that the edges of holes are de-burred, chamfered or radiused as appropriate and that mating surfaces are free from swarf or other foreign matter.

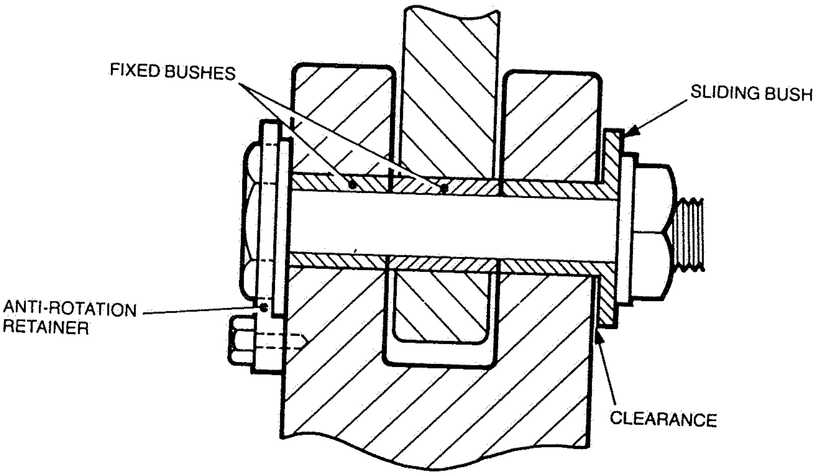

Figure 1 FORK FITTING WITH SLIDING BUSH AND ANTI-ROTATION RETAINER WHEN APPLICABLE

2.2 Before bolts are inserted it must be ensured that parts are correctly assembled and that no mis-alignment is present. Where one component is a fork-type fitting, a sliding bush may be fitted in one arm of the fork; provided that a clearance is maintained between the head of the bush and the fork during tightening of the assembly bolt (Figure 1), stressing of the fork fitting will be avoided. In other cases a good fit is obtained by selective assembly or by fitting shims or washers; if play is present in this type of joint the tightening of attachment bolts will induce a stress and weaken the fork fitting.

2.3 In some instances assembly instructions may require good bearing contact between the mating surfaces of the various components and also on the pressure faces of bolt heads and nuts. Tapered bolt holes should be checked by applying engineers blue to the hole and lightly rotating the bolt, while flat surfaces should be checked on a surface table, or by the use of engineers blue or feeler gauges during a trial assembly. Poor bearing surfaces should then be corrected by light lapping. Each hole should be checked using its own assembly bolt.

2.4 In some instances the surfaces of bolt holes in critical locations are stressed to prevent crack propagation and fatigue failure. Plastic deformation of the material surrounding the holes is produced by some form of broaching, such as the use of an interference fit mandrel, before the assembly bolt is fitted. In the case of tapered bolts in aluminium alloy components the hole is reamed until the bolt stands proud of the surface by a specified amount then, during final tightening, the tapered bolt expands the hole and induces compressive stress in the hole surface.

2.5 When performing operations such as drilling, reaming, lapping, etc., prior to final assembly of a joint, it is essential that the assembly is trued and held securely in position by clamps, slave bolts etc. This will prevent the ingress of swarf between faying surfaces and ensure that the joint is retained in this position when the joint bolts are finally inserted. Greater joint accuracy will be ensured if the joint bolts are inserted in sequence on each side of the joint immediately after each bolt fitting operation.

2.6 Parallel holes which have been opened to full size during assembly may be checked for size by means of plug gauges, but in certain instances, particularly when interference fits are required, the use of more specialised measuring equipment such as a pneumatic bore gauge may be necessary.

2.7 Careless fitting or assembly can considerably reduce the fatigue life of a joint. A burr on a bolt, or a piece of swarf left in a hole can scratch the surface of the hole and result in the concentration of stresses. To prevent the scoring of bolts and holes thorough cleanliness must be maintained and if shouldered bolts are used a 'bullet' should be fitted to protect the thread and provide a lead-in for the bolt shank. Lubrication of the bolts is usually recommended and the lubricant (or sealant) should be kept in a sealed container to prevent contamination when not in use. (See paragraph 3.)

2.8 It will be appreciated that many highly stressed joints will require no hand fitting. The components may be jig built to very fine tolerances which obviate most of the fitting precautions outlined in the preceding paragraphs. However, a high standard of cleanliness and care in handling the components is still necessary if design strength is to be maintained.

2.9 Where joints or fittings have more than one bolt, progressive tightening should be carried out in order to prevent stresses being induced. In some cases the final tightening sequence will be stipulated on the appropriate drawing. Nuts should be fitted finger-tight then progressively tightened to the appropriate pre-load value, but new parts may require bedding-in by first tightening to half the pre-load, slackening, then finally tightening in accordance with the manufacturer's recommendations.

3 JOINTING COMPOUND

3.1 There are a number of different compounds in use which are selected according to the type of joint, the probable frequency of disassembly, the material involved, the method of assembly, the protective treatments applied and the conditions of operation.

3.2 Pigmented varnish jointing compound to DTD 369, or other compounds covered by specification DTD 900, are frequently used to prevent scuffing and corrosion in joints, and cold-setting polysulphide synthetic rubber materials are often used for joint sealing. Other materials may be specified for use in particular locations, and reference should be made to the appropriate aircraft manual for instructions regarding their use.

3.3 In joints where hard-setting compounds are specified, precautions should be taken to ensure that the joint is tightened whilst the compounds are still wet, otherwise dimensional tolerances may be seriously affected if the compounds become dry before the joint is tightened.

3.4 Care should be taken to ensure that only the specified jointing compound is used, since, for example, that complying with DTD 369 is not suitable where temperatures in the vicinity of the joint may exceed 200° C, whilst hard-setting compounds are unsuitable in areas where vibration may occur.

3.5 Jointing compounds will give unsatisfactory results if kept in open containers which allow them to become semi-dry before application, and to ensure consistent results from occasional use are often supplied in squeeze-tubes.

3.6 Sealants are usually supplied in twin-pack form, and mixing instructions should be followed carefully. Once mixed the sealant starts to harden, and final assembly of a joint should be completed within a specified application time. Sealant which is not used within its application time must be discarded.

4 TIGHTENING OF BOLTS

4.1 The tension (pre-load) applied to a bolt during tightening should be greater than the highest stress likely to be encountered in service. The most efficient joint would be obtained by tightening each bolt to its yield point but, due to manufacturing tolerances and other variables, the practice would be dangerous to apply; in addition, each bolt could only be used once. A number of other ways of pre-loading bolts have been devised, and although these may result in a less-than-optimum tension, have proved satisfactory in service.

4.2 Under-tightening of bolts in highly stressed joints may, when load is applied, result in lack of contact or rigidity between the separate parts of the assembly. Where alternating or fluctuating loads are applied to such joints early fatigue failure may occur. Conversely, over-tightening is likely to cause immediate failure of the bolts or distortion of one or more parts of the assembly.

4.3 The general problem of applying a specified pre-load to a bolt is also affected by the need to line up split-pin holes. Unless the bolt pre-drilling suits the joint and nut dimensions, or the bolt is drilled after tightening, the applied pre-load will be inaccurate to the extent of the nut adjustment. In some applications this inaccuracy may be acceptable, but in others the selection of alternative nuts or washers may be recommended.

NOTE: For some installations the bolt head is indexed and must be maintained in the required position by an anti-rotation retainer (see Figure 1).

4.4 **Torque Loading.** The most common method of pre-loading is by applying a specified torque to the nut during tightening. Laboratory tests are carried out to ascertain an appropriate torque loading for any particular application, taking into account the type of thread, bolt and nut materials, manufacturing tolerances, type of anti-corrosive treatment and type of lubricant. This loading is applied by means of a torque wrench and results in a reasonably consistent pre-load being applied to the bolt. The use of torque wrenches is discussed in Leaflet **BL/6-30**.

4.5 **Pre-load Indicating Washers.** The value of the pre-load applied to a fastener by means of a torque wrench may vary considerably and, because of this, specified torque loadings are usually low compared with the actual strength of the fastener. In certain critical bolted joints the manufacturer may consider that more accurate clamping is required and specify the use of pre-load indicating (PLI) washers.

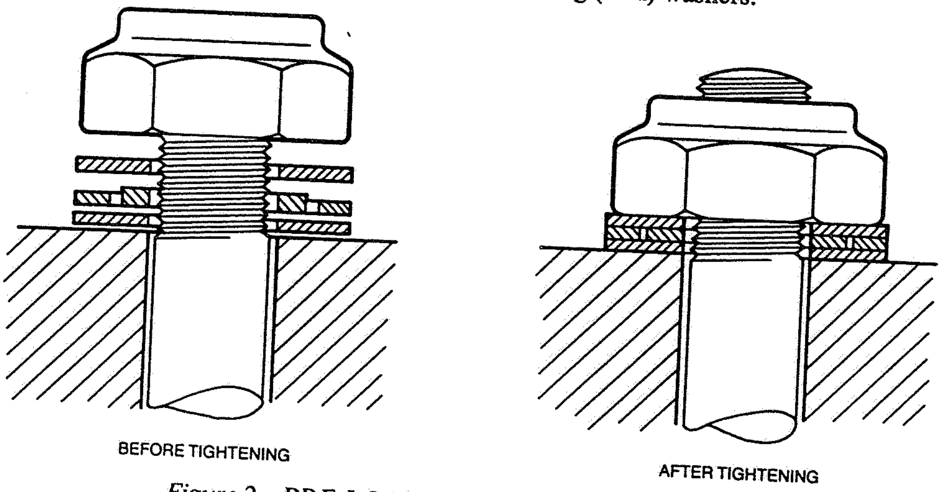

Figure 2 PRE-LOAD INDICATING WASHERS

4.5.1 PLI washers consist of concentric inner and outer rings, and two high-strength steel washers as shown in Figure 2. The outer ring is thinner than the inner ring and has a series of radial holes drilled through it.

4.5.2 A stiff wire tool is inserted in holes in the outer ring and used to check whether the ring is free to rotate (Figure 3). As the nut is tightened the inner ring is compressed until, at a predetermined pre-load, the outer ring is nipped between the washers; at this point the outer ring can no longer be rotated and tightening is complete.

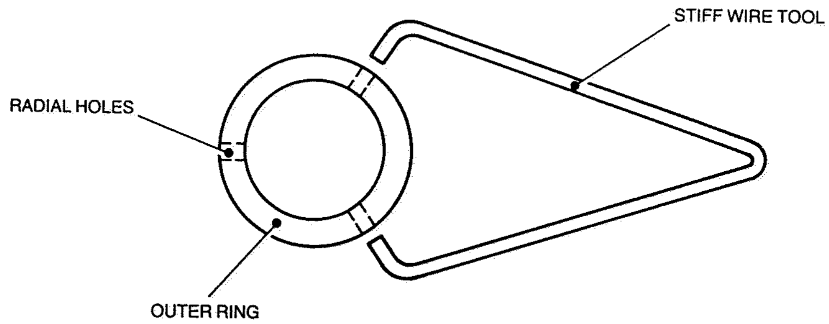

Figure 3 CHECKING PLI WASHER FOR ROTATION

4.5.3 PLI washers are unaffected by thread or nut friction, or by lubrication, and provide a means of pre-loading a bolt which is more consistent than torque loading. The pre-load applied to any particular size of bolt can be varied to suit its application by changes in the material or dimensions of the inner ring. However, since the inner ring is compressed during tightening it can only be used once, and if slackened must be replaced.

4.5.4 Due to the method of tightening, PLI washers can only be used with self-locking nuts.

4.6 **Shear Type Fasteners.** A number of proprietary fasteners are available which permit a reasonably accurate pre-load to be applied to a bolt without the use of torque wrenches. The nut normally used has an upper hexagonal wrenching portion, separated from the main nut by a deep groove. The hexagon portion shears off during tightening when a predetermined clamping force is reached.

4.7 **Bolt Extension.** An accurate method of pre-loading which, unfortunately, can not often be used in airframe applications for reasons of inaccessibility, is the measurement of bolt extension. The bolts are tightened until a specified extension has taken place, as measured by means of a micrometer or similar instrument.

4.8 **Dished Washers.** These washers are sometimes used on dynamically loaded structures. The washers consist of circular discs of constant thickness and have an initial 'dish' raising the centre, so that when nipped they act as a spring of very high rating and will accommodate a certain amount of stretch in the bolt shank, or bedding-in of the head. By variation of the thickness, outer diameter and height, a wide variety of load deflection characteristics can be obtained, but unlike pre-load indicating washers, there is no reliable way of ensuring when optimum tightness has been reached.

4.9 **Standard Spanners.** The use of standard spanners is seldom recommended as the only method of tightening a critical bolted joint. British Standard 192 gives the lengths of spanners to be used with the different sizes of nuts, and this leverage is usually adequate for general engineering work. It would, however, be impossible for even a skilled operator to apply a consistent amount of pre-load to a variety of bolt sizes. A reasonably accurate torque loading could be applied, in emergency, by using, for example, a double ended ring spanner and a spring balance, with the direction of pull at 90° to the spanner. The balance reading multiplied by the spanner length would give the torque loading applied.

NOTE: In certain installations the material of the component dictates use of special tools or protection from contact with standard tools.

5 INSPECTION OF BOLTED JOINTS

5.1 Unless bolts are extracted, visual examination is unlikely to reveal the faults which are usually associated with the beginning of cracks, fretting, corrosion etc. However, visual inspection is important as a means of checking that there are no indications of movement in the joint and that the external protective treatment is in good condition.

5.2 At the periods specified in the approved Maintenance Schedule, bolts should be extracted to enable a detailed examination to be made. Although this can be done most conveniently if the joint is broken down during major overhaul, on some aircraft one or more bolts may be required to be removed from critical joints at more frequent intervals. Whenever bolts are to be removed from these joints it will be necessary to support the surrounding structure in such a way as to remove the loads normally taken by the joint. The supports should be adjusted so that no residual loads are present in the joint when the bolts are removed, and this may often be checked by fine adjustments to the supports until the bolts rotate easily. Bolts may often be removed by means of a suitable extractor but, if the bolts are tight or stuck because of the presence of corrosion products or jointing compound, it may be preferable to punch them out with a drift. Extreme care is necessary to avoid damaging the bolt threads as this could result in damage to the hole and induce stress failure; it is also advisable to support the structure round the head of a bolt using a hollow dolly.

5.3 **Examination of Bolts.** When bolts are removed they should be examined for signs of steps, cracks, fretting or corrosion. An appropriate type of non-destructive testing must be used when checking for cracks, the electromagnetic process being suitable for most steel bolts. See Leaflet **BL/8-5**.

5.3.1 Where applicable, the protective coating should be examined for condition and, if the plating is scored or partially rubbed away, the bolt should either be replated or discarded.

5.3.2 The threads should be thoroughly cleaned and examined to ensure freedom from damage. Failure to do this may result in excessive friction between the bolt and nut, and lead to incorrect pre-loading if a torque wrench is used.

5.3.3 If, after examination, a doubt exists regarding the serviceability of the bolts, they should be rejected.

5.4 **Examination of Bolt Holes.** The bolt holes should be examined for signs of scoring, fretting, corrosion and cracks. A preliminary examination should be made before the hole is cleaned, since this is the most suitable time for detecting corrosion deposits, but it may be found that jointing compound obscures much of the hole surface.

5.4.1 The hole should be cleaned out with a suitable solvent, such as trichloroethylene, and then re-inspected.

5.4.2 The inspection of bolt holes can sometimes be difficult, but an optical aid such as a borescope is often used and eddy current methods are also frequently recommended.

5.5 **Fretting.** Examples of aircraft components which have failed through fatigue originating in areas of fretting, have shown that fractures do not necessarily pass through adjacent bolt holes.

5.5.1 Fretting at major joints is often revealed, by black or grey dust or paste in aluminium structures and brown rust stains in steel parts, at the periphery of faying surfaces. Cracks may develop from the outer edge of a fretted area and extend across the component. An examination of a component showing signs of fretting should, therefore, include the flat surfaces as well as the bolt holes.

5.5.2 An inspection of this nature would entail disassembly, and examination by means of penetrant dye, eddy current or ultrasonic (surface wave) methods.

5.6 **Reassembly of the Joint.** When reassembling the joint the assembly recommendations given in the preceding paragraphs should be taken into consideration.

6 LOCKING Locking devices must be sufficiently effective to prevent loosening or turning of the threaded parts and they should be fitted as specified in the relevant drawing or manual. Most locking devices may only be used once, but those which can be re-used should be checked for effectiveness before being refitted.

AL/7-9

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AIRCRAFT

STRUCTURES

INSPECTION OF WOODEN STRUCTURES

1 INTRODUCTION This Leaflet gives guidance on the inspection of wooden aircraft structures for evidence of deterioration of the timber and glued joints. It should be read in conjuction with the relevant aircraft manuals, approved Maintenance Schedules and manufacturers' instructions, from which details of particular structures may be obtained.

1.1 Information on the conversion of timber into aircraft parts is given in Leaflet **BL/6-6** and on the use of synthetic resin adhesives in **BL/6-7.**

2 CAA POLICY Airworthiness Notice No. 50 describes the extent of the deterioration which has been found in wooden structures and the dismantling which may be necessary to enable thorough inspections to be carried out. Airworthiness Notice No. 67 reflects the CAA policy towards re-certification and flying of certain types of aircraft manufactured principally from wood. It also contains a list of aircraft with glued ply and timber torsion box spars, which will only be granted a new Certificate of Airworthiness following detailed investigation of each aircraft.

2.1 While these notices express concern at the extent of deterioration found in some aircraft, it is also pointed out that there is no reason why aircraft constructed in these materials should not have a satisfactory life provided they are protected from the adverse effects of extreme temperature and humidity and are kept in suitable hangars when not in use.

3 GLUED STRUCTURES Provided that protective varnish was applied to all exposed wood surfaces after gluing and satisfactorily maintained during the life of an aircraft, rapid deterioration of timber and glued joints would be unlikely. However, access to internal structure is often difficult or even impossible, and deterioration takes place for a variety of reasons.

3.1 Some of the main factors which may cause deterioration are:—

(i) Chemical reactions of the glue itself due to ageing or moisture, to extremes of temperature or to a combination of these factors.
(ii) Mechanical forces due mainly to timber shrinkage.
(iii) Development of mycological growths (i.e. fungus).
(iv) Oil percolating from the engine installation.
(v) Fuel contamination due to system leaks or spillage in the tank bays.
(vi) Blockage of water drainage holes.

3.2 Aircraft which are exposed to large cyclic changes of temperature and humidity are especially prone to timber shrinkage which in turn may lead to glue deterioration. The amount of movement of timber members due to these changes varies with the volume of each member, the rate of growth of the tree from which the timber was cut and the way in which the timber was converted. Thus, two major members in an aircraft structure, secured to each other by glue, are unlikely to have identical characteristics and differential loads will, therefore, be transmitted across the glue film with changes of humidity. This will impose stresses in the glued joint which, in temperate zones, can normally be accommodated when the aircraft is new and for some years afterwards. However, with age the glue tends to deteriorate, even when the aircraft is maintained under ideal conditions, and stresses at the glued joint, due to changes in atmospheric conditions, may cause failure of the joint.

3.2.1 In most wooden aircraft of monoplane construction the main spars are of box formation consisting of long top and bottom transverse members (i.e. spar booms) joined by plywood webs. The spar booms may be built up from laminations glued together, and at intervals vertical wooden blocks are positioned between the two booms to add support to the plywood sides.

3.2.2 The main spars carry most of the loads in flight and are, at times, subject to flexing. The glued joints should, therefore, be free from deterioration but, unless the spar is dismantled or holes cut in the webs, internal inspection may be virtually impossible.

3.2.3 Long exposure to inclement weather or strong sunlight will tend to destroy the weatherproofing qualities of fabric coverings and of surface finishes generally. If fabric-covered ply structures are neglected under these conditions the surface finish will crack, allowing moisture to penetrate to the wooden structure and resulting in considerable deterioration through water soakage.

4 SURVEY OF STRUCTURE Before commencing a detailed examination of an aircraft structure, the aircraft should be inspected externally for signs of gross deformation, such as warped wing structures, tail surfaces out of alignment or evidence of obvious structural failure. In some cases of advanced deterioration this assessment may be sufficient to pronounce the aircraft beyond economical repair, and thus avoid further work.

4.1 Whenever possible the aircraft should be housed in a dry, well ventilated hangar, and all inspection panels, covers and hatches removed before continuing with the survey. The aircraft should be thoroughly dried out before examining glued joints or carrying out repairs.

4.1.1 Immediately after opening the inspection panels, etc., each component should be checked for smell. A musty smell indicates fungoid growth or dampness and, if present, necessitates further examination to establish which areas are affected.

4.1.2 Where the wings, fuselage or tail unit are designed as integral stressed structures, such as inner and outer ply skins glued and screwed to structural members (Figure 1) no appreciable departure from the original contour or shape is acceptable.

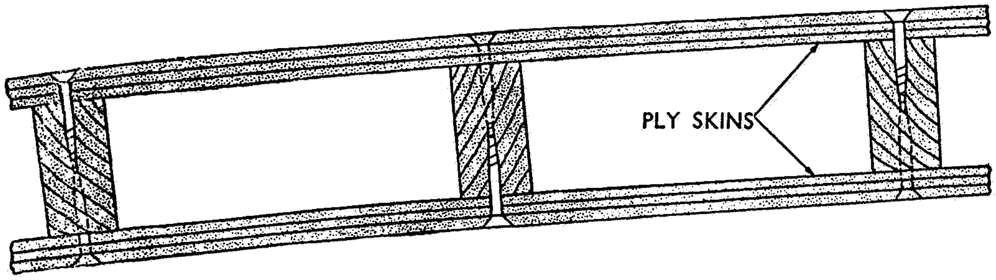

Figure 1 DOUBLE SKIN STRUCTURE

4.1.3 Where single skin plywood structures are concerned, some slight sectional undulation or panting between panels may be permissible provided the timber and glue is sound. However, where such conditions exist, a careful check must be made of the attachment of the ply to its supporting structure, and moderate pressure with the hand, to push the ply from the structure, should be used. A typical example of a distorted single skin structure is illustrated in Figure 2.

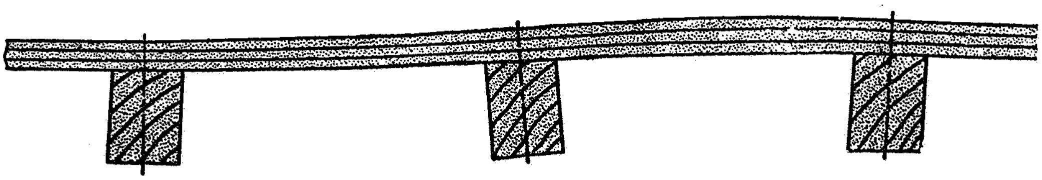

Figure 2 SINGLE SKIN STRUCTURE

4.1.4 The contours and alignment of leading and trailing edges are of particular importance and a careful check should be made for deformities. Any distortion of these light ply and spruce structures indicates deterioration, and a careful internal inspection should be made for security of these parts to the main wing structure. If a general deterioration is found in these components the main wing structure may also be affected.

4.1.5 Where there are access panels or inspection covers on the top surfaces of wings or tailplane, care is necessary to ensure that water has not entered at these points where it can remain trapped to attack the surrounding structure.

4.2 Splits in the proofed fabric covering on plywood surfaces should be investigated by removing the defective fabric in order to ascertain whether the ply skin beneath is serviceable. It is common for a split in the ply skin to be the cause of a similar defect in the protective fabric covering.

4.3 Fabric having age cracks, and thick with repeated dopings, may indicate that the structure underneath has not been critically examined for a considerable time. Insertion patches in the fabric could also indicate that structural repairs have been made at that point.

4.4 Whilst a preliminary survey of the external structure may be useful in roughly assessing the general condition of the aircraft, it should be noted that timber and glue deterioration often takes place inside a structure without any external indications. Where moisture can enter a structure, it will tend to find the lowest point, where it will stagnate and promote rapid deterioration. Other causes of glue deterioration are listed in paragraph 3.1.

5 INSPECTION OF TIMBER AND GLUED JOINTS Assessment of the integrity of glued joints in aircraft structures presents considerable difficulties since there is no positive non-destructive method of examination which will give a clear indication of the condition of the glue and timber inside a joint. The position is made more difficult by the lack of accessibility for visual inspection.

5.1 The inspection of a complete aircraft for glue or wood deterioration will necessitate checks on remote parts of the structure which may be known, or suspected trouble spots and, in many instances, are boxed in or otherwise inaccessible. In such instances, considerable dismantling is required and it may be necessary to cut access holes in ply structures to facilitate the inspection; such work must be done only in accordance with approved drawings or the repair manual for the aircraft concerned and, after the inspection has been completed, the structure must be made good and protected in an approved manner.

5.2 All known or suspected trouble spots must be closely inspected regardless of log book records indicating that the aircraft has been well maintained and properly housed throughout its life.

NOTE: Where access is required and no approved scheme exists, a scheme should be obtained from the aircraft manufacturer or an Organisation appropriately approved by the CAA for such work.

5.3 **Access Holes.** In general, access holes are circular in shape and should be cut with a sharp trepanning tool to avoid jagged edges. It is essential to avoid applying undue pressure to the tool, especially towards the end of the cut, otherwise damage may be caused to the inner face of the panel by stripping off the edge fibres or the ply laminations.

5.3.1 Where rectangular access holes are prescribed care is necessary to ensure that they are correctly located and that corner radii are in accordance with drawing requirements.

5.3.2 The edges of all access holes must be smoothed with fine glasspaper, preferably before inspection is commenced, since contact with the rough edges may cause wood fibres to be pulled away.

5.4 It is important that the whole of the aircraft structure, including its components, e.g. tailplane, elevators, etc., is inspected in detail before any decision is reached regarding general condition. It is possible for the main airframe to be in good condition but for a marked deterioration to have occurred in, for example, a control surface.

5.5 **Glue Line.** When checking a glue line (i.e. the edge of the glued joint) for condition, all protective coatings of paint should be removed by careful scraping; it is important to ensure that the wood is not damaged during the scraping operation, and scraping should cease immediately the wood is revealed in its natural state and the glue line is clearly discernible.

5.5.1 The inspection of the glue line is often facilitated by the use of a magnifying glass. Where the glue line tends to part or where the presence of glue cannot be detected or is suspect, then, providing the wood is dry, the glue line should be probed with a thin feeler gauge and, if any penetration is possible, the joint should be regarded as defective.

NOTE: It is important to ensure that the surrounding wood is dry, otherwise a false impression of the glue line would be obtained due to closing of the joint by swelling. In instances where pressure is exerted on a joint, either by the surrounding structure or by metal attachment devices such as bolts or screws, a false impression of the glue condition could be obtained unless the joint is relieved of this pressure before the glue line inspection is carried out.

5.5.2 The choice of feeler gauge thickness will vary with the type of structure, but a rough guide is that the thinnest possible gauge should be used. Figure 3 indicates the points where checks with a feeler gauge should be made.

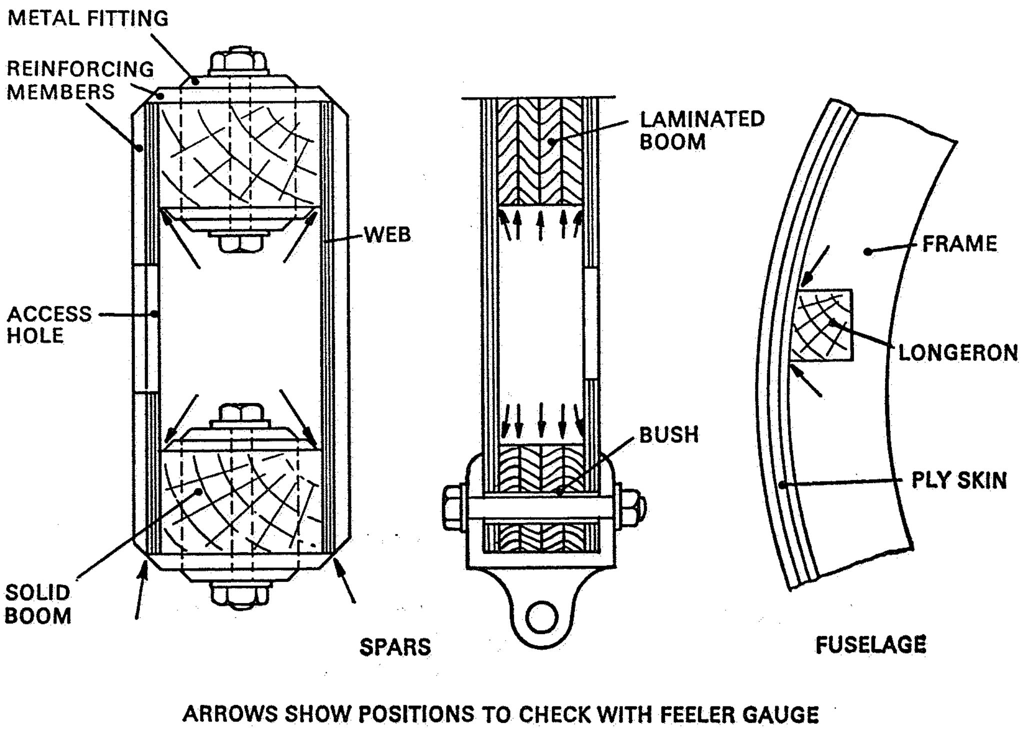

Figure 3 GLUE LINE CHECKS

5.6 **Timber Condition.** Dry rot and wood decay are not usually difficult to detect. Dry rot is indicated by small patches of crumbling wood, whilst a dark discolouration of the wood surface or grey streaks of stain running along the grain are indicative of water penetration. Where such discolouration cannot be removed by light scraping the part should be rejected, but local staining of the wood by the dye from a synthetic adhesive hardener can, of course, be disregarded.

5.6.1 **Water Penetration of Structure.** In some instances where water penetration is suspected, the removal of a few screws from the area in question will reveal, by their degree of corrosion, the condition of the surrounding joint (see Figure 4).

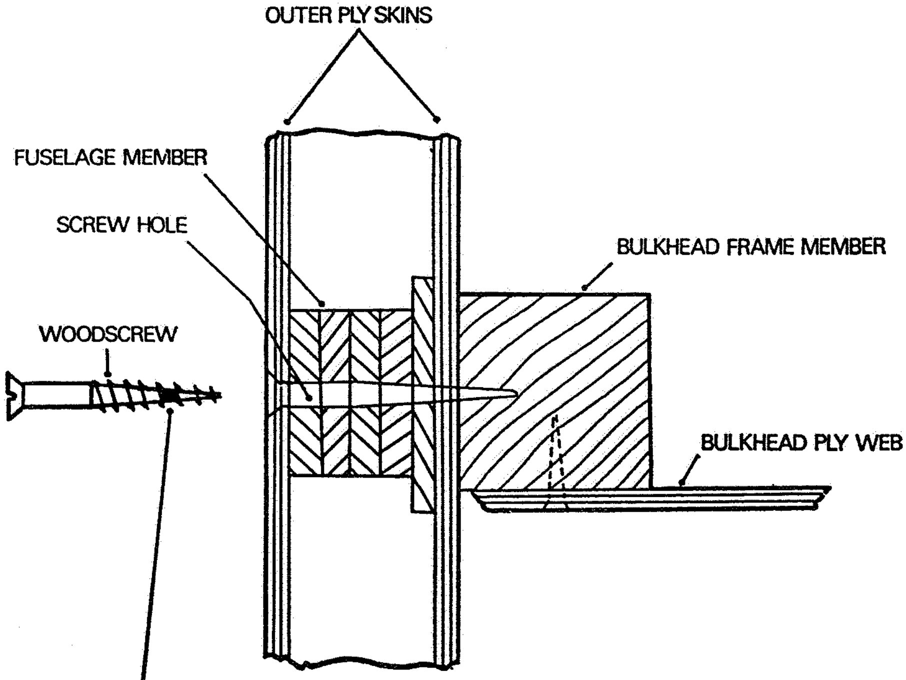

Figure 4 CHECK FOR WATER PENETRATION

(i) Slight corrosion of the screw due to the adhesive will occur following the original construction, therefore, the condition of the screw should be compared with that of a similar screw, removed from another part of the structure known to be free from water soakage.

NOTE: Plain brass screws are normally used for reinforcing glued wooden members, although zinc coated brass is sometimes used. Where hard woods such as mahogany or ash are concerned, steel screws are sometimes used. Unless otherwise specified by the aircraft constructor, it is usual to replace screws with new screws of identical length but one size larger.

(ii) Another means of ascertaining if water penetration has taken place is to remove the bolts holding fittings at spar root-end joints, aileron hinge brackets, etc. (see Figure 3). Primary joints may have bushed holes, and the bushes should also be withdrawn. Corrosion on the surface of these bolts and bushes, and timber discolouration, will provide a useful indication of any water penetration which has taken place. Bolts and bushes should be smeared with an approved protective treatment before being refitted through wooden members.

NOTE: When refitting bolts it is important to ensure that the same number of shrinkage washers are fitted as were fitted originally.

(iii) Experience of a particular aircraft will indicate those portions of the structure most prone to water penetration and moisture entrapment (e.g. at window rails or the bottom lower structure of entry doors), but it must be borne in mind that this is not necessarily indicative of the condition of the complete aircraft.

(iv) Where drain holes have become blocked, water soakage will invariably be found. Drain holes should be cleared during routine maintenance.

5.6.2 **Water Penetration of Top Surfaces.** As indicated in paragraph 3.2.3, the condition of the proofed-fabric covering on ply surfaces is of great importance. If any doubt exists regarding its proofing qualities or if there are any signs of poor adhesion, cracks, or other damage, it should be peeled back to reveal the ply skin.

(i) The condition of the exposed ply surface should be examined and if water penetration has occurred, this will be shown by dark grey streaks along the grain and a dark discolouration at ply joints or screw countersunk holes, together with patches of discolouration. If these marks cannot be removed by light scraping or, in the case of advanced deterioration, where there are small surface cracks or separation of the ply laminations, then the ply should be rejected. Where evidence of water penetration is found, sufficient of the surfaces should be stripped to determine its extent.

(ii) Providing good care is taken of the protective covering from the beginning, much deterioration can be avoided.

5.6.3 **Miscellaneous Defects.** During the inspection of the aircraft, the structure should be examined for other defects of a more mechanical nature. Guidance on such defects is given in the following paragraphs.

(i) **Shrinkage.** Shrinkage of timber, as well as inducing stresses in glued joints, can cause looseness of metal fittings or bolts and, if fluctuating loads are present, can result in damage to the wood fibres at the edges of the fittings or around the bolt holes. Shrinkage can be detected by removing any paint or varnish as described in paragraph 5.5, and attempting to insert a thin feeler gauge between the timber and the fitting or bolt head.

(ii) **Elongated Bolt Holes.** Where bolts secure fittings which take load-carrying members, or where the bolts are subject to landing or shear loads, the bolt holes should be examined for elongation or surface crushing of the wood fibres. The bolts should be removed to facilitate the examination and, in some cases, the bolt itself may be found to be strained. Rectification of elongated bolt holes must be carried out in accordance with the approved Repair Manual, the usual method being to open out the holes and fit steel bushes.

(iii) **Bruising and Crushing.** A check should be made for evidence of damage such as bruises or crushing of structural members, which can be caused, for example, by overtightening bolts. Repair schemes for such damage are governed by the extent and depth of the defect.

(iv) **Compression Failures.** Compression failures, sometimes referred to as compression 'shakes', are due to rupture across the wood fibres. This is a serious defect which at times is difficult to detect, and special care is necessary when inspecting any wooden member which has been subjected to the abnormal bending or compression loads which may occur during a heavy landing. In the case of a member having been subjected to an excessive bending load, the failure will appear on the surface which has been compressed, usually at a position of concentrated stress such as at the end of a hardwood packing block; the surface subjected to tension will normally show no defects. In the case of a member taking an excessive direct compression load, the failure will usually be apparent on all surfaces. Where a compression failure is suspected, a hand torch shone along the member, with the beam of light running parallel to the grain, will assist in revealing this type of failure.

(v) **Previous Repairs.** When examining a structure for signs of the defects mentioned above, particular attention should be paid to the integrity of repairs which may have been carried out previously.

6 JOINT FAILURE A glued joint may fail in service as a result of an accident or due to excessive mechanical loads having been imposed upon it, either in tension or in shear. It is often difficult to decide the nature of the load which caused the failure, but it should be borne in mind that glued joints are generally designed to take shear loads.

6.1 If a joint is designed to take tension loads, it will be secured by a number of bolts or screws (or both) fairly closely pitched in the area of tension loading. If a failure occurs in this area, it is usually very difficult to form an opinion of the actual reasons for it, due to the considerable break-up of the timber occurring in close proximity with the bolts.

6.2 In all cases of glued joint failure, whatever the direction of loading, there should be a fine layer of wood fibres adhering to the glue, whether or not the glue has come away completely from one section of the wood member. If there is no evidence of fibre adhesion, this may indicate glue deterioration, but if the imprint of wood grain is visible in the glue this is generally due to 'case hardening' of the glue during construction of the joint, and the joint has always been below strength. If the glue exhibits a certain amount of crazing or star shaped patterns, this indicates too rapid setting, or the pot life of the glue having been exceeded. In these cases, the other glued joints in the aircraft should be considered suspect.

NOTE: The use of a magnifying glass will facilitate the above inspections.

6.3 Damage caused by a heavy landing may be found some distance away from the landing gear attachment points. Secondary damage can be introduced by transmission of shock from one end of a strut or bracing to its opposite end, causing damage well away from the point of impact. A thorough inspection of the existing paint or varnish at suspected primary or secondary impact points may reveal, by cracks or flaking, whether damage has actually occurred.