

**AL/7-10**

Issue 2.

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**AIRCRAFT  
STRUCTURES****GLASS WINDSCREEN ASSEMBLIES**

**1 INTRODUCTION** This Leaflet gives guidance on the installation and maintenance of aircraft glass windscreen assemblies of both the simple and complex electrically heated type. As the assemblies fitted to different aircraft vary considerably, the information given in this Leaflet should be read in conjunction with the Maintenance Manuals and the approved Maintenance Schedule for the type of aircraft concerned. Reference should also be made to Leaflet AL/11-4, Windscreen De-icing and Anti-icing Systems for details concerning the installation and maintenance of the components associated with electrically-heated windscreens and also for the overall testing of a system. The CAA Requirements regarding tests on pressure panels are given in Chapter D3-7 of British Civil Airworthiness Requirements.

**2 GLASS** Glass is a hard, brittle material having the outstanding quality of transparency. To overcome brittleness but to leave transparency unimpaired is the main object of the manufacture of safety glass as used for aircraft windscreens. Examples of specifications which meet the requirements are DTD 218 Laminated Safety Glass, DTD 869 Laminated Safety Glass, High Light Transmission, DTD 761 Safety Glass Windscreen, Gyro Sight Quality and DTD 5576A Electrically Heated Laminated Safety Glass.

**2.1 Characteristics of Glass.** Glass, unlike metals, is non-crystalline. When heated or cooled it shows no sharp change in physical properties and has no definite melting point, but at about 600°C plate and sheet glass begin to flow under their own weight.

**2.1.1** Glass may be broken by loading in various ways, e.g. impact, tension, twist, compression or shear and fracture will occur under any type of loading when deformation has produced the necessary tensile stress.

**2.1.2** The breaking strength of glass is greatly influenced by five factors:—

- (i) Heat treatment (paragraph 2.2).
- (ii) Length of time of loading (paragraph 2.3).
- (iii) The rate of application of a load (paragraph 2.4).
- (iv) The condition of the surfaces and edges (paragraph 5).
- (v) Method of installation (paragraph 3.2).

**2.2 Heat Treatment**

**2.2.1 Annealing.** After manufacture glass is cooled very slowly so that stress set up during the forming of the sheet may dissipate. If this were not the case, built-in tensile stress would weaken the glass to such an extent that it could break spontaneously. When glass of greater strength than annealed glass is required, a tempered glass is used.

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2.2.2 **Tempered Glass.** The glass is heated to some point within the range in which it becomes soft and then the surfaces are quickly cooled by blasts of compressed air. This chills and hardens the outer surfaces whilst the inside is still hot and contracting, thus putting the outer 'skins' of the glass in a state of compression, resulting in a considerable increase in strength.

- (i) The main drawback of tempering is that the glass will break up into tiny particles when fractured (the greater the degree of tempering the smaller will be the particle size) thus seriously obstructing vision.
- (ii) In the United Kingdom, glass which has been tempered to give maximum strength is termed 'toughened glass' (e.g. Type 1 of DTD 5576A). The term 'strengthened glass' (e.g. Type 2 of DTD 5576A) is used to indicate glass which has been tempered to a lesser degree than toughened glass. Although less strong than toughened glass it has the advantage of larger particle size should fracture occur.
- (iii) Because of the physical nature of tempered glass it cannot be filed, drilled or trimmed in any way, therefore any adjustments required during fitting must, of necessity, be done on the mounting frame. Great care is necessary when fitting the glass to prevent damage, for example chipping. Scratches, chips, flaws and other surface defects weaken glass very considerably and on this score alone every effort must be made to avoid such defects, particularly at the edges of the glass (see paragraph 5).

2.3 **Fatigue.** Cyclic fatigue of toughened glass at commonly used stress level, is effectively non-existent.

2.4 **Safety Factors.** The safety factors required on glass components are very much higher than for other materials used in aircraft construction, because of the loss of strength with duration of load, scatter in strength inherent in glass, thickness tolerances and high notch sensitivity.

**3 WINDSCREEN DESIGN** The design of windscreens varies considerably according to the type of aircraft to which they are fitted, the extent of de-misting and impact strength required and also on whether an electrical method of anti-icing is to be used. The details given in the following paragraphs are of a general nature, outlining some design features of typical windscreen assemblies.

3.1 Windscreens are of laminated construction and in general can be considered as belonging to one of two categories, (i) the simple windscreen, usually fitted to non-pressurised aircraft having limited performance, and (ii) the electrically-heated panel windscreen fitted to pressurised aircraft with all-weather capability.

3.1.1 **Simple Windscreens.** A panel is usually made up of two pre-formed and pre-tempered glass layers or plies, each of which is bonded to a sandwiched sheet or ply of reinforcing material termed the 'interlayer'. The suitability of a material for use as an interlayer depends on a number of factors, the most important of which are its ability to withstand impact, to prevent breakage into dangerous fragments and to prevent detachment of such fragments from the inner surface of a panel. The material normally used for the interlayer is polyvinyl butyral (plasticised with dibutyl sebacate or triethylene glycol de-hexoate), generally referred to as vinyl.

- (i) The vinyl and glass layers are bonded by the application of pressure and heat, the temperature being considerably less than that required for tempering the glass and below the temperature at which vinyl would flow. The bond is achieved without the use of a cement as vinyl, after laminating, has a natural affinity for glass.

3.1.2 **Electrically Heated Windscreens.** These windscreens are used on pressurised aircraft to prevent the formation of ice and mist on the panels and to improve the impact resistance of the windscreen panel at low temperatures (see Appendix 2 of Chapter D4-2 of British Civil Airworthiness Requirements). The physical properties of vinyl vary considerably with changes in temperature. Considering a range of ambient temperatures normally encountered under flight operating conditions, the vinyl would be brittle in the lower part of the range and plastic in the upper part. Since the desired impact resistance characteristics of a windscreen depend to a large degree on the plasticity of the vinyl interlayer, it follows that impact resistance is dependent on interlayer temperature.

- (i) The panels are of special laminated construction containing a resistance type heating element in the form of a film deposited on the inner surface of the outer glass layer. The heating element is supplied with power from the aircraft electrical system via terminals on the panel frame and by busbars 'fired' on to a glass layer at the top and bottom edges of the element. The temperature of the panel is controlled by a temperature-sensing element laminated into the panel and connected to an automatic control unit (see Leaflet AL/11-4).
- (ii) The windscreens in certain of the larger types of aircraft consist of up to seven transparent layers made up of glass, vinyl, acrylic plastic and polyester material. In a typical assembly, three thin vinyl interlayers are employed and they sandwich two layers of thick stretched acrylic plastic. Together the acrylic layers provide most of the windshield structural integrity. The outer layer of the windscreen is a thin, chemically toughened and abrasive-resistant glass layer, and its inner face is covered with the heating element which is supplied with power from busbars at the top and bottom of the windscreen. Two sensing elements for automatic temperature control and an overheat sensing element are laminated into the panel. Only one of the control elements is used; the other serves as a spare. The inner layer of the windscreen assembly is made of an abrasion-resistant polyester material.
- (iii) There are two types of heating elements in general use; namely, tin oxide and gold film, the latter complying with specification DTD 5576A. These panels are briefly described in the following paragraphs.
  - (a) **Tin Oxide Film Panels.** In this type of panel, the heating element is produced by spraying with a flame gun a coating (0.00002 inch thick) of tin oxide at 1000°C on the inner surface of the outer glass layer which is then bonded to the vinyl interlayer.
  - (b) **Gold Film Panels.** In these panels a combined film of gold and metal oxide is used as the heating element. The film is electrically-deposited on the surface of the glass in a vacuum chamber.

3.2 **Windscreen Attachment Methods.** There are several methods of attaching windscreen assemblies dependent on the type employed. The method frequently adopted for simple type windscreens is the one generally referred to as 'Friction Mounting'; it is illustrated in Figure 1. The periphery of the panel is clamped between metal glazing strips and the fuselage frame by a series of bolts. To avoid damaging the glass and to ensure that the joint will be watertight, a suitable lining, usually in the form of a special rubber strip or moulding, is fitted or bonded to the structure.

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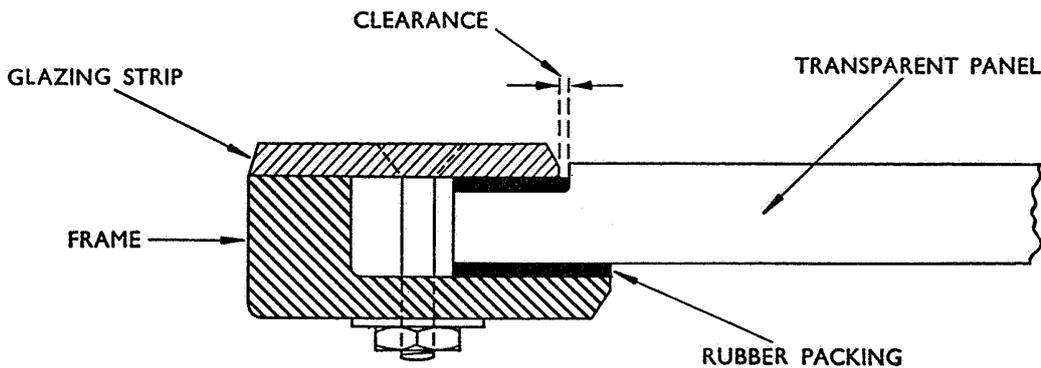


Figure 1. FRICTION MOUNTING

3.2.1 The impact strength of a laminated panel is based on the ability of the interlayer to stretch and deform and thus absorb the shock load, assuming that the impact is great enough to shatter the glass layers. Under such conditions it is essential that the vinyl interlayer be held securely around the edges of the panel. It is for this reason therefore, that panels designed to resist high impact loads and in particular electrically heated panels, are secured to the windshield frames by bolts passing through the edges of the panels rather than relying on the clamping action shown in Figure 1.

- (i) The vinyl interlayer of this type of windscreen is generally thicker than that used in ordinary laminated windscreens and it is extended beyond the periphery of the glass layers. In windscreens employing layers of acrylic plastic this applies to these layers also. A further refinement in the design is an aluminium alloy reinforcing strip, which is in the form of a frame and is embedded in the vinyl. This strip, together with aluminium alloy inserts in each of the bolt holes, assists in preventing the vinyl from deforming at the edges under pressurisation loads and also when tightening bolts during installation. A typical assembly is shown in Figure 2.

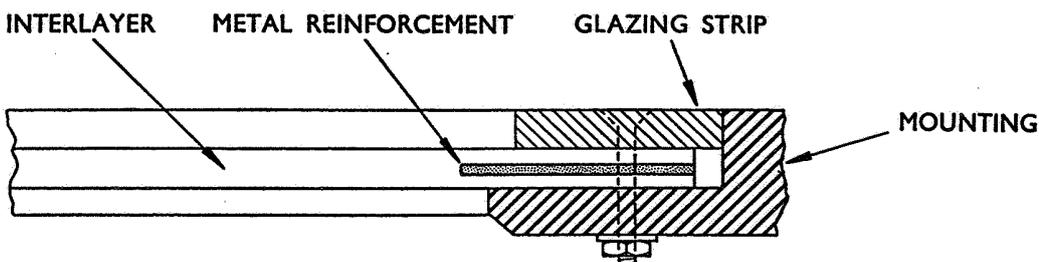


Figure 2. EXTENDED INTERLAYER METHOD

- 4 **INSTALLATION** The installation of windscreen panels must be in accordance with the procedure specified in the relevant aircraft Maintenance Manual. The information given in the following paragraphs is of a general nature and is intended as a guide.

4.1 Before installation, panels should be carefully checked for any sign of damage such as scratches and chips (see paragraph 5.1.2 and 5.1.3). The frames must be clean and seals, where fitted, must be undamaged. Frame mounting faces should be inspected for flatness and freedom from distortion.

NOTE: Cleaning agents must be of the type specified in the relevant aircraft Maintenance Manual and should not be applied indiscriminately to windscreens and surrounding structure. Incorrect cleaning agents may attack the interlayer and cause delamination.

4.2 Where specified, clearances between panels and fuselage structure must be checked to ensure that they are within limits. In some instances, particularly for simple type windscreens, the edges of panels are rebated (see Figure 1) to accommodate the glazing strips and specified clearances between strips and raised portions of panels must be maintained.

4.3 The condition of pressure and weather seals should be examined before installation of a panel and, where necessary, replaced or repaired in the manner specified for the particular type of aircraft.

4.4 In installations requiring a fluid plastic compound for sealing purposes, the compound must be applied in a uniform layer and of the correct thickness to form a gasket between windscreen and fuselage frames, the required thickness being obtained by bolting a windscreen to its respective frame. In some cases a bedding-down template is provided for this purpose.

NOTE: The compound must be left to cure for the relevant time period before finally tightening the attachment bolts.

4.5 A silicone grease (sometimes referred to as a release agent) of the type specified in the appropriate aircraft Maintenance Manual, should be applied to the mating surfaces of windscreen frames to form a silicone film which is non-adhesive to pressure and weather seals and facilitates subsequent removal of panels.

NOTE: In some types of aircraft, a preformed strip or gasket may also be fitted to serve this purpose.

4.6 On electrically heated windscreen panels fitted to certain types of aircraft, a code number is etched in the corner of the glass near the busbar terminals to indicate the heating element resistance. As it is possible for the number to be covered when the panel is installed, details should be noted before installation to ensure correct heating circuit connections.

4.7 In aircraft in which a standby magnetic compass is located on a structural support between two windscreen panels, care must be taken to ensure that the panel attachment bolts in the vicinity of the compass position are of non-magnetic material. After installation, a check compass swing must be carried out to prove the accuracy of the standby compass, with current to the windscreens switched both 'on' and 'off'.

4.8 Attachment bolts and nuts should be coated with a compound to provide a seal at each of the bolt holes. Where compounds are specified, details of types and methods of use are contained in the relevant aircraft Maintenance Manual.

4.9 During the initial stages of fitting attachment bolts, the panel should always be adequately supported to prevent it resting on the bolts thus preventing the countersunk heads from seating correctly. Locating keys are provided for this purpose in some types of aircraft and they should be used in the manner specified. When installing windscreens of the extended interlayer type, it is important to ensure that the specified clearance exists between fixing holes and bolts.

4.10 Attachment bolts should be tightened evenly and in a staggered sequence ensuring that the panel is not distorted and that bolt torque loadings are as specified.

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- 4.11 Cable terminals on electrically heated windscreen panels should be suitably protected against damage. After installation the anti-icing system cables should be connected to their respective terminals, identified in accordance with the relevant wiring diagram and the heating system checked for correct functioning.
- 4.12 After installation of a windscreen panel in a pressurised cabin type aircraft, and elapse of the requisite curing time for sealing compounds, a cabin pressurisation and leak rate test should be carried out if prescribed in the relevant aircraft Maintenance Manual.

5 **INSPECTION AND MAINTENANCE** The information given in the following paragraphs is of a general nature and should be read in conjunction with the Maintenance Manuals and approved Maintenance Schedules for the aircraft concerned. Information on the inspection and maintenance of circuits and components associated with electrically heated windscreen panels is contained in Leaflet AL/11-4; reference should therefore be made to this Leaflet.

5.1 **Damage.** Panels should be inspected for defects and any signs of damage such as delamination, chipping and cracking of glass layers. The following brief descriptive details are intended as a guide to this type of damage and other defects which may occur.

5.1.1 **Delamination.** This is a defect which can occur in laminated windscreens characterised by the separation of a glass layer from the vinyl interlayer. Delamination should not be confused with deliberate stress-relieving edge separation of panels which is sometimes employed. In such cases a parting medium is used, introducing a separation penetrating the edges of the panel assembly to a distance of 0.25 inch to 1 inch and giving a yellowish or brownish appearance at the edges.

(i) Defective delamination has characteristics that tend to divide it into the following main types, and resulting from different types of stress at the glass/vinyl interface.

(a) **Clear (or cloudy).** Of the two types, delamination is apt to be clear. However cloudy delamination will result if moisture penetrates the delaminated area. In doubtful cases delamination can be confirmed by carrying out a reflection test by means of a flaw detector using a light beam. The beam is directed on to the surface of the windscreen and produces two sharply defined lines on a ground-glass screen representing the top and bottom surfaces of the windscreen. Any delamination present will produce an additional line and its proximity to either of the other lines is helpful in deciding which of the layers has separated.

(b) **Rough-edge.** This is characterised by its irregular, sharp or jagged boundary. It may develop long finger-like projections if, during the course of delamination the parting between vinyl and glass is not uniform.

(c) **Smooth-edge.** Smooth-edge delamination advances with a smooth boundary. It does not have rough or jagged areas within it, nor indications of internal cracks or chips.

(ii) A small amount of delamination is permitted on most aircraft but details of the permissible extent and any limits concerned with aircraft flight operations, e.g. flights under pressurised conditions, should be obtained from the relevant aircraft Maintenance Manual and Flight Manual.

5.1.2 **Scratches.** Scratches are defects in the surface of a panel and every effort must be made to avoid them. They are normally more prevalent on the outer surface where windshield wipers are indirectly the primary cause. Any dust or grit trapped

by a wiper blade can immediately become an extremely effective cutting device as soon as the wiper is set in motion. Wiper blades must therefore be maintained in a clean condition and should only be operated when the windscreens are wet.

- (i) On the basis of severity, scratches may be classified as hairline, light and heavy.
  - (a) **Hairline Scratches.** A hairline scratch can be seen but is difficult to feel with a fingernail. It can be caused by wiping the glass with a dry cloth. To avoid hairline scratches, the glass should be cleaned with a mild detergent and water, using a soft brush or clean, soft cotton cloth, followed by drying with a clean, soft cotton cloth.
  - (b) **Light Scratches.** A light scratch is less than .010 inch deep and can be felt with a fingernail. This type of scratch ordinarily has few edge chips.
  - (c) **Heavy Scratches.** A heavy scratch is .010 inch or more in depth and can be readily felt with a fingernail. This type of scratch is apt to show extensive edge chipping.
- (ii) If the integrity of a panel is not suspected and provided visibility is not seriously affected, scratches are permissible within limits detailed in the relevant aircraft Maintenance Manual.
- (iii) Scratches can be removed by polishing, but due to an uneconomic time factor, possible optical distortion and problems of assessing optical standards acceptable in the ultimate operational situations, it is recommended that a panel assembly be returned to the manufacturer and replaced by a serviceable assembly.

**5.1.3 Chipping.** Chips are flakes or layers of glass broken from the surface which can occur if the exterior surfaces of a panel are struck by a sharp object. The inner surfaces of a lamination of the panel may also chip in unheated areas, as a result of high internal stresses. There are two types of chips: conchoidal and V-shaped. Conchoidal chips are usually circular or curved in shape with many fine striations that follow the outline of the outer edge. V-shaped chips are sharp and narrow, the 'V' appearing to propagate toward the interior of the glass. Visibility through chipped areas of a windscreen panel is usually poor.

- (i) Chips occurring at the inner surfaces of glass panes are critical because the existing condition may result in cracking or shattering of a pane, or in the case of an electrically heated windscreen, destruction of the resistance heating film. These chips are usually associated with rough-edge delamination (see paragraph 5.1.1).

**5.1.4 Cracks.** These are serious defects which, depending on the type of glass and the formation and propagation of the cracks, may result in considerable strength reduction of the windscreen and effects on visibility varying from slightly impaired to complete obscurity. In annealed glass the damage may take the form of single cracks, or cracks forming an irregular criss-cross pattern. The more usual result of damage to strengthened glass is the formation of cracks spreading radially from the point of damage and in these cases, vision is impaired but not completely obscured. Cracks in a toughened glass form a pattern defined as shattering, a defect resulting in considerable reduction in strength and loss of vision. A windscreen having such a defect should be removed and replaced by a serviceable assembly.

- (i) The extent to which cracks are permitted, limitations on aircraft operation and the action to be taken in order to rectify the defects, may vary between aircraft types. Details are given in the relevant aircraft Maintenance Manual and Flight Manual and reference must therefore always be made to these documents.

**5.1.5 Vinyl Rupture.** Vinyl rupture consists of a failure across the section of vinyl at the inner edge of the metal insert (Figure 2) and necessitates changing the panel.

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5.1.6 **Vinyl 'Bubbling'**. Small bubbles occurring within the vinyl interlayer of electrically heated windscreens are not a delamination nor are they structurally dangerous. They are usually due to overheating conditions, being formed by a gas liberated by the vinyl. They need not be a cause for windscreen replacement unless vision is seriously impaired. Their presence, however, may indicate a defective window heat control system which should be rendered inoperative pending rectification. (See also Leaflet AL/11-4).

5.1.7 **Discolouration**. Electrically heated windscreens are transparent to direct light but they normally have a distinctive colour when viewed by reflected light. This apparent discolouration is due to the resistance heating film and it may vary slightly between windscreens. Only black or brown discolouration, when viewed normal to the surface, should be regarded as a possible defect necessitating removal of the windscreen and replacement by a serviceable one. The cause of such discolouration may be a burnout of the heating film or a carbon deposit between a busbar and the heating film due to overheating.

5.2 **Sealants**. Weather sealants provided around the periphery of windscreens must be inspected for evidence of erosion, lack of adhesion, separation or holes. The obvious purpose of maintaining an effective weather sealant is to protect the windscreens against moisture entry and the delamination or electrical problems associated with moisture penetration. When new sealant is required, the damaged material should be removed, the area cleaned, and new material applied in the manner prescribed in the relevant aircraft Maintenance Manual.

**NOTE:** Damaged material should always be removed with a plastic tool that will fit, without binding, in the gap between windscreen and frame. The use of a metal tool is inadvisable, as this could damage the glass or vinyl interlayer.

5.3 **Cleaning of Windscreens**. Windscreens should be washed regularly with warm water and mild detergent, using a clean, soft cloth or cotton wool pad; after washing the panels should be rinsed and dried with a clean, soft cotton cloth. Scratching of the glass must be avoided.

5.3.1 Some aircraft manufacturers recommend the use of a proprietary detergent which is also suitable for the surrounding aircraft structure and therefore to some extent simplifies cleaning operations; it is important that only the detergent specified is used and that the prescribed proportion of detergent to water is observed.

5.3.2 Grit, dirt, etc., should be removed at regular intervals from recesses, for example, where the panel joins the frame, to prevent it being picked up by the cleaning cloths and causing scratching. The accumulation of cleaning and polishing materials in recesses must be avoided.

6 **STORAGE** Extreme care is necessary during transportation, storage and handling of windscreens to prevent damage. It is recommended that panels should be packed with both faces covered with adhesive polythene; they should then be wrapped in acid-free paper and cellulose wadding and put into reinforced cartons, these being covered with waxed paper and secured with adhesive tape.

6.1 The panels should be stored in their cartons on suitable racks, away from sunlight or strong artificial light, at a controlled temperature of between 50°F to 70°F in well ventilated conditions.

6.2 It is important to ensure that during handling or storage the thicker glass ply of a laminated panel is kept uppermost to prevent delamination (paragraph 5.1) and that the polythene film is not removed until the panel is fitted to the aircraft.

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**AIRCRAFT  
STRUCTURES****THE EFFECT OF DISTURBED AIRFLOW ON AEROPLANE  
BEHAVIOUR**

**1 INTRODUCTION** This Leaflet gives general guidance on the cause and effect of disturbed airflow on aeroplane behaviour, with particular reference to high-performance aeroplanes. It emphasises the need for special care in the preservation of correct airframe contours because of the serious effect on aeroplane behaviour, particularly at high speeds, of seemingly trivial discontinuities in contour, profile, etc.

**1.1** It is important that the point of transition from laminar to turbulent airflow on aerofoil surfaces occurs at the position intended in the design. At high subsonic speeds the transition point may be designed to be effective at a position some 30 to 50% along the wing chord from the leading edge, and can be very sensitive to even small protuberances or discontinuities on the wing surface.

**1.2** Faulty contours can have dangerous effects on an aeroplane flying at or near the stalling speed, whilst rough surfaces, badly fitting joints, gaps, etc., will adversely affect, to some extent, performance in all regimes of flight. However, defects which may be considered of minor importance to low-speed aeroplanes may have a considerable influence on aeroplanes flying at higher speeds. For example, the behaviour of the airflow over an aileron can be seriously affected by those departures from design which influence the position of the transition point, thus affecting the response, or the rate of response, of the aeroplane, the trim and the drag.

**1.3** No attempt is made in this Leaflet to describe any aerodynamic principle or theory; any description or illustration given is solely to help clarify the 'cause and effect' of the defect and is not considered to be a formal aerodynamic representation.

**1.4** Since the methods used to determine the causes of flying faults (and the methods of rectification) vary considerably with different types of aeroplanes, it is essential that the manufacturer's instructions, as specified in the relevant manuals, should be carefully followed.

**1.5** Guidance on the rigging and adjustment of flying controls is given in Leaflet AL/3-7, on the general rigging of aeroplanes in Leaflet AL/7-12, and on the inspection of aeroplanes after heavy landings or abnormal flight loads in Leaflet AL/7-1.

**2 GENERAL** In high performance aeroplanes the surfaces subjected to airflow are constructed to within relatively close contour and gap limits, and these limits have to be maintained if increased drag and other penalties are to be avoided. In this connection, the most critical areas of the aeroplane, where high accuracy in manufacture and the greatest care in maintenance are involved, include the leading edges of wings, tail plane and flying control surfaces, shrouds and trailing edges, engine intakes and static-vent areas. However, it should be noted that production tolerances are normally permitted, and thus it should never be necessary to adjust any dimension to give an accuracy greater than that required by design solely for the purpose of maintaining performance standards.

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2.1 Modern high performance aeroplanes are so constructed that the original smoothness of contour is maintained more effectively than in previous generations of aeroplanes (e.g. by the use of machined skin panels). Nevertheless, small departures from the prescribed alignment and contours can occur during service and may be very difficult to recognise. Although such irregularities may have a negligible effect at lower speeds, changes of trim may occur as the aeroplane reaches its limiting Mach number.

NOTE: Although an aeroplane may be flying at subsonic speed, it is not unusual for the airflow over certain sections to be at transonic or supersonic speed.

2.2 Apart from changes of attitude and trim which may or may not occur due to departures from the original aerodynamic contours (e.g. malalignment of control surfaces, incorrect fitting of inspection panels, fairings and cowlings, dents or wrinkles in wing skins, protruding bolt heads, etc.), such defects will also cause an increase in drag, resulting in a deterioration in aeroplane performance and range. For long-distance flights the results could be a marked increase in fuel consumption and seriously reduced fuel reserves.

2.3 In addition to defects which may be 'built in' as described in paragraph 2.2, it should be borne in mind that fairings and other fittings which are insecurely attached, might distort in flight, with similar results.

2.4 In summing up, it can be said that anything which disturbs the normal smooth airflow over an aerodynamic surface will have an adverse effect on the handling and performance of the aeroplane. However, if such adverse effects are reported, the full range of ground-set trim adjustments should be utilised before a search is made for the less obvious profile defects.

3 **DEFECTS** For the purpose of this Leaflet, it is assumed that the more common control faults, such as mechanical stiffness, jerkiness of controls, excessive play, etc., have been dealt with, and that servo motors, cable tensions, spring struts, rigging limits, etc., are satisfactory.

3.1 **Engine Cowlings and Fairings.** The correctness of the fit of engine cowlings and fairings is important and must be within drawing tolerances, since, for example, if excessive airflow enters inside the cowlings, considerable pressure build-up may occur and drag may result (see also paragraph 3.4.2). The gaps between the edges of cowlings and fairings should be within design limits (see Figure 1) and no overlap should be permitted unless this is the design intention. It is essential that any rubbing strips or seals on to which the cowlings or fairings bed should be in good condition.

3.1.1 The contours of cowlings and fairings should be maintained in the design condition, since dents, bent corners or protruding attachment bolts or other securing devices will affect the flow of air over the component. It should also be ensured that the cowlings and fairings are so adjusted and locked that they cannot move or vibrate in flight as a result of aerodynamic loads.

3.1.2 The contours of turbine engine air-intake ducts are of particular importance, since dents or damage to the lips of the ducts or the skin inside will interfere with the smooth airflow to the engine, with a resultant loss in performance and an increase in fuel consumption. In some cases such defects have resulted in rough running of the engine because of uneven distribution of air to the compressor and, in other cases, in inefficient operation of the engine cooling system.

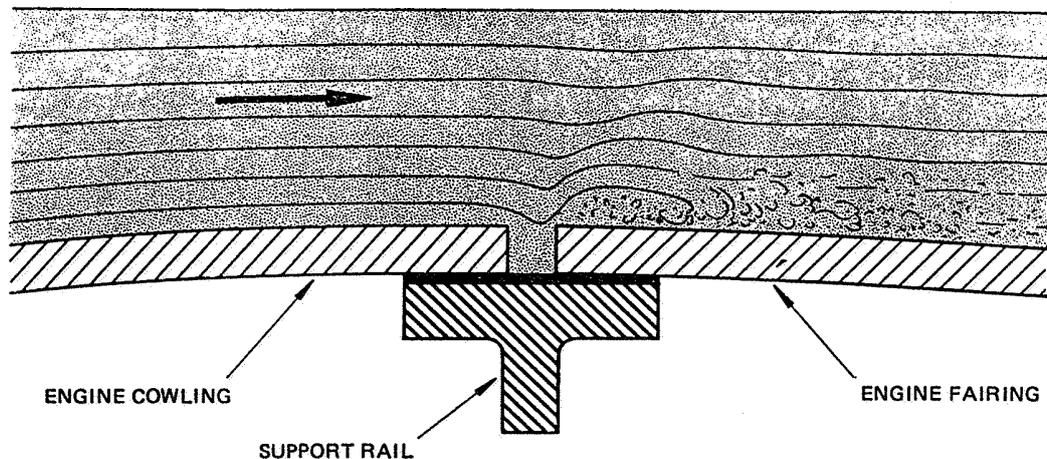


Figure 1 DRAG DUE TO GAP IN COWLINGS

3.1.3 Cowlings and fairings should be stored and handled with care (see also paragraph 4.4). Attachment devices, locating dowels and fittings should be checked for looseness resulting from strain, wear, etc. Toggle fasteners should be correctly adjusted to give the required 'over-centre' loading and the associated fairings should be a good flush fit.

3.2 Fuselage. Cabin pressure leaks can cause a severe disturbance to the smooth flow of air along the fuselage and will create a considerable increase in drag. It should be ensured that cabin pressurisation seals at entrance doors, emergency hatches, clear-  
 vision panels, etc., provide a complete and effective seal. The effect of such a defect is  
 illustrated in Figure 2.

3.2.1 Entrance doors, hatches, etc., should be carefully checked for alignment with the fuselage skin, with the fuselage pressurised where appropriate, since if any wear has occurred to the latches, locks, rails or hinges, it may permit the door, hatch, etc., to protrude beyond the normal fuselage contour, creating a disturbance to the airflow.

3.2.2 It should be noted that the effect of pressurisation leaks, malalignment of aerodynamic contours, etc., is particularly detrimental towards the forward end of the fuselage, and special care should therefore be given to the fit of windscreens, glazing strips, crew entrance doors, nose fairings and radomes.

3.3 Wings. The smoothness and contour of the wing surfaces, especially the top surfaces, is of the utmost importance if increased drag is to be avoided and the lateral trim of the aeroplane is to remain unaffected throughout the speed range.

3.3.1 It is necessary, for example, on aeroplanes fitted with fuel filler caps designed to be flush with the top surface of the wing, to ensure that the cap is fitted properly and not protruding above the wing contour; this is particularly important, for example, after fitting new sealing washers.

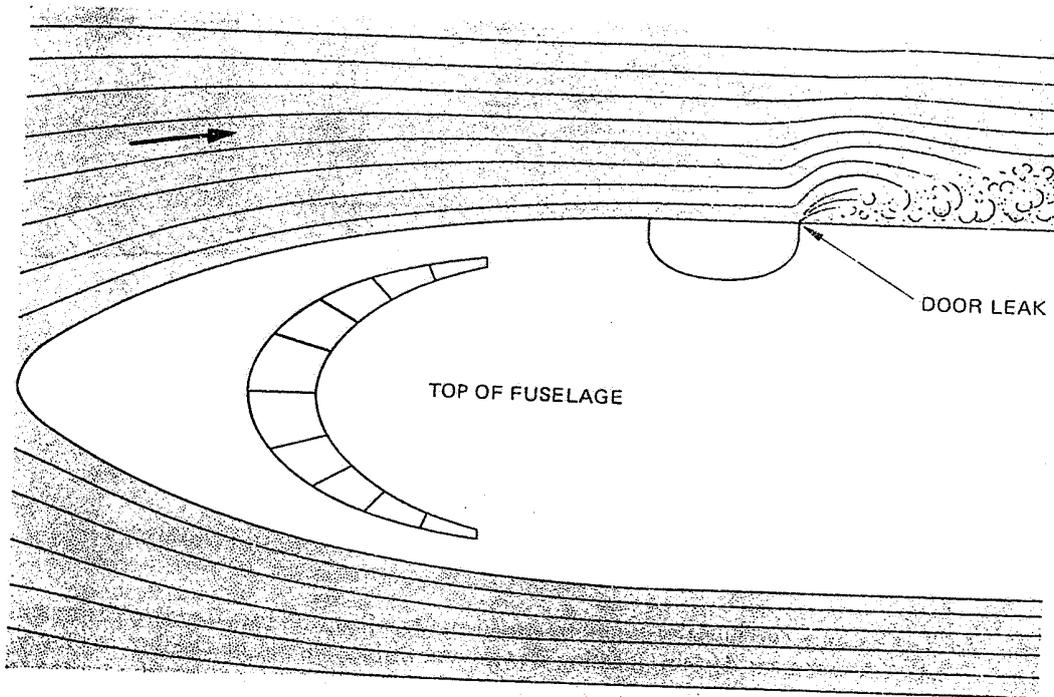


Figure 2 PRESSURE LEAK FROM FUSELAGE

3.3.2 Even small irregularities such as those caused by protruding rivet or bolt heads, badly replaced screws in panels, stepped or gapped panel joints, convexity and concavity or ripples in the wing skin which may not be obvious during normal inspection, must not be ignored, since all can result in a break in the smoothness of the airflow over the wing.

3.3.3 An important factor from the point of view of high Mach number performance, is waviness, and this is most important near the leading edges of lifting surfaces. Waviness can cause early shock-wave effects, which result in increased drag and a lower buffet boundary.

3.3.4 On aeroplanes which carry dinghies or life-rafts in wing stowages, the fit of the stowage cover is of paramount importance in maintaining the design airflow over the wing. The fit of the cover with the surrounding skin contour must be maintained within permitted tolerances. Correct fit may be obtained by adjustment of the cover retaining attachments, but can also be affected by the weather-seal around the interior of the cover.

3.3.5 The wing tip is also an important part of a wing, and should be examined for surface condition. Detachable wing tips should also be examined to ensure that the chord line and rigging are satisfactory.

3.3.6 To ensure freedom from defects such as those described in 3.3.1 to 3.3.5, some manufacturers of high speed aeroplanes provide contour jigs or templates with which to check the wing surfaces, including the leading edges, shrouds, and trailing edges. Such jigs should be used with considerable care and in accordance with the manufacturer's instructions; any departures from contour in excess of permitted limits should be rectified.

3.3.7 When jigs are not available, a rough check for contour defects may, in some cases, be made by running the fingers around the suspected surfaces, since this may reveal irregularities in surface finish which may not otherwise be perceptible. It is also sometimes helpful in the detection of more obvious defects, such as skin dents, malalignment of shrouds and ailerons, etc., when jigs are not available, to stretch a thin cord across the wing, from the leading edge to the trailing edge and parallel to the line of flight, and to check as indicated in Figure 3.

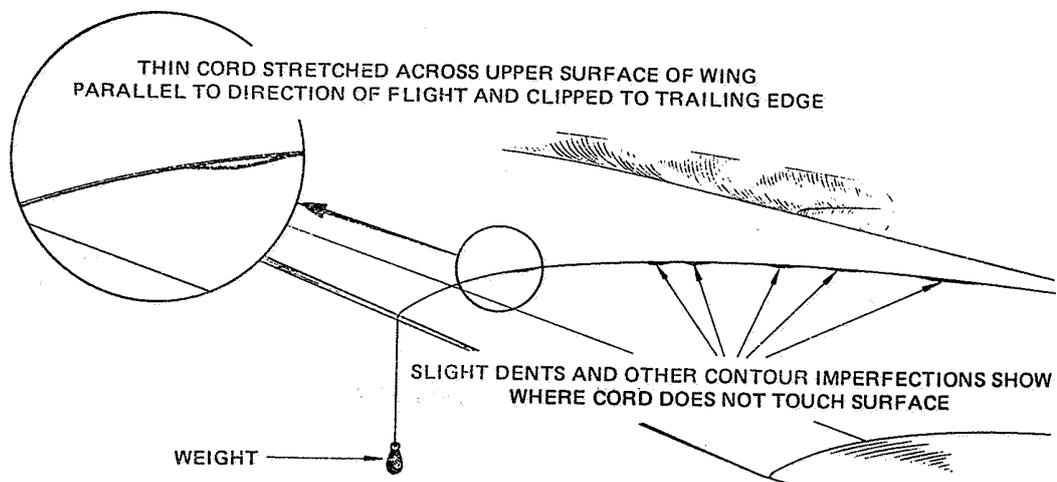


Figure 3 CHECKING CONTOURS

3.3.8 It is sometimes possible to make a rough check on the more obvious types of defects by locking all the flying controls in the neutral position and then standing aft of the aircraft as shown in Figure 4. This may reveal distortion or damage to the trailing edges of the wings, flying controls and shrouds, which may sometimes be caused by accidental contact with ground equipment.

(a) By slightly altering his position (up or down) the observer can make a rough check on the control surfaces and the rear of the wing surfaces. This is mainly done to check access points, tank doors, rear edges of cowlings, etc., to ensure that they blend into the natural contours of the aerofoil surfaces.

3.3.9 A check similar to that outlined in paragraph 3.3.8 can be made from a position forward of the wing, in order to check the contour of the wings and tailplane, with special emphasis on the leading edges, since defects in these areas are particularly critical.

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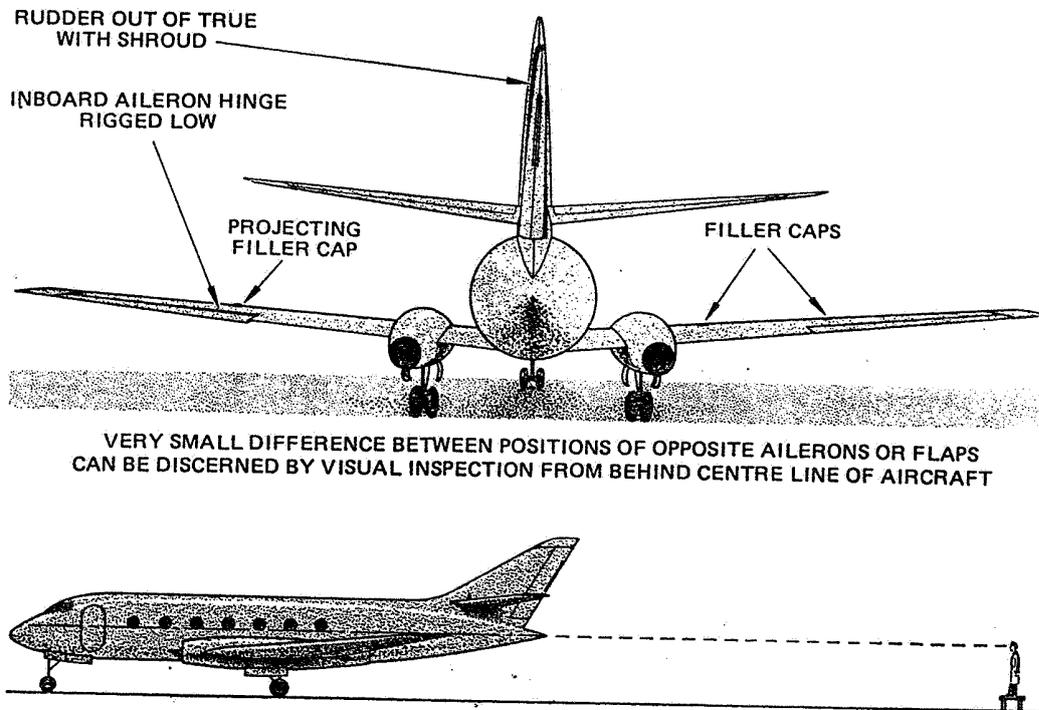


Figure 4 CHECKING BY OBSERVATION

3.4 **Landing Gear Doors and Fairings.** Landing gear doors and fairings are often the cause of considerable drag and should, therefore, be carefully inspected in the retracted position for fit, contour and sealing. In addition, such components may be subjected to high aerodynamic loads, and the possibility exists that badly fitting or ineffectively secured panels could become detached from the aeroplane, with serious results. Where such components are subjected to high aerodynamic loads the rigging procedures normally incorporate a degree of pre-loading to counter the effect of air loading.

3.4.1 In some cases it may be found necessary to simulate aerodynamic loads by loading the doors with weights or by use of a spring balance. This practice would indicate any excessive play or backlash in the mechanical linkage. In mechanically-actuated door operating systems, this check would be sufficient to ensure against sag in flight, but when the door operating system is completely or partially hydraulically operated, subsequent sag in flight may depend on the efficiency of the hydraulic system. In the latter case every effort should be made to ensure that the relevant part of the hydraulic system is free from both internal and external leaks.

3.4.2 A landing gear door, fairing or seal which is in any way badly fitting when the door is closed may allow air to enter the landing gear bay and eventually escape at the aft end of the door or fairing, creating considerable drag. In this case drag is caused

by the fact that the air leaking into the cavity loses speed and then has to be speeded up again as it leaks out at the other side. Figure 5 illustrates the more serious case of flow breakaway as a result of leakage, but even if this does not occur, the drag penalty may still be quite high.

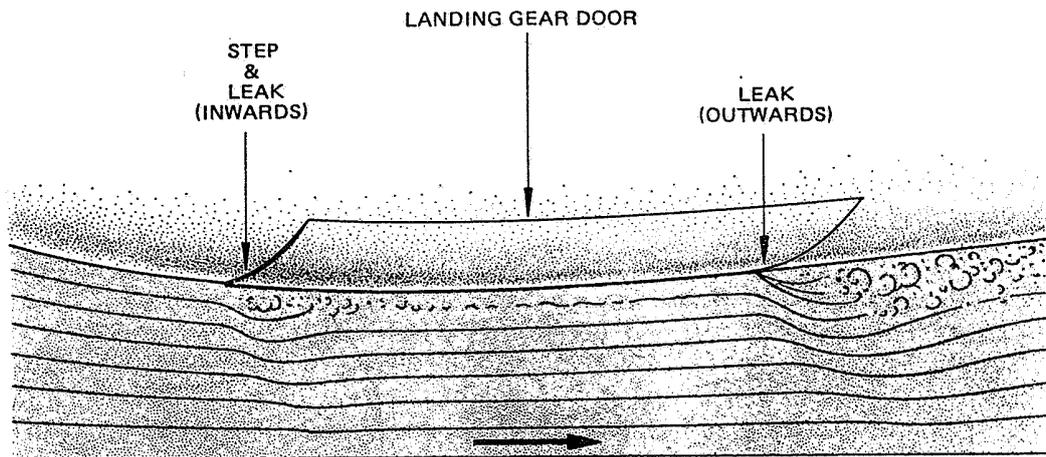


Figure 5 LEAKS AT LANDING GEAR DOOR

- 3.5 **Flaps.** The undersurface of the flaps should be examined for damage caused by debris thrown up during take-off and landing, and flap shrouds should be checked for security, damage and distortion. The flaps should also be checked for sagging when in the "up" position. In the case of flaps which employ slots for improved efficiency it should be ensured that the correct gaps are maintained.
- 3.6 **Aileron Shrouds.** The clearances between ailerons and aileron shrouds are very critical and must be checked carefully. The shrouds should be rigid and free of any form of damage on both bottom and top surfaces, and care must be taken to ensure that no distortion of the shroud, or the wing skin immediately in front of the shroud has occurred, since this could upset the airflow over the aileron in a manner similar to that illustrated in Figure 6.
- 3.7 **Movable Leading Edge Devices.** Movable leading edge devices should be checked in the retracted position to ensure that they conform to the contour of the main wing, particularly on the upper surface. The condition of any seals in the leading edge should also be checked, to ensure that there is no air leakage from the lower to the upper surface. The leading edge devices should also be checked in the extended position to ensure that the correct gap is maintained between the devices and the wing.
- 3.8 **Airbrakes/Spoilers.** Airbrakes and spoilers should be checked to ensure that they are a flush fit when retracted. Where spoilers are used for lateral control, they should be checked to ensure that the 'dwell' before spoiler extension with control displacement is correct.

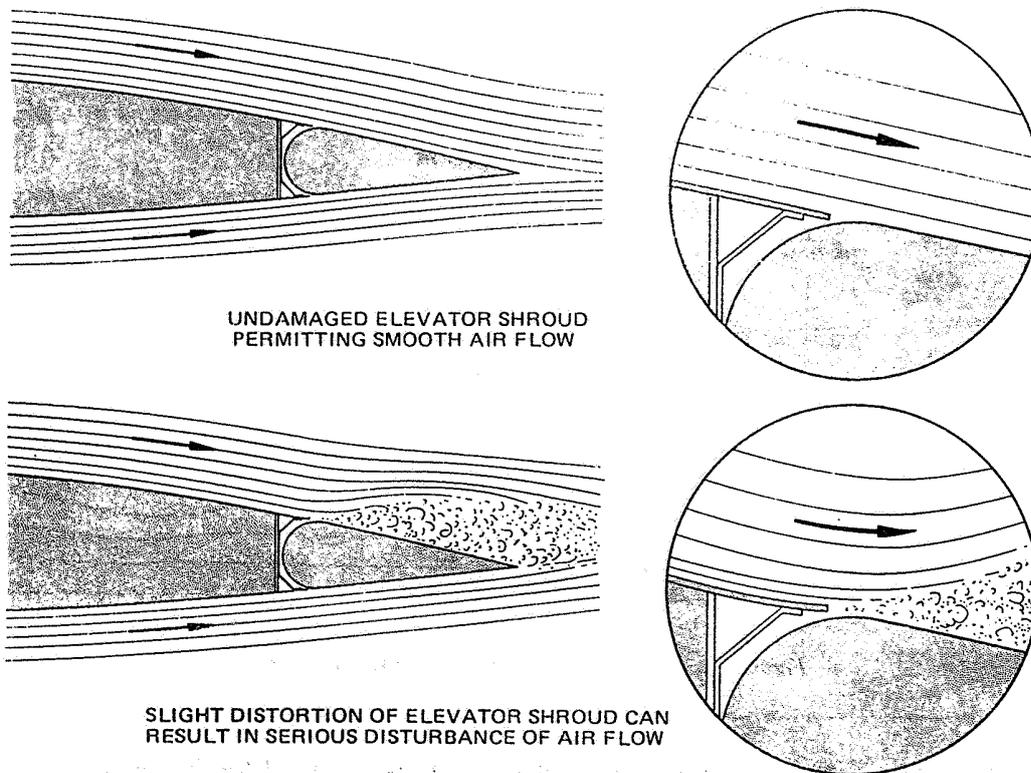


Figure 6 AIRFLOW OVER ELEVATOR

- 3.9 **Vortex Generators.** A check should be made to ensure that vortex generators are not bent or distorted, and that none is missing.
- 3.10 **Wing Fences.** Wing fences should be checked for alignment and, in addition, the condition of any seals between the fence and the wing should be carefully checked.
- 3.11 **Tail Unit.** Care should be taken to ensure that any fillets between the tailplane and fin, and the fin and fuselage, are in good condition and free from dents and other damage.
- (a) The leading edges and surfaces of the tailplane and elevators should be checked for damage caused by debris thrown up during engine run, take-off and landing.
  - (b) Particular care should be paid to the alignment and clearance of rudder and elevator shrouds, since these can become very critical at speeds approaching Mach 1. Slight distortion of tailplane shrouds or excessive clearances can create a breakaway of the airflow over the elevator surfaces at high speeds which can result in little or no response to elevator control inputs. As these conditions would generally occur only at speeds approaching the limiting Mach number for the aeroplane concerned, it should be assumed that the lack of elevator response might occur in a dive when a dangerous condition could result. The airflow which occurs over the elevators is illustrated in Figure 6.

- 4      **PRECAUTIONS DURING MAINTENANCE**      To ensure as far as possible against damage to aeroplane surfaces during maintenance, the precautions outlined in the following paragraphs are recommended as the minimum necessary.
- 4.1      When working on the top surfaces of aeroplanes, precautions should be taken to avoid damage to the surface by scratching, etc., and suitable mats or protective coverings, as detailed in the appropriate manual, should always be placed in position before work is commenced.
  - 4.2      Ladders or trestles should never be rested against any part of the aeroplane, and fuelling hoses should not be dragged over flying control surfaces, wing leading or trailing edges, etc.
  - 4.3      When removing inspection covers, panels, cowlings, fairings, etc., they should never be levered off, since this may damage and distort them. Leverage should not be applied when securing or unlocking fasteners, since this may strain the fasteners to such an extent that the associated panel could become loose.
  - 4.4      Cowlings, fairings, etc., should never be placed directly on to concrete floors. It is recommended that suitable racks should be provided on to which the cowlings can be placed immediately after removal from the aeroplane.
  - 4.5      When a panel, fairing, etc., is removed, it should be checked to ensure that the condition of any rubber moulding or sealing strip is satisfactory.
  - 4.6      In certain wet take-off conditions followed by freezing, the landing gear door seals may sustain damage as a result of icing, and these should be checked for any such damage.
  - 4.7      On aeroplanes having painted surfaces, it is essential that the thickness of the paint coating, particularly at leading edges, should be carefully controlled, since the amount of paint on the top side of a leading edge can easily influence the trim of an aircraft. This is particularly important where fillers are used to restore leading edge contours and the finished work should always be checked with a contour jig.
  - 4.8      All surfaces should be kept clean, since dirt, oil or mud will always adversely affect the performance of the aeroplane.
  - 4.9      When changing control surfaces or other aerofoil components, care should be taken to ensure that the new components fitted are in correct aerodynamic alignment with the surrounding structure, since the slight differences which can occur in nominally similar components, as a result of manufacturing tolerances, could affect the trim or performance of the aeroplane.
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**AL/7-12**

Issue 1.

15th April, 1964.

**AIRFRAME****STRUCTURES****RIGGING CHECKS ON AIRCRAFT**

- 1 **INTRODUCTION** This leaflet gives guidance on methods of checking the relative alignment and adjustment of aircraft main components and should be read in conjunction with the appropriate manual for the aircraft concerned. Information on flying control components and the rigging of flying controls is given in Section AL/3 of the Procedures. Guidance on checking the rigging of aircraft after abnormal flight loads or heavy landings is given in Leaflet AL/7-1.
  
- 2 **LEVELLING THE AIRCRAFT** The position or angle of main components is related to a longitudinal datum line parallel to the aircraft centreline and a lateral datum line parallel to a line joining the wing tips. Before these positions or angles are checked,

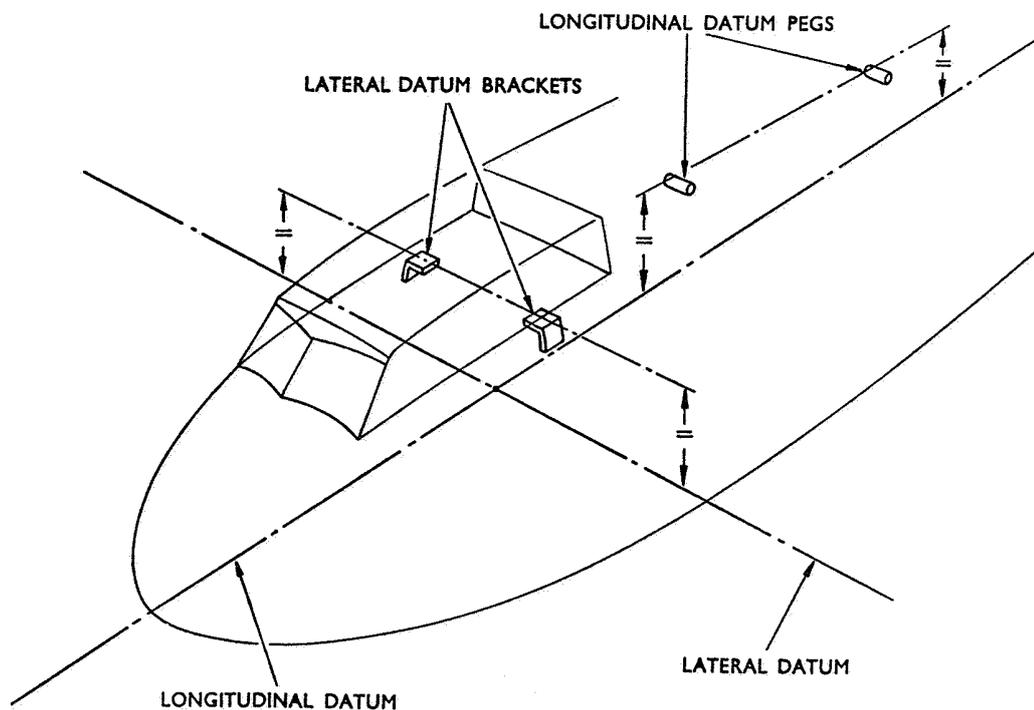


Figure 1 DATUM LINES AND LEVELLING POINTS

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the aircraft should (generally) be brought to the rigging position (i.e. with the lateral and longitudinal datum lines horizontal) by means of jacks or trestles, depending on the particular aircraft type, with the wheel just clear of the ground.

2.1 For the purpose of checking the level of smaller types of aircraft, fixed or portable datum pegs or blocks, on which can be rested a straight-edge and spirit level and which are generally attached to the fuselage parallel to or co-incident with the datum lines, are used, although in some instances parts of the structure which run parallel with the datum lines (e.g. top longerons or canopy rails of some aircraft) may be utilised. A typical levelling arrangement is shown in Figure 1.

2.2 The methods of checking the levelling given in paragraph 2.1 are also applicable to many of the larger types of aircraft, but other methods are sometimes used, e.g. the "grid" method illustrated in Figure 2. The grid plate is a permanent fixture on the floor of the aircraft and, when the aircraft is to be levelled, a plumb bob is suspended from a predetermined position in the roof of the aircraft over the grid plate. The adjustments necessary to the lifting gear to bring the aircraft to the level position are indicated by the grid scale, true level being obtained when the plumb bob is immediately over the centre point of the grid.

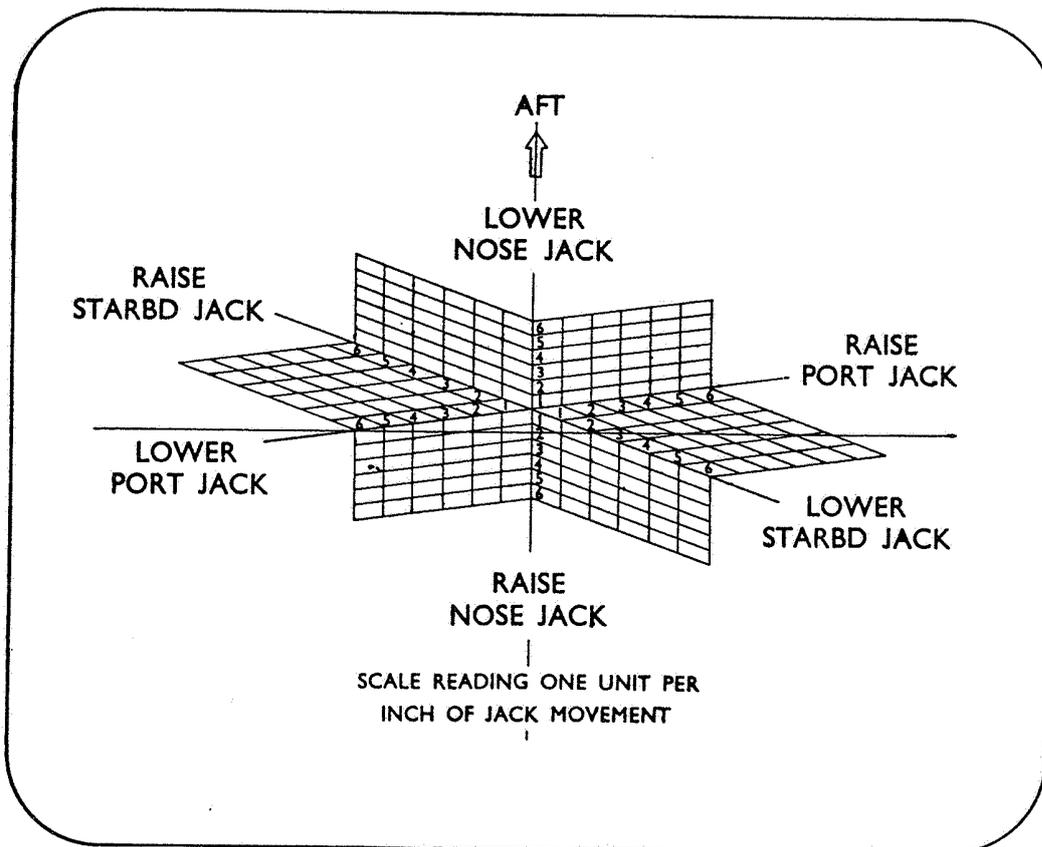


Figure 2 TYPICAL GRID PLATE

- 2.3 The method of bringing the aircraft to the rigging position depends largely on the size and type of aircraft and whether a nose wheel or tail wheel configuration applies, the general procedures applicable to each case being given in paragraphs 2.9 and 2.10 respectively. However, there are certain precautions that must be observed in all instances and guidance on these is given in paragraphs 2.4 to 2.8. Guidance on precautions to be taken when lowering the aircraft is given in paragraph 4.
- 2.4 A level site capable of bearing the load to be applied should be selected for the operation otherwise, where trestles are used, it may not be possible to level the aircraft, and where jacks are used, the danger of the jacks toppling and dropping the aircraft would exist.
- 2.5 Rigging checks should not normally be undertaken in the open, but if this is unavoidable the aircraft should be positioned nose into wind. In any case the aircraft should not be lifted in strong winds or gusts.
- 2.6 The weight and loading of the aircraft for the rigging check should be exactly as described in the manual or as quoted on the original rigging chart supplied by the manufacturer. Variations from this condition, especially in the case of larger aircraft, will prohibit a comparison with the original figures. In any case the aircraft should not be lifted until it is ensured that the maximum jacking weight (if any) specified by the manufacturer will not be exceeded.
- 2.7 All equipment which may cause damage to the aircraft during the lifting operation should be moved away before lifting is commenced and no personnel other than those directly connected with the rigging check should be permitted on or around the aircraft for the duration of the complete operation.
- 2.8 For most aircraft the brakes should be OFF and the wheels chocked prior to lifting but for aircraft fitted with levered suspension undercarriage units the wheels should be left unchocked.

### 2.9 Tail Wheel Aircraft

- 2.9.1 The tail should be raised to an approximately level position by means of the appropriate jacks or adjustable trestle accurately positioned under the rear lifting position. Where single-engine aircraft in particular are concerned, it may be necessary to weight down the tail to prevent the aircraft nosing over due to the weight of the engine. This weight must not be allowed to swing but must touch the ground and be secured by a taut rope to that part of the aircraft specified by the manufacturer.
- 2.9.2 The appropriate jacks or adjustable trestles should be accurately positioned under the main lifting points and the aircraft raised evenly by operating both jacks or trestle gears together until the wheels are just clear of the ground and the aircraft is in the (approximate) rigging position.

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2.9.3 The lateral and longitudinal levels should be checked and adjusted as necessary by means of the lifting gear. Where hydraulic jacks are used, the locking devices provided must be applied immediately the aircraft has been correctly positioned and, to ensure the safety of personnel, at any time when the jack is not actually being operated during the lifting of the aircraft.

2.9.4 If steady trestles are placed under the wings after the aircraft has been supported in the rigging position, it must be ensured that they are not in contact with the wings when incidence or dihedral checks are being made, that no adjustments are made to the lifting gear with the steady trestles in position and that the trestles are removed before any attempt is made to lower the aircraft (paragraph 4).

2.10 **Nose Wheel Aircraft.** The appropriate trestles or jacks should be accurately positioned under the main, nose and (if applicable) tail positions. The main and nose lifting gear should be operated simultaneously and evenly until the aircraft is just clear of the ground and the operation completed as described in paragraphs 2.9.3 and 2.9.4.

**3 RIGGING CHECKS** Although the dihedral (paragraph 5.2) and incidence (paragraph 5.5) angles of conventional modern aircraft cannot be adjusted (with the possible exception of adjustable tailplanes) they should be checked at specified periods and after heavy landings or abnormal flight loads (see also Leaflet AL/7-1) to ensure that the components are not distorted and that the angles are within permitted limits. The relevant figures together with permitted tolerances are specified in the appropriate manual for the aircraft concerned, but the actual figures relevant to an individual aircraft are recorded in the aircraft log book.

3.1 The usual method of checking rigging angles is by the use of special boards (or the equivalent) in which are incorporated or on which can be placed an instrument for determining the angle, i.e. a spirit level or clinometer as appropriate. On a number of modern aircraft the rigging can be checked by means of sighting rods and a theodolite. Guidance on rigging checks with rigging boards is given in paragraphs 3.3 and 3.4 and on the use of sighting rods in paragraph 3.5.

3.2 **Sequence of Rigging Checks.** A suitable sequence for checking the rigging is as follows; it is essential that the checks should be made at all the positions specified in the relevant manual.

- (i) Wing dihedral angle(s)
- (ii) Wing incidence angle(s)
- (iii) Engine alignment
- (iv) Tailplane lateral level or dihedral

(v) Tailplane incidence angle

(vi) Verticality of fin

(vii) Symmetry check

NOTE: Where rigging checks on control surfaces are being combined with these checks, guidance on suitable methods is given in Leaflets AL/3-1 and AL/3-5.

### 3.3 Checking Aircraft with Rigging Boards

3.3.1 **Dihedral.** The dihedral angle should be checked in the specified positions with the special boards provided by the aircraft manufacturer or, if no such boards are provided, with a straight-edge and clinometer. The methods of checking with both types of board are shown in Figure 3.

NOTE: Certain portions of the wings or tailplanes may sometimes be horizontal or on rare occasions, anhedral angles may be present.

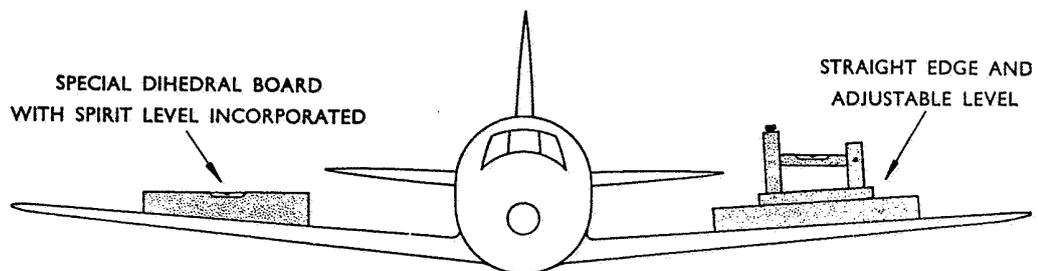


Figure 3 CHECKING DIHEDRAL

3.3.2 **Incidence.** The incidence is usually checked in at least two specified positions, inboard and outboard, on the component to ensure that it is free from twist.

- (i) There are a variety of types of incidence boards, some having stops at the forward edge which must be placed in contact with the leading edge of the wing, whilst others are provided with location pegs which fit into some specified part of the structure, but the main purpose in each case is to ensure the board is fitted in exactly the position intended and, if the rigging is correct, that a clinometer on the top of the board will register zero or within a permitted tolerance about zero. In most instances the boards are kept clear of the wing contour (so that the incidence check is not influenced by any irregularities which may occur in the contour) by means of short feet attached to the board. A typical wooden incidence board is shown in Figure 4 although, of course, some are manufactured of metal.

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- (ii) It must be borne in mind that modifications in areas where incidence boards are located may affect results. For example, if leading-edge deicing shoes were fitted this might seriously affect the position taken up by a board having a leading edge stop as shown in Figure 4.

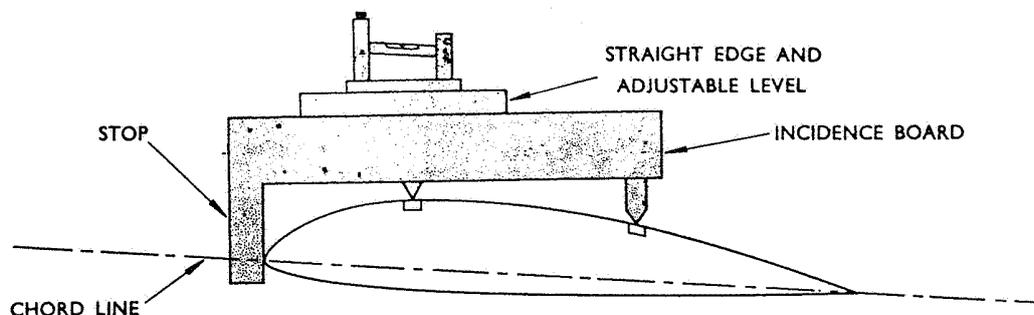


Figure 4 TYPICAL INCIDENCE BOARD

- (iii) Where possible, the verticality of the incidence board should be checked with a plumb bob. Where the checks are being taken in the open (see paragraph 2.5) and it is difficult to steady the plumb bob due to wind, the suspension of the plumb bob in a container of oil or water will be of assistance.

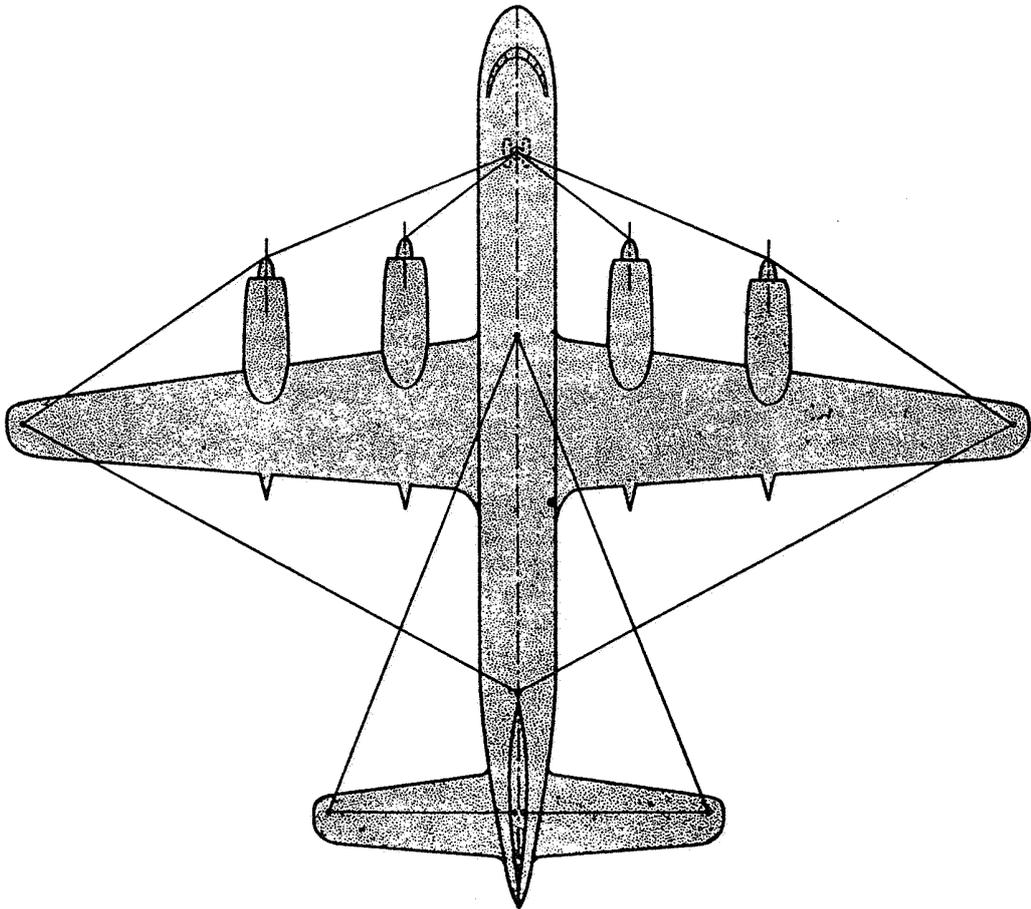
**3.3.3 Verticality of Fin.** After the rigging of the tail planes has been checked, the verticality of the fin relative to a lateral datum can be checked from a given point on either side of the top of the fin to a given point on the port and starboard tail planes respectively; the measurements should be similar within prescribed limits. When the verticality of the fin stern post has to be checked, it may be necessary to remove the rudder and drop a plumb bob through the rudder hinge attachment holes, when the cord should pass centrally through all the holes. It should be noted that some aircraft have the fin offset to the longitudinal centreline to counteract engine torque.

**NOTE:** Guidance on the checks necessary after the refitting of a flying control surface is given in the AL/3 group of leaflets.

**3.3.4 Engine Mountings.** Engines attached to the wings are usually mounted with the thrust line parallel to the horizontal longitudinal plane of symmetry but not always parallel to the vertical longitudinal plane, since, due to their disposition along the wing, the outboard engines are often offset a degree or so to enable the slipstream from the propellers to converge on the tailplane. The check to ensure that the position of the engine, including the degree of offset, is correct depends largely on the type of mounting, but usually entails a measurement from the centre line of the mounting to the longitudinal centre line of the fuselage at a point specified in the relevant manual. (See also Figure 5).

3.3.5 **Symmetry Check.** Figure 5 illustrates the principle of a typical symmetry check, the relevant figures and tolerances for which will be found in the appropriate manual, although the actual measurements relating to the aircraft concerned are given in the aircraft log book.

- (i) For the smaller types of aircraft the measurements between points are usually taken by means of a steel tape. It is recommended that a spring balance should be used on the longer distances to obtain an equal tension, 5 lb. usually being sufficient.
- (ii) Where the larger types of aircraft are concerned, it is more usual to chalk the floor locally under the positions where the dimensions are to be taken, to drop plumb bobs from the checking points, marking the floor with an "X" immediately under the point of each plumb bob, and then to measure the distance between the centre of the markings. This method has the advantages of ensuring more accurate measurement and reducing the amount of walking necessary on main planes and tail planes.



*Figure 5* SYMMETRY CHECK

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3.4 **Rigging Checks on Biplanes.** In general the rigging checks applicable to single-engined biplanes during reassembly after overhaul are as follows, but specific requirements relating to a particular type of aircraft should be ascertained from the relevant approved manual. The use of rigging boards, etc., is described in paragraph 3.3, as are other checks (such as the symmetry check) which are not peculiar to biplanes.

3.4.1 The fuselage should be levelled laterally and longitudinally as described in paragraph 2. The centre-section should be placed on suitable trestles and the centre-section struts and wires (complete with fork-ends) attached.

NOTE: It is important that the fork-ends should be screwed the same number of turns on each end of the wire to provide for subsequent adjustment.

3.4.2 The centre-section should be erected onto the fuselage and the stagger (paragraph 5.7) and lateral symmetry checked. The stagger should be checked by dropping plumb bobs from the leading edge of the upper portion of the centre-section (or other defined position) and measuring the distance from the plumb bobs to the leading edge of the lower portion of the centre-section (or other defined position). If necessary, the stagger can be adjusted by means of the front centre-section struts on most aircraft of this type. The symmetry about the centre line should be checked by measuring from plumb bobs to the sides of the fuselage and can be adjusted, if necessary, by means of the bracing wires.

NOTE: It is essential that the centre-section rigging checks should be accurately carried out, since small errors in the centre-section bracing can result in large errors in the general rigging.

3.4.3 The port (or starboard) top main plane should be attached to the centre-section, care being taken to ensure that the main plane is adequately supported during the assembly. The landing wires (paragraph 5.4) should then be attached to the centre-section, the port (or starboard) lower main plane attached to the centre-section, the interplane struts, flying wires (paragraph 5.3) and incidence wires (paragraph 5.6) fitted and the whole assembly lightly tensioned up. The completed side of the aircraft should be steadied with a trestle whilst the opposite side is assembled in the same order.

NOTE: Although usually of similar appearance, front and rear interplane struts are usually of slightly different lengths to compensate for wing contour, thus it is important to ensure that the correct strut has been fitted in the correct position.

3.4.4 After assembly the fuselage level should be rechecked and adjusted as necessary, after which the main planes should be trued-up by adjustments to the appropriate wires, the aim being to achieve the correct dihedral first and then to work the incidence and stagger together. Care must be taken during rigging to ensure that the main flying and landing wires are not over-tensioned to the extent of bowing the main plane spars or interplane struts.

NOTE: The specified lengths and permitted tolerances applicable to all wires are given in the rigging diagrams appropriate to the aircraft type, but the actual figures to which the aircraft had previously been rigged is recorded in the aircraft log book. If using the same components it is advisable to re-rig to the log book figures, since these may have been determined specifically to counteract a flying fault.

- 3.4.5 After the rigging of the main planes has been completed, it should be ensured that all forkends, etc., are in safety, are not "butting" against the ends of the fitting and have been correctly locked (Leaflets AL/3-1 and BL/5-1), that the wires are in streamline and that anti-chafing discs and spreader bars are correctly fitted to prevent vibration of the wires.
- 3.4.6 **Empennage.** The empennage should be attached in accordance with the instructions contained in the relevant manual and adjusted (where this is possible) to within the limits specified in the relevant rigging diagram. It should be noted that the tail plane struts are usually handed and, unless these are correctly positioned, the fairings will not be in line of flight.  
 NOTE: Tail planes provided with an adjustment mechanism must be set to the neutral position before checking is commenced.
- 3.4.7 **Twin-Engine Biplanes.** The general procedure for rigging twin-engined biplanes is basically similar to that described above for single-engined biplanes but it must be ensured that the weight of the engines is taken up on the appropriate struts before completing the general rigging.
- 3.5 **Checking Rigging with Sighting Rods.** This method of checking rigging is used mainly on the larger types of aircraft and consists basically of sighting with a theodolite positions of datum marks on a series of rods of graduated lengths, each of which is inserted into a specified jugged position on the underside of the aircraft.
- 3.5.1 For the initial check, the aircraft should be brought to the rigging position (paragraph 2) and the sighting rods inserted at the appropriate stations.  
 NOTE : Since any rod can be fitted into any socket, it is important to ensure that the rods are inserted in their correct positions.
- 3.5.2 A theodolite, erected at an appropriate distance and position from the aircraft should be levelled up with the datum mark on the master sighting rod (usually the shortest rod fitted under the fuselage) and then readings should be taken from this sighting line at each rod station and recorded. A typical method of taking the readings is illustrated in Figure 6.
- NOTE: (i) A method which provides accurate vertical adjustment and rigidity for a theodolite is to mount it on a hydraulic jack.  
 (ii) It may not be possible in every instance to obtain a reading on every sighting rod from one theodolite position, in which case the theodolite should be appropriately repositioned realigned on the master rod, and the check continued in the same manner as before.

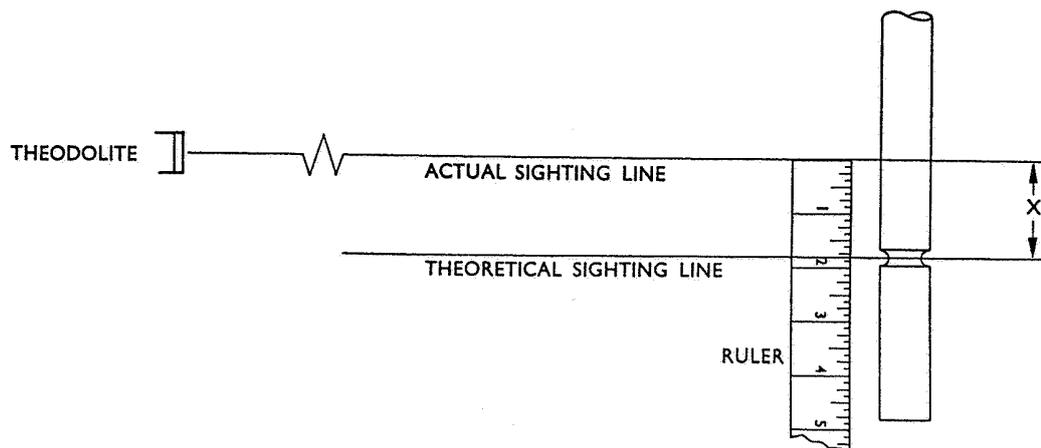


Figure 6 TYPICAL METHOD OF TAKING READINGS

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3.5.3 The readings thus obtained must be within the tolerances permitted by the manufacturer (details of which are usually included in the rigging drawing), and entered in the aircraft log book for permanent record.

3.5.4 There are two basic methods applicable to the use of sighting rods and these are described below.

(i) On some types of aircraft the sockets into which the sighting rods are inserted are adjustable in the vertical direction so that once variations from nominal figures have been recorded, the rods can be "zeroed" and permanently locked. Thus the sighting line on all subsequent checks should in fact coincide with the datum marks on all the rods if the rigging is correct. Rods used for this method have the single datum as illustrated in Figure 6.

(ii) The second method is to use sighting rods on which are marked the datum line, on either side of which is also marked graduations indicating the permissible tolerance on the nominal figure in increments of  $\frac{1}{4}$  degrees. With this method the sockets into which the rods are inserted are not adjustable and subsequent readings should be given the actual figures recorded on the initial check.

NOTE: When rods of the "screw-in" type are used it should be ensured that they are fully screwed home before the check is commenced.

3.5.5 When a component (e.g. wing or tail plane) is changed, it will be necessary to again carry out the initial check to ascertain actual figures.

**4 LOWERING THE AIRCRAFT** Before any attempt is made to lower the aircraft to the ground it must be ensured that wing supports and any other equipment which might foul and damage the aircraft are moved clear. The aircraft should be lowered evenly and, when the aircraft weight is accepted on the undercarriage, the jacks should be further lowered to ensure that they can be removed without fouling the aircraft structure.

## 5 DEFINITIONS

5.1 **Anhedral.** An inclination outwards and downwards relative to the lateral datum.

5.2 **Dihedral.** The angle (or angles) at which the wings and tail planes are inclined outward and upward relative to the lateral datum.

5.3 **Flying Wires.** Wires the principal function of which is to transfer the lift of the main planes to the main structure. These wires are sometimes termed "lift wires".

5.4 **Landing Wires.** Wires which brace the main plane against forces opposite in direction to the direction of lift, as occur, for example, in landing. These wires are sometimes termed "anti-lift wires".

- 5.5 **Incidence.** The angle between the chord line of the wing or tail plane and the longitudinal datum.
- 5.6 **Incidence Wires.** Wires bracing the main plane structure in the plane of a pair of front and rear struts.
- 5.7 **Stagger.** The distance between the leading edge of the lower plane and the projection of the leading edge of the upper plane on the chord of the lower plane.



**AL/7-13***Issue 3.**June, 1980.***AIRCRAFT****STRUCTURES****INSPECTION OF METAL AIRCRAFT STRUCTURES**

- 1 INTRODUCTION** This Leaflet gives general guidance on the inspection of those parts of a metal aircraft structure which, because of their remoteness, complexity or boxed-in design, are not readily accessible for routine maintenance or require special attention in the light of operational experience.
  
- 2 GENERAL** Deterioration may arise from various causes and can affect various parts of the structure according to the design of the aircraft and the uses to which it is put. Therefore, this Leaflet should be read in conjunction with the appropriate manufacturer's publications and the Maintenance Schedule for the aircraft concerned.
  - 2.1** Although considerable guidance may be given in the appropriate publications as to suitable opportunities for inspecting normally inaccessible structures (e.g. when a wing tip is removed permitting access to the adjacent wing structure) experience should indicate to the operator further opportunities for such inspections which can be included in the Maintenance Schedule. Apart from the airworthiness aspects, these combined inspections could often be to the operator's advantage, since they would obviate the need for future dismantling.
  - 2.2** Where access has been gained to a part of the structure which is normally inaccessible, advantage should be taken of this dismantling to inspect all parts of systems thus exposed. Guidance on the inspection of pipes, controls, etc., is given in the appropriate CAIP Leaflets.
  
- 3 CORROSION** The presence of corrosion in aircraft structures is liable to result in conditions which may lead to catastrophic failures. It is therefore essential that any corrosive attack is detected and rectified in the earliest stages of its development.
  - 3.1** In general, no corrosive attack on an aircraft structure will occur without the presence of water in some form. However, a fact less well appreciated is that, in a wide variety of ambient conditions, condensation will form on various parts of the structure and this is one of the main causes of corrosion.
    - 3.1.1** By the nature of their operation, aircraft are exposed to frequent changes of atmospheric temperature and pressure and to varying conditions of relative humidity; therefore, all parts of the structure are subject to some form of condensation. The resultant water takes into solution a number of corrosive agents from the atmosphere or from spillages (which convert the water into a weak acid) and will corrode most metal surfaces where the protective treatment has been damaged or is inadequate. Cases of serious corrosion have been found in both closed and exposed parts of structures of aircraft operated under a wide variety of conditions.

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3.1.2 Corrosion can be intergranular; therefore, the removal of the surface products of corrosion followed by reprotection is not necessarily effective. Once the surface is penetrated the reduction in strength due to corrosion is disproportionate to the reduction in thickness of the metal.

3.2 **Treatment and Rectification of Corrosion.** Reference should be made to Leaflet **BL/4-1** on the nature and control of corrosion, to Leaflet **BL/4-2** on the removal and rectification of corrosion, and to Leaflet **BL/4-3** on methods of protection from corrosion. Information on some of the protective treatment processes commonly used to protect structural parts can be found in the following Leaflets:—

- BL/7-1** Anodic Oxidation
- BL/7-2** Cadmium Plating
- BL/7-3** Chromate Treatment of Magnesium Alloys
- BL/7-4** Phosphating of Steels
- BL/6-20** Painting

3.3 **Air-conditioned Compartments.** In air-conditioned compartments, condensation will occur where the warm inside air impinges on the colder areas of the structure such as the inner surfaces of a pressure cabin skin. Considerable quantities of water will tend to collect and run down the inside of the cabin walls.

3.3.1 To avoid corrosion it is important to ensure that the water is unimpeded in its flow down to the bilge area. The structure and all drain holes through stringers, etc., should be kept clean and free from obstructions, and drainage ducts should be checked for clearance and damage. A check should be made to ensure that water or moisture is not being trapped by the thermal acoustic lining or any other form of upholstery.

3.3.2 Water collecting in the lower parts of the structure and in the bilge area can be highly contaminated. It will not only contain the corrosive agents mentioned in paragraph 3.1.1, but also other impurities due to fumes, spillages, etc., emanating from the galley, toilets and smoking compartments, thus intensifying the corrosive nature of the water. At specified periods these parts of the structure should be thoroughly cleaned and carefully inspected for signs of corrosion and for deterioration of the protective treatment.

3.3.3 Thermal acoustic linings usually have a waterproof covering on the side adjacent to the structure, or the thermal acoustic material may be completely enveloped in a waterproof covering. Any damage to the waterproof covering may lead to considerable absorption of water into the lining, setting up corrosion between the damaged lining and the surrounding structure.

NOTE: Water soakage of upholstery and especially of thermal acoustic linings can also result in an appreciable increase in aircraft weight. Instances have also occurred where saturated compartment linings have caused electrical failures.

3.4 **Structural Parts Susceptible to Corrosion.** The constructor's publications give general guidance on the inspection of those parts of the structure which are most likely to be attacked by corrosion. Nevertheless, it should be noted that, in the light of operational experience, other parts of the structure may require special attention. Engineers should be on the alert for any signs of corrosion in parts of the structure not specifically mentioned in the constructor's publications or instructions.

3.4.1 In 'blind' or boxed-in structures where accessibility is difficult and where cleaning and maintenance are awkward, dirt and dust tend to collect and lodge in various parts. This dirt and dust acts as a 'wick' for moisture which, in the course of time, will work through any inadequate protective treatment and penetrate to the metal to act as an electrolyte. Even on new aircraft the problem is still present in some boxed-in or intricate structures.

NOTE: Protective treatments with a rough surface finish, such as primer paints, tend to hold dust and dirt, and cleaning is rendered more difficult because of this tendency of dust and dirt to adhere to such surfaces. Hard gloss finishes, such as epoxy resin paints, will provide a more effective and lasting protection.

3.4.2 Completely boxed-in structures should be adequately vented to prevent stagnation of the internal air. It is important to ensure that vents and drain holes are clear, are of the correct size and are unobstructed by ice in freezing conditions on the ground.

3.4.3 Honeycomb structures, especially those in components of small cross-sectional area (e.g. wing flaps), are often prone to the collection of water if careful attention has not been given to the sealing around attachment screw holes and at skin joints to prevent ingress of moisture. Cases are known where the trapped water in the structure has frozen and caused distortion of the outer skin of the component due to internal expansion.

3.4.4 Fuselage keel areas, structures concealed by upholstery (see e.g. paragraph 3.3) and the double skin of freight bay floors, are typical areas liable to corrosion. Special attention should be given to all faying surfaces in these areas and particularly the faying surfaces of stringers to skin panels and skin lap joints. In general, visual inspection supplemented by radiological methods of examination is a satisfactory way of detecting corrosion, provided it is expertly carried out and proper correlation between the findings of each method is maintained. In some instances, however, normal methods of visual inspection supplemented by radiological examination have not proved satisfactory and dismantling of parts of the structure may be required to verify the condition of the faying surfaces.

3.4.5 Structures constructed from light gauge materials which are spot-welded together, such as the faying surfaces of stringers mentioned in the previous paragraph, are liable to serious and rapid corrosion as this method of attachment precludes the normal anti-corrosive treatments (e.g. jointing compound) at the faying surfaces. Cases of serious corrosion have also been found in similar structures riveted together where the jointing compound has been found to be inadequate.

3.4.6 In some instances, where stringers are of top-hat section and are bonded to the panel by a thermosetting adhesive, corrosion has been known to affect the stringers, the panel and the bonding medium; such stringers are often sealed at their ends to prevent the ingress of moisture, etc. Where adhesive is used to attach a doubler to a skin, corrosion can occur between the surfaces and will eventually be indicated by a quilted appearance.

3.5 **Exhaust Gases.** Structural parts which are exposed to exhaust gases are prone to corrosion due to the sulphur content of exhaust gases and jet efflux. Although this problem can be reduced by regular and thorough cleaning, particular attention should be given to the condition of the protective treatment of these structures.

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## 3.6 Stress Corrosion

3.6.1 Stress corrosion in aluminium tends to occur mainly in the high-strength alloys and is due to locked-in stresses resulting from some aspects of heat treatment or inappropriate assembly practices. Stress corrosion takes the form of cracking which, in conjunction with other corrosion, can lead to the sudden and complete failure of structural parts.

3.6.2 Stress corrosion cracking in titanium depends on the composition of the alloy, its processing and its notch sensitivity. Some titanium alloys may develop rapid crack growth if contaminated with a saline solution after a crack has been initiated.

3.7 Fretting. Fatigue failures often result from fretting at structural bolted joints. Fretting is revealed by black or greyish brown powder or paste around the periphery of the faying surfaces and may result in the formation of cracks at the outer edge of the fretted area; these cracks may develop across the component and will not necessarily pass through the bolt hole. Dismantling of suspect parts is usually necessary and an inspection by penetrant dye, magnifying lens, eddy current or ultrasonic (surface wave) methods should be carried out.

4 SPILLAGE Spillage or system leaks of extraneous fluids which may penetrate the structure during maintenance, repair or operation of the aircraft, should be carefully traced and thoroughly cleaned out. Where required, any protective treatment should be restored. Fluids such as ester-based engine oils, glycol defrosting fluids, etc., will damage most protective treatments not intended to be in contact with them. Accidental spillage of refreshments such as mineral waters, coffee, etc., have a particularly deleterious effect on floor structures.

4.1 With an aircraft in operation there are areas where spillages invariably occur, such as in galleys and toilet compartments. Here, careful cleaning and the maintenance of any special floor protection is important. The floor structures around and below these compartments should receive special attention to ensure protection against seepage and corrosion. Where animals are carried, special precautions are essential because corrosion due to animal fluid can cause rapid deterioration of metals. The floor and sides of compartments in which animals are housed should be protected by suitable means against seepage, and the structure below the floor should be carefully inspected for any signs of seepage or corrosion.

NOTE: Where animals are not housed in containers specially designed for air transport, unbroken impervious sheeting such as waterproof canvas or heavy polythene sheet, should be laid on the floor and fixed at the required height on the fuselage sides and bulkheads to prevent any seepage into the aircraft structure. A form of matting, preferably made of absorbent material, should be laid on the sheeting to prevent damage due to animal movements.

4.2 Battery compartments should be examined for any signs of acid corrosion. Compartment vents should be clean and undamaged and the anti-sulphuric protective treatment should be carefully maintained. Special attention should be given to the structure in the immediate vicinity of the battery for any signs of corrosion caused by acid spillage or a damaged battery. It should be noted that heavy concentrations of battery fumes, resulting from faulty compartment venting or a runaway battery, may also lead to corrosion in the surrounding structure.

NOTE: If there is any indication of corrosion, the parts affected should be cleaned with a solution of water and washing soda, then rinsed with fresh water and dried out. After 24 hours a re-check should be made for further signs of corrosion and, if satisfactory, the protective treatment should be restored.

4.3 The spillage of mercury in an aircraft can have devastating effects on any aluminium alloy skin or structure with which it comes into contact. The effects of mercury spillage and the various methods of decontamination, where this is possible, are discussed in Leaflet **BL/4-10**.

**5 CORROSIVE EFFECTS OF AGRICULTURAL CHEMICALS** On aircraft used for crop spraying or dusting, considerable attention and special care should be given to the inspection of the structure owing to the highly corrosive nature of certain of the chemicals used for these purposes. The corrosive effect of some of the chemicals used for agricultural purposes may not always be fully known. Some chemicals which were considered to be harmless to aircraft materials, have proved, in the course of time, to be corrosive.

5.1 Thorough cleaning of the whole aircraft structure after agricultural spraying operations is very important. Unless otherwise specified by the manufacturer of the chemical, the aircraft should be thoroughly washed, both internally and externally, with copious supplies of clean water. Engine intakes and exhausts, and other openings, should be blanked during the washing to prevent the ingress of water. After washing, it is essential to check that no pockets of chemicals or water remain trapped in the structure, that all drains are clear and that all covers or devices used to prevent the ingress of chemicals are properly refitted.

5.2 A check should be made to ensure that the spray equipment tanks, pipes, pumps, etc., are leak-proof and that spray booms or spray nozzles are in their correct positions.

5.3 When filling up with chemical spray fluids care is necessary to avoid spillage. Where there is no provision to prevent spilled fluid finding its way into the structure, it is essential to avoid over-filling, and the chance of accidental spillage can be reduced by using the proper filling equipment. If spillage does occur, it should be cleaned out immediately before it has penetrated into parts of the structure where cleaning would be more difficult.

**6 METAL FATIGUE** Metal fatigue can be briefly described as a weakening of a metal part under repeated applications of a cycle of stress. The weakening effect can be seriously accelerated by corrosion of the metal.

6.1 In the early stages, fatigue damage is difficult to detect by visual inspection and one of the methods of non-destructive examination outlined in the **BL/8** series of Leaflets (see also paragraph 9) is usually specified; the method used depending on the type of structure and material concerned. In the majority of cases the presence of fatigue damage is revealed by the formation of a small hairline crack or cracks.

6.2 Those parts of a structure where fatigue damage may occur are determined by design calculations and tests based on the expected operational use of the aircraft, and substantiated by operational experience. At the periods specified in the appropriate publications, examination or renewal of the parts will be required. These periods are usually in terms of flying time or the number of landings, or from readings logged by load recording instruments. With certain materials and structures, renewal or sampling checks may be required on a calendar basis.

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6.3 It is important to note that some parts of a structure may be liable to fatigue damage resulting from unforeseen causes, e.g. parts damaged or strained on assembly, invisible damage to the structure during assembly or maintenance work, or fretting (see Leaflet AL/7-8). When carrying out inspections it is important to check carefully for any signs of cracks emanating from points of stress concentration such as bolt-holes, rivets, sharp changes in section, notches, dents, sharp corners, etc. Fatigue damage can also be caused by pits and notches created by corrosion, although the corrosion may no longer be active. During the application of repeated stress cycles, crevices can be opened up and may eventually result in a fatigue failure.

NOTE: Poor fitting or malassembly can reduce fatigue life considerably. A spar has been known to fail under tests at a fraction of its normal life as a result of the stress concentration caused by a tool mark in a bolt-hole. Defects such as a burr on a bolt can cause a scratch inside the bolt-hole, which can seriously accelerate fatigue damage in a stressed member.

7 **CLEANLINESS** It is important that aircraft should be thoroughly cleaned periodically and reference should be made to Leaflet BL/6-19.

7.1 Care should be taken not to damage protective treatments when using scrubbing brushes or scrapers, and any cleaning fluids used should have been approved by the aircraft constructor. For final cleaning of a boxed-in type of structure an efficient vacuum cleaner, provided with rubber-protected adaptors to prevent damage, should be used. The use of air jets should be avoided as this may lead to dirt, the products of corrosion, or loose articles, being blown from one part of the structure to another.

8 **INSPECTION** The structure should be maintained in a clean condition and a careful check should be made for any signs of dust, dirt or any extraneous matter, especially in the more remote or 'blind' parts of the structure. Loose articles such as rivets, metal particles, etc., trapped during construction or repair, may be found after the aircraft has been in operation for some considerable time. It is important to examine these loose articles to ensure that they did not result from damaged structure. It is generally easy to determine if a loose article has formed part of the structure by its condition, e.g. an unformed rivet could be considered as a loose article, but a rivet which had been formed would be indicative of a failure.

## 8.1 General

8.1.1 The structure should be examined for any signs of distortion or movement between its different parts at their attachment points, for loose or sheared fasteners (which may sometimes remain in position) and for signs of rubbing or wear in the vicinity of moving parts, flexible pipes, etc.

NOTES: (1) A wing structure has been known to have had a rib sheared at its spar attachments due to the accidental application of an excessive load, without any external evidence of damage, because the skin returned to its original contour after removal of the load.

(2) For the inspection of bolted joints see Leaflet AL/7-8.

8.1.2 The protective treatment should be examined for condition. On light alloys a check should be made for any traces of corrosion, marked discoloration or a scaly, blistered or cracked appearance. If any of these conditions is apparent the protective treatment in the area concerned should be carefully removed and the bare metal examined for any traces of corrosion or cracks. If the metal is found satisfactory, the protective treatment should be restored.

NOTE: To assist in the protection of structures against corrosion some constructors may attach calcium chromate and/or strontium chromate sachets to the vulnerable parts of the structure. The presence of chromate in the sachets can be checked by feel during inspection. After handling these materials, the special precautions, e.g. hand washing, given in the constructor's manual, should be followed.

8.1.3 In most cases where corrosion is detected in its early stages, corrective treatment will permit the continued use of the part concerned. However, where the strength of the part may have been reduced beyond the design value, repair or replacement may be necessary. Where doubt exists regarding the permissible extent of corrosion, the constructor should be consulted.

8.1.4 The edges of faying surfaces should receive special attention (see also paragraph 3.4.4); careful probing of the joint edge with a pointed instrument may reveal the products of corrosion which are concealed by paint. In some instances slight undulations or bumps between the rivets or spot welds, or quilting in areas of double skins due to pressure from the products of corrosion, will indicate an advanced state of deterioration. In some cases this condition can be seen by an examination of the external surface, but as previously mentioned in this Leaflet, dismantling of parts of the structure to verify the condition of the joints may be required.

NOTES: (1) To avoid damage to the structure, the probing of a joint with a pointed instrument should be carried out with discretion by an experienced person. Any damage done to the protective paint coating, however small, should be made good.

(2) Where dismantling of parts of the structure is required, reference should be made to Leaflet AL/9-1.

8.2 **Visual Examination.** Nearly all the inspection operations on aircraft structures are carried out visually and, because of the complexity of many structures, special visual aids are necessary to enable such inspections to be made. Visual aids vary from the familiar torch and mirrors to complex instruments based on optical principles and, provided the correct instrument is used, it is possible to examine almost any part of the structure.

NOTE: Airworthiness Requirements normally prescribe that adequate means shall be provided to permit the examination and maintenance of such parts of the aeroplane as require periodic inspection.

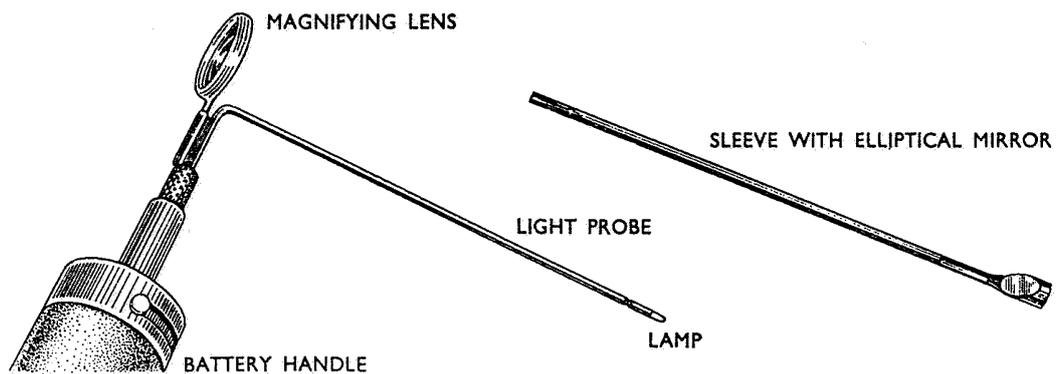


Figure 1 TYPICAL LIGHT PROBE

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**8.2.1 Light Probes.** It is obvious that good lighting is essential for all visual examinations, and special light probes are often used.

- (a) For small boxed-in structures or the interior of hollow parts such as the bores of tubes, special light probes, fitted with miniature lamps, as shown in Figure 1, are needed. Current is supplied to the lamp through the stem of the probe from a battery housed in the handle of the probe. These small probes are made in a large variety of dimensions, from 5 mm ( $\frac{1}{8}$  in) diameter with stem lengths from 50 mm (2 in) upwards.
- (b) Probes are often fitted with a magnifying lens and attachments for fitting an angled mirror. Such accessories as a recovery hook and a recovery magnet may also form part of the equipment.
- (c) For the larger type of structure, but where the design does not permit the use of mains-powered inspection lamps, it is usually necessary to use a more powerful light probe. This type of light probe consists of a lamp (typically an 18 watt, 24 volt type) which is protected by a stiff wire cage and mounted at one end of a semi-flexible tube or stem. On the other end is a handle with a light switch and electrical connections for coupling to a battery supply or mains transformer. As the diameter of the light probe is quite small it can be introduced through suitable apertures to the part of the structure to be inspected.

**NOTE:** Where spillage or leakage of flammable fluids may have occurred or when inspecting fuel tanks, etc., it is important to ensure that the lighting equipment used is flameproof, e.g. to BS 229.

**8.2.2 Inspection Mirrors.** Probably the most familiar aid to the inspection of aircraft structures is a small mirror mounted at one end of a rod or stem, the other end forming a handle. Such a mirror should be mounted by means of a universal joint so that it can be positioned at various angles thus enabling a full view to be obtained behind flanges, brackets, etc.

- (a) A useful refinement of this type of mirror is where the angle can be adjusted by remote means, e.g. control of the mirror angle by a rack and pinion mechanism inside the stem, with the operating knob by the side of the handle, thus permitting a range of angles to be obtained after insertion of the instrument into the structure.
- (b) Mirrors are also made with their own source of light mounted in a shroud on the stem and are designed so as to avoid dazzle. These instruments are often of the magnifying type, the magnification most commonly used being 2X.

**8.2.3 Magnifying Glasses.** The magnifying glass is a most useful instrument for removing uncertainty regarding a suspected defect revealed by eye, for example, where there is doubt regarding the presence of a crack or corrosion. Instruments vary in design from the small simple pocket type to the stereoscopic type with a magnification of 20X. For viewing inside structures, a hand instrument with 8X magnification and its own light source is often used.

- (a) Magnification of more than 8X should not be used unless specified. A too powerful magnification will result in concentrated viewing of a particular spot and will not reveal the surrounding area. Magnification of more than 8X may be used, however, to re-examine a suspected defect which has been revealed by a lower magnification.
- (b) When using any form of magnifier it is most important to ensure that the surface to be examined is sufficiently illuminated.

**8.2.4 Endoscopes.** An endoscope (also known as an introscope, boroscope or fibrescope, depending on the type and the manufacturer) is an optical instrument used for the inspection of the interior of structure or components. Turbine engines, in particular, are often designed with plugs at suitable locations in the casings, which can be removed to permit insertion of an endoscope and examination of the interior parts of the engine. In addition, some endoscopes are so designed that photographs can be taken of the area under inspection, by attaching a camera to the eyepiece; this is useful for comparison and record purposes.

- (a) One type of endoscope comprises an optical system in the form of lenses and prisms, fitted in a rigid metal tube. At one end of the tube is an eyepiece, usually with a focal adjustment, and at the other end is the objective head containing a lamp and a prism. Depending on the design and purpose of the instrument a variety of objective heads can be used to permit viewing in different directions. The electrical supply for the lamp is connected near the eyepiece and is normally supplied from a battery or mains transformer.
  - (i) These instruments are available in a variety of diameters from approximately 6 mm ( $\frac{1}{4}$  in) and are often made in sections which can be joined to make any length required. Right-angled instruments based on the periscope principle are also available for use where the observer cannot be in direct line with the part to be examined.
- (b) A second type of endoscope uses 'cold light', that is, light provided by a remote light source box and transmitted through a flexible fibre light guide cable to the eyepiece and thence through a fibre bundle surrounding the optical system to the objective head. This type provides bright illumination to the inspection area, without the danger of heat or electrical sparking, and is particularly useful in sensitive or hazardous areas.
- (c) A third type of endoscope uses a flexible fibre optical system, thus enabling inspection of areas which are not in line with the access point.

**9 NON-DESTRUCTIVE EXAMINATION** In cases where examination by visual means is not practicable or has left some uncertainty regarding a suspect part, the use of one of the methods of non-destructive examination will normally determine the condition of the part.

**9.1** A brief outline of the methods of non-destructive examination most commonly used on aircraft structures is given in the following paragraphs. For further information on these and other methods reference should be made to the **BL/8** series of Leaflets. The selection of the method to be used will depend largely on the design of the structure, its accessibility and the nature of the suspected defect.

**9.2 Penetrant Dye Processes (BL/8-2).** These processes are used mainly for checking areas for those defects which break the surface of the material, which may be too small for visual detection by 2X magnification and where checking at higher magnifications would be impractical. Basically, the process consists of applying a red penetrant dye to the bare surface under test, removing after a predetermined time any excess dye and then applying a developer fluid containing a white absorbent. Any dye which has penetrated into a defect (e.g. crack) is drawn to the surface by the developer and the resultant stain will indicate the presence and position of the defect.

**NOTE:** Penetrant dye processes of inspection for the detection of surface defects require no elaborate equipment or specialised personnel. It is emphasised that the cleanliness of the surface to be tested is of prime importance if this process is to reveal microscopic cracks.

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- 9.2.1 The manufacturer's detailed instructions regarding the applications of the process should be carefully followed. The most suitable processes for testing parts of aircraft structures 'in situ' are those which employ water-washable dye penetrants, with the penetrant and developer contained in aerosol packs.
- 9.2.2 The characteristics of the red marks, such as the rapidity with which they develop and their final size and shape, provide an indication as to the nature of the defect revealed.
- 9.2.3 After test, the developers should be removed by the method prescribed by the process manufacturer and the protective treatment should be restored.

NOTE: A similar process to the Penetrant Dye Process is the Fluorescent Penetrant Process. However, this process is less adaptable for testing aircraft parts 'in situ' because portable 'black light' lamps are used to view the parts, and dark room conditions are generally required.

- 9.3 **Radiographic Examination (BL/8-4).** The use of radiography will often facilitate the examination of aircraft structures, and it is used for the detection of defects in areas which cannot be examined by other means because of inaccessibility or the type of defect.

- 9.3.1 Radiography can be a valuable aid to visual inspection, and the examination of certain parts of an aircraft structure by an X-ray process will often result in a more comprehensive inspection than would otherwise be possible. However, radiographic methods can be both unsatisfactory and uneconomical unless great care is taken in the selection of suitable subjects. In this respect the opinion of the aircraft constructor should be sought.
- 9.3.2 During routine inspections, the use of radiography based on reliable techniques of examination can result in more efficient and rapid detection of defects. In some instances, defects such as cracking, loosening of rivets, distortion of parts and serious corrosion of the pitting type can be detected by this method. It should be borne in mind, however, that a negative result given by a general NDT method such as radiography is no guarantee that the part is free from all defects.
- 9.3.3 Where radiography is used for the detection of surface corrosion it is recommended that selected areas should be radiographed at suitable intervals, each time simulating the original radiographic conditions, so that the presence of corrosion will become apparent by a local change in the density of succeeding radiographs.
- 9.3.4 The accurate interpretation of the radiographs is a matter which requires considerable skill and experience if the maximum benefits are to be obtained. It is essential that the persons responsible for preparing the technique and viewing the results have an intimate knowledge of the structure.

NOTE: Close contact should be maintained with the aircraft constructor who will be aware of problem areas on an aircraft and be able to advise on particular inspection techniques.

- 9.4 **Ultrasonic Examination (BL/8-3).** In some instances ultrasonic examination is the only satisfactory method of testing for certain forms of defects. Ultrasonic flaw detectors can be used to check certain aircraft parts 'in situ' and it is sometimes an advantage to use this method to avoid extensive dismantling which would be necessary in order to use some other method. The chief value of ultrasonic examination in such circumstances is that cracks on surfaces which are not accessible to visual examination should be revealed. Thus solid extrusions, forgings and castings which are backed by skin panels, but which have one suitably exposed smooth surface, can be tested for flaws on their interface surface without breaking down the interface joint. On some aircraft,

spar booms and similar extruded members require periodic examination for fatigue cracks, but the areas of suspected weakness may be inaccessible for examination by the penetrant dye method. In such cases radiography may be recommended, but where ultrasonic testing can be used it will give quicker results on those parts which lend themselves to this form of testing, and may also be useful to confirm radiographic evidence.

**9.5 Eddy Current Examination (BL/8-8).** Eddy current methods can detect a large number of physical and chemical changes in a conducting material, and equipment is designed specifically to perform particular types of test, e.g. flaw detection, conductivity measurement and thickness measurement.

**9.5.1** The main advantages of this method of inspection are that it does not require extensive preparation of the surface or dismantling of the part to be tested and does not interfere with other work being carried out on an aircraft. In addition, small, portable, battery-operated test sets can be used in comparatively inaccessible parts of the structure.

**9.5.2** Eddy current testing is usually of the comparative type, indications from a reference piece or standard being compared with indications from the part under test. A technique for detecting a particular fault is established after trials have indicated a method which gives consistent results.

**9.6 Magnetic Flaw Detection (BL/8-5).** Magnetic flaw detection methods are seldom used on aircraft structures and are generally restricted to the manufacturing, fabrication and inspection of parts. The method has, however, sometimes been used where other non-destructive testing methods have proved to be unsatisfactory. Before using the method, the effects of magnetisation on adjacent structure, compasses and electronic equipment should be considered, and it should be ensured that the magnetic ink or powder can be satisfactorily removed. If this method is used, demagnetisation and a test for remnant magnetism must be carried out to ensure that there will be no interference with the aircraft avionic systems and magnetic compasses.

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**AL/7-14**

Issue 1.

December, 1981.

**AIRCRAFT****STRUCTURES****REPAIR OF METAL AIRFRAMES**

- 1 INTRODUCTION** This Leaflet gives general guidance on repairs to the structure of metal aircraft and should be read in conjunction with the relevant approved publications.

**NOTE:** This Leaflet incorporates the relevant information previously published in Leaflet **AL/9-1**, Issue 2, dated 15th April 1965.

- 1.1** Repairs must be carried out in accordance with the appropriate Repair Manual or approved repair drawings relative thereto, in conjunction with any other related information contained in other documents recognised or approved by the CAA.

**NOTE:** For American manufactured general aviation aircraft, where specific repair manuals or repair documentation is not available, the FAA publication "Advisory Circular AC 43.13-1A Acceptable Methods and Techniques—Aircraft Inspection and Repair" may be used for guidance\*.

- 1.2** Chapter **A4-2** of British Civil Airworthiness Requirements prescribes that in the case of structural repairs to aircraft where the repairs are of a major nature or not covered in the particular approved manual, the approved organisation or the appropriately licensed aircraft maintenance engineer concerned should advise the nearest CAA area office of the nature of the repair or repairs before work commences (see Airworthiness Notice No. 2 for addresses). Repair schemes not previously approved by the CAA will normally be investigated as modifications in accordance with the procedures in **BCAR Chapter A4-1**.

**2 PREPARATION FOR REPAIR**

- 2.1 General.** Details of the inspections necessary before repair and the methods of assessing the extent of damage, supporting the structure, checking alignment and geometry, and assessing allowance for dressing of damage and limits of wear are generally given in the Repair Manual.

**2.1.1** In the case of damage not covered by the Repair Manual but which, nevertheless, is thought to be repairable, a suitable repair scheme can often be obtained by application to the aircraft constructor (or to a Drawing Office holding the appropriate Design Approval). When supplying information of the damage to the constructor, photographs showing details of the damage are often helpful and may save both time and expense.

- 2.2 Preliminary Survey of Damage.** A preliminary survey enables the damage to be classified (e.g. negligible, repairable or necessitating replacement) and a decision to be made as to the preparations necessary before commencing the repair. How the aircraft was damaged or overloaded should be determined as accurately as possible, and perusal of the pilot's or ground staff's accident report will give guidance to the necessary checks.

\*Obtainable from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, U.S.A.

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- 2.2.1 Structure distortion which can be evident at the site of the incident, may not be apparent when the aircraft is lifted and the locally imposed loads have been removed. Therefore, the aircraft should normally be inspected on the site where the damage occurred and the damage and distortion plotted on a station chart and ideally photographed before the aircraft is moved, providing a valuable indicator as to areas that require a more detailed inspection.
- 2.2.2 Depending on the results of the preliminary survey, the expected duration of the repair work and the precautions necessary as a result of local conditions, it may be necessary (among other things) to remove the batteries, drain the fuel system and/or inhibit the engines.
- 2.3 **Supporting the Aircraft.** If the aircraft requires lifting to facilitate the repair operations or supporting to avoid distortion of structural parts during dismantling, the aircraft should preferably be placed in the rigging position (see Leaflet AL/7-12). To ensure that the aircraft has not moved during the progress of the repair a daily check should be carried out by a responsible person, such checks being based on inspections to ensure that seals placed on jacks have not broken and, at the other end of the range, theodolite checks carried out against established references.
- 2.3.1 Trestling and jacking equipment is usually designed for this operation by the aircraft manufacturer and will facilitate any alignment, rigging or functioning checks necessary during or after repair. With large aircraft it is essential to follow the jacking instructions laid down by the aircraft manufacturer and to use the recommended equipment. The jacks used for these aircraft are usually fitted with a pressure gauge, so that each jack load can be calculated during the lifting operation. In some cases extension and retraction of all jacks used in a lifting operation are controlled from a central source.
- NOTE:** If the fuel system is not drained, the maximum permissible jacking weight should be verified before lifting.
- 2.3.2 **Additional Support.** In some instances it may be necessary to provide additional support or temporary bracing in order to prevent distortion or movement of the airframe during removal of primary structure such as stressed skin and other load bearing panels; this is usually provided by means of adjustable trestles and/or jury bracing devices.
- 2.3.3 **Adjustable Trestles.** Adjustable trestles are often made up from specially designed sets of steel members which can be bolted together to form trestles of various sizes. The sets usually contain top cross-beams, adjustable at each end by means of screw jacks, which can be fitted with wooden formers shaped to the contour of the structure they are required to support. To avoid damage to the structure, the formers should be lined with a layer of felt or similar cushioning material, which must be dry and free from extraneous matter (particularly swarf), and covered with polythene sheeting. Rubber should not be used for lining.
- (a) Prior to use, the trestles should be checked for correct assembly and it is important to ensure that the maximum permissible load will not be exceeded.
- (b) Trestling positions or 'strong points' where trestles may be positioned are given in the Maintenance and Repair Manuals and may also be stencilled on the aircraft. The positioning of the trestles in relation to these points should be carefully supervised, since supporting an aircraft at other than recognised load-bearing positions may result in considerable damage.
- 2.3.4 When adjustable trestles or jacks are being used to support a structure during repair, the adjusting mechanism, controls, etc., of such should be locked to prevent inadvertent movement whilst repairs are in progress.

**2.3.5 Jury Structures.** Special bracing devices, often referred to as 'Jury' structures, are sometimes needed to take the loads carried by structural parts before they are removed or cut for repair purposes. A jury structure may consist of no more than a length of timber cramped or bolted to the structure, or it may be a specially made strut or jig designed to prevent movement and distortion by holding various key points of the structure in their correct positions. When such devices are made up locally, it must be ensured that they conform in every way with the requirements of the Repair Manual, especially with regard to strength and accuracy of dimensions.

**2.4 Alignment and Geometry Checks.** In instances where the airframe has sustained unusually high loading, structural distortion may have occurred. Although in most instances there will be visual evidence (e.g. skin wrinkling, cracking of paint at the joints of structural members, loose rivets, etc.), this is not always the case and alignment and geometry checks should be made. Similarly, if the aircraft has been damaged by impact, malalignment and distortion of the structure may have occurred in areas remote from the initial impact point in addition to the damage which may be clearly visible at the impact point.

**2.4.1** The control and structural integrity of an aircraft are, to a large extent, dependent on the correct alignment of its separate components, not only in themselves but in their relationship one to another, and malalignment may result in the imposition of stresses of such magnitude that a premature structural failure could occur. It is therefore essential that alignment is checked before, during and after repair work and guidance on this is given in Leaflet **AL/7-12**.

**2.5 Cleaning.** When the structure requires cleaning, this should be carefully supervised, otherwise useful evidence may be lost (e.g. the products of corrosion will help in locating corroded parts and the presence of a dark dusty substance at a structural joint will indicate fretting). Where mud, oil or other extraneous matter has to be removed, the cleaning solutions should be those given in the Repair or Maintenance Manual. Where a fire has occurred, it is important to remove all traces of fire extinguishant and smoke deposits as soon as possible, as some of these products promote rapid corrosion.

**2.5.1** It is important that the cleaning fluids specified in the manual are used in the strengths recommended and in applications where their use has been specified. Cases have arisen where cleaning fluid in combination with kerosene has had a deleterious effect on aircraft structure, the penetrating quality of kerosene promoting seepage into skin joints. Such cases are particularly troublesome and it becomes difficult to diagnose the cause of corrosion. Unspecified cleaning fluids may contaminate or destroy pressure cabin and fuel tank sealing media and should not be used.

**3 INSPECTION BEFORE REPAIR** Structural damage can result from a variety of causes, such as impact, corrosion, fatigue, fire and overloads due to heavy landings or turbulence. In every case careful inspections must be made to ascertain the full extent of the damage and to ensure that other damage not necessarily associated with the particular incident is also rectified. The applicability of all repair schemes involved should be established as soon as possible by reference to the Repair Data, so that if none is given to cover the case in point, delay is avoided in making application to the aircraft constructor for a suitable scheme. Guidance on the nature of the inspections to be made and subsequent repairs is given in the following paragraphs.

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- 3.1 **Cracks.** Care should be taken that cracks, however minor they appear to be, are not overlooked. Where visual inspection is not completely satisfactory, especially at points of concentrated stress, one of the methods of non-destructive examination described in the BL/8 series of Leaflets should be used.
- 3.2 **Corrosion.** Particular attention should be given to evidence of corrosion. Guidance on the methods of assessing the damage and of carrying out any rectification necessary is given in Leaflets **BL/4-1**, **BL/4-2** and **BL/4-3**. In cases of doubt, the use of one of the non-destructive testing methods detailed in the BL/8 series of Leaflets may be beneficial.
- 3.3 **Scores and Abrasions.** Where a score or abrasion in a stressed part is within the limits specified in the Repair Data for blending out into a smooth surfaced shallow depression, it is often necessary to submit the part to one of the non-destructive testing processes described in the BL/8 series of Leaflets. This will ensure that minute cracks are detected and included in the assessment of damage.
- 3.4 **Bolted Joints.** Checks should be made on all bolted joints in the locality of the damaged area, or where overstressing is suspected, for evidence of bolt and associated hole damage. Where no obvious sign of movement is detected, sample inspection by removal of bolt(s) is often advised. (For bolted joint inspection see also Leaflet **AL/7-8**.)

### 3.5 Skin Panels

- 3.5.1 Where buckling of a skin panel is apparent, a careful check of the area and related structure should be made for loose bolts, loose or sheared rivets, cracks and distortion. This should include any remote positions where the loads induced by the particular incident may have spread. In some instances where buckling is within limits specified in the Repair Manual, schemes are provided for fitting a strengthening member, otherwise a new panel should be fitted after any associated structure has been repaired.

NOTE: Loose rivets are often indicated by grey or brown stains around the head.

- 3.5.2 Where denting in skin panelling is in the form of a smooth and fairly circular depression and no other damage is present, it may in some cases, be considered negligible provided the ratio between the depth and area of the depression is within the limits given in the Repair Data. For example, if a depression of 1.2 mm (0.05 in) is within the limits of the depth permitted, then provided the smallest linear dimension across the depression is not less than fifteen times the depth of the depression the damage may be considered negligible. In the example given above the smallest linear dimension permitted would be 1.2 mm x 15 = 18 mm (0.05 in x 15 = 0.75 in).

- 3.6 **Internal Inspection.** The internal inspection of a structure is particularly important since damage or defects can often be present without any outward indication. In instances where the damage is extensive, the whole structure should be inspected. Guidance on the internal inspection of structures, together with the various aids which may be used to facilitate the inspection, is given in Leaflet **AL/7-13**, which should be read in conjunction with this Leaflet.

NOTE: In areas where sealants are used (i.e. integral tanks and pressure cabins), structure inspection is made more difficult and it may be necessary to remove the sealant at sample areas to ensure that the structure is free from damage. The sealant should be removed using only the solvent specified, and eventually restored strictly in accordance with the instructions given in the relevant manual or repair scheme.

**3.7 Removal of Damage.** In some instances it will be necessary to cut away the damaged material and dress back the surrounding structure. Although it should be ensured that no more material than is necessary is removed, it is necessary to make sure that the adjacent structure to which the repair is to be applied is in a sound condition.

**3.7.1** When removing riveted structure, care must be taken not to damage those rivet holes which are to be used again (e.g. by burring, enlargement or undercutting) since circular, smooth-edged holes are essential if the risk of failure by fatigue is to be kept to a minimum.

NOTE: A method widely used for removing rivets is to centre-punch the middle of the preformed rivet head and then, using a drill equal in diameter to that of the rivet, drill only to the depth of the rivet head. The area surrounding the rivet should then be supported on the reverse side and the rivet punched out with a parallel pin-punch slightly smaller in diameter than the rivet.

**3.7.2** Bolt holes should be treated with equal care, it being particularly important that the holes in stressed parts should be free from scores or burrs. Where necessary, bolts should be eased with penetrating oil before extraction but it is also necessary to ensure that the oil does not damage adjacent sealing media. Bolts on which the nuts were locked by a peening over process must have the burrs removed to remove the nuts and these bolts must not be used again.

NOTE: A check should be made to note whether the structure 'springs' as bolts are withdrawn. If this occurs interchangeability fixtures should be used when rebuilding the structure to ensure correct alignment and prevent the introduction of locked-in stresses.

**3.7.3** When damaged panels are to be removed by cutting (i.e. not by dismantling at a production joint) all edges must be free from burrs and notches and trimmed to a smooth finish. It is important that the corner radii of stressed panels are correct and that the dimensions and locations of cuts are within the limits specified in the repair drawing.

**3.7.4** Special care is necessary when damaged parts are removed by cutting, to ensure that the remaining structure or material is not damaged by drills, rotary cutting tools, hack-saw blades, etc.

**3.7.5** Repairs in pressure cabin and integral fuel tank areas may involve separation of members riveted and sealed together. Some sealants have considerable adhesion and may cause difficulty in separating the members after the rivets have been removed. Where such separation is necessary, the solvents specified and methods of separation detailed in the Repair or Maintenance Manual must be strictly followed.

NOTE: After repairs in a pressurised area or a fuel tank, either a leak test or a pressure test may be specified in the appropriate manual.

**3.8 Wear.** Where holes are found to be elongated by stress the part must be renewed. However, if elongation is due to wear and is beyond the limits permitted by the Repair Manual, rectification schemes are usually given.

**3.8.1** The corresponding pin or bolt assemblies should be inspected for wear, distortion, 'picking-up' and shear, and where necessary renewed. Lubricating ducts should be checked for obstruction.

**3.8.2** Where bushed holes are fitted it is usual to renew the worn bush, but where the hole in the fitting has become enlarged so that the new bush is loose, a repair scheme is usually available for reaming out the hole and fitting an oversize bush.

**3.8.3** When excessive wear has taken place in unbushed holes the fitting should be renewed unless there is an approved scheme available whereby the hole can be reamed oversize and a bush fitted; in some cases an oversize bolt or pin may be specified.

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- 3.8.4 Wear in ball and roller bearings should be checked as described in Leaflet **BL/6-14**.
- 3.9 **Fire Damage.** It is extremely difficult to assess the damage caused to a structure which has been exposed to an abnormally high temperature, since apart from the more obvious damage, such as buckling, the mechanical properties of some of the light alloys may be adversely affected, without any apparent indication. In some instances non-blistering of the paint is a good guide that temperatures have not been unduly high but this cannot be taken as a general rule.
- 3.9.1 In some cases an eddy current test can determine the extent of fire or heat damage by measuring the change in conductivity in the material (see Leaflet **BL/8-8**), but where doubt exists, sample portions of panels, ribs or frames should be cut out for mechanical testing by an approved test house. Where it is not possible to remove such samples the advice of the aircraft constructor should be sought.
- 3.9.2 It is generally necessary to renew any parts made from magnesium, plastics or rubber which were in the vicinity of a fire. This applies, for example, to the bag type of fuel tank in contact with a tank bay wall, the other side of which was affected by the fire.
- 3.10 **Damage by Lightning.** In a properly bonded aircraft, lightning damage is not usually of a major character and can generally be rectified by the application of one of the standard repairs. However, it is important to note that because of the unpredictable nature of the damage it is important to make a thorough inspection of the whole aircraft, its engines, systems and equipment. The most common form of damage is numerous small burns or punctures in the skin of the aircraft, or the disintegration or burning of non-metallic materials on the exterior, e.g. radomes, radio aerial covers and navigation light covers.
- 3.10.1 Where a control surface has been struck, the bearings and hinges should be checked for pitting and/or stiffness due to the passage of the lightning discharge, and all control surfaces should be checked for full and free movement.
- 3.10.2 The bonding of the aircraft should be checked as described in Leaflet **EEL/1-6**.
- 3.10.3 The compasses may have been affected by the magnetising of steel parts near to them and should be checked swung as described in Leaflets **AL/10-5** or **AL/10-6** as appropriate. If the compasses are found to be affected, a landing compass should be used to locate the disturbing magnetic fields, and steel parts found to be magnetised should be de-magnetised, as described in Leaflet **BL/8-5**.
- 3.10.4 When a structure is de-magnetised, the compasses and any instruments having permanent magnets in their mechanisms should be temporarily removed from areas in which degaussing is being carried out.
- 3.11 **Repair Report.** A report detailing all the repair work and the procedures involved should be compiled. The details of the rectification work necessary should be based on approved repair schemes, the reference numbers and any other relevant details of which should be quoted.
- 3.11.1 In addition, the report should record any maintenance work, such as mentioned in paragraph 3.8, which could usefully be carried out during the repair work, since this may obviate the need for further dismantling after a relatively short period.

3.11.2 According to the nature of the repair, stage inspections will be necessary during the progress of the repair work (e.g. inspection of rivet or bolt holes, inspection of structures before covering for workmanship, protection, security, locking of screw-threaded parts and duplicate inspection of controls. These inspections should be listed on an Inspection Record Sheet in a sequence related to the repair report, and should give details of the inspection required.

NOTE: Before any disturbed parts of the aircraft or engine control systems are concealed, they must be inspected in duplicate as prescribed in Chapter A5-3 of BCAR and further guidance for this is given in Leaflet AL/3-7.

4 REPAIRS A repair to a stressed structure usually involves the removal of damaged panels, the complete or partial removal of structural members such as frames, ribs and stringers and the rebuilding of the structure in accordance with the repair scheme. The particular procedure involved will obviously vary with the design of the aircraft but paragraphs 4.1 to 4.3 cover the general aspects of a repair.

NOTE: If the repair is at all extensive it is often advantageous to have the approved repair drawings duplicated and displayed at the site of the repair.

4.1 Materials used for the repair should be checked for correct specification and gauge thickness and, where applicable, heat treated in accordance with specification requirements.

NOTE: General guidance on the heat treatment of wrought aluminium alloys is given in Leaflet BL/9-1.

4.2 On completion of bending or forming operations the material must be free from defects such as scratches, scribe marks, hair line fractures on the outside of bends, cracks at edges adjacent to bends, tool marks, twisting and warping.

NOTE: Complete detail parts must be manufactured by suitably Approved Organisations in accordance with the appropriate drawings. The holder of an Aircraft Maintenance Engineer's Licence in Category B is not authorised to certify the manufacture of aircraft parts.

4.3 Where panels are concerned, care is necessary to prevent buckling and distortion, particularly in the case of large panels, which should be allowed to attain the ambient temperature of the repair site before being fitted. Where the application of heat (e.g. by means of an electric blanket) during the fitting of a panel is specified, it is important that the heat application and control should be strictly in accordance with the requirements of the applicable Repair Data.

4.3.1 In some instances the aircraft constructor may provide preformed and partially built-up parts for incorporation into the repair (e.g. sections of leading edge fitted with nose ribs, panels fitted with stringers, saddle pieces, bridging joints in stringers, etc.), and it should be ensured that such parts are correctly identified and bear evidence of prior inspection.

4.3.2 Particular attention should be given to the drilling of holes, which should be circular and free from scores and sharp edges in order to satisfy design requirements. In some cases it may be specified or recommended that holes in stressed parts should be drilled with a drill reamer, or drilled and then reamed to size. It is also important that drills are sharpened correctly so as to produce the intended hole diameter; a drill running off-centre will produce an oversize hole.

4.3.3 Where existing rivet holes are to be used again, repair schemes may often call for special repair rivets to be used. These rivets have a slightly larger shank diameter but the same size head. However, when necessary (e.g. due to hole damage), the use of rivets the next size larger than the original may be permitted, in which case it should be ensured that the landing limits between the new rivets and the sheet edge or other rivets

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are maintained. In instances where blind rivets are used it is usually necessary to replace the original rivet by the next size larger, and the same precautions regarding landing limits apply.

- 4.3.4 With some repair schemes the method of riveting may be very similar for a wide range of applications, but may vary in detail according to the location of the repair (e.g. the type of rivet or the pitch may vary). Similar variations may also apply to the type of jointing compound used (e.g. in pressurised areas), and to the protective treatment required. The repair drawing should therefore be studied very carefully for any special instructions.
- 4.3.5 Care is necessary, particularly with large repairs, in keeping swarf out of places where it may present a hazard. This applies to joints, wiring looms, exposed moving surfaces (e.g. jack rams and pulley assemblies), and unsealed bearings, all of which should be protected before work is commenced. When drilling through laminations or lap joints which cannot subsequently be separated for cleaning, it is essential to ensure that the parts comprising the joint are held firmly together during the drilling operation.
- 4.3.6 Before assembling a joint it should be ensured that the contacting surfaces are clean and free from swarf, and that all holes and edges are deburred. If specified, jointing compound should be applied evenly before final assembly and riveting and should form a fillet at the edges of the joint when assembly is complete. The manufacturer's instructions regarding the mixing, working and curing time of the jointing compound should be carefully followed.
- 4.3.7 Guidance on riveting aircraft structures, particularly from a repair aspect, is given in Leaflet **BL/6-29**, on the assembly of bolted joints in Leaflet **AL/7-8** and on the main types of rivets in Leaflets **BL/6-27** and **BL/6-28**.
- 4.3.8 When repairs have been made to control surfaces, the balance may have been upset by the additional weight of metal or paint. Such surfaces should be checked for balance by the method given in the appropriate manual and the balance corrected as necessary. For reasons of balance the repairs permitted on control surfaces are often limited in area and position.

## 5 METAL-TO-METAL ADHESIVE

- 5.1 Since a metal adhesive often requires special heating and pressing equipment, its use may be impracticable for repair work. The damaged part should therefore be cut out as shown in the approved Repair Scheme and a new part riveted in position.
- 5.2 It is possible, however, in certain large repairs to obtain from the aircraft manufacturer a built-up section or pre-formed skin panel with parts secured in position by adhesive. The repair then consists of removing the damaged section complete and riveting the replacement section into position.
- 5.3 When it is necessary to remove parts which are secured with adhesive, e.g. a stringer, this can be done as shown in Figure 1. Care should be taken to avoid damaging any parts or material other than those to be removed.

NOTE: When paint is removed in the area of a metal-to-metal adhesive joint, only the paint stripper stipulated should be used. Some strippers may have a deleterious effect on metal-to-metal adhesives.

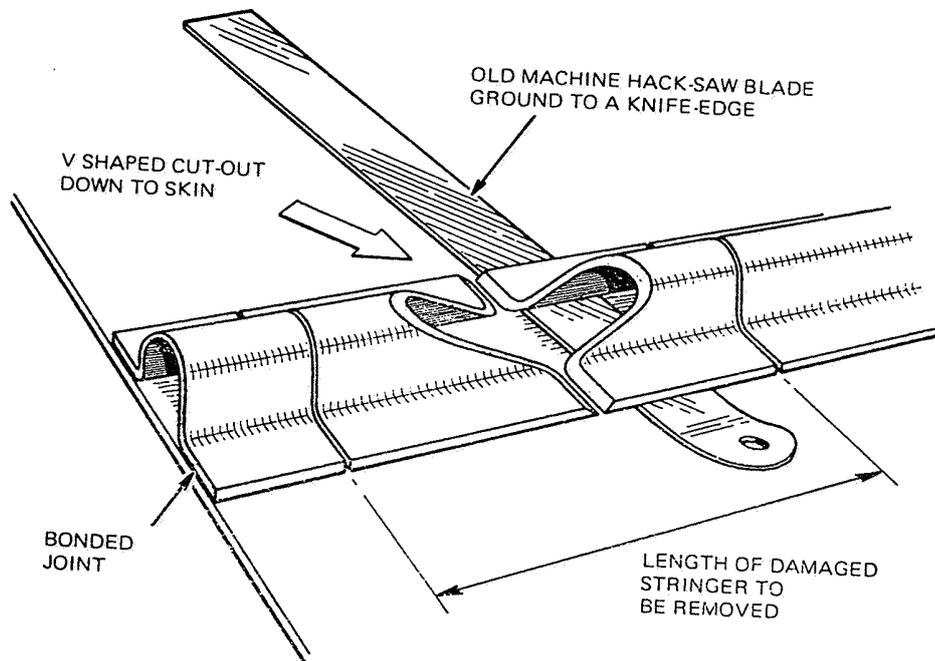


Figure 1 REMOVAL OF BONDED COMPONENT

- 6 REPAIRS BY WELDING** Repairs by means of welding are often specified for welded structures such as landing gear structures, engine mountings, etc. The welding procedure to be used will depend on the design and construction of the structure and will be fully detailed in the Repair Data. It will often be necessary to use jigs or jury structures to ensure that the main structure is held in the correct position during welding.
- 6.1 Welding Procedures.** Some of the welding procedures most commonly used for aircraft repairs are the following: Oxy-Acetylene Welding (Leaflet BL/6-4), Arc Welding (Leaflet BL/6-5) and Spot Welding (Leaflet BL/6-12).
- 6.1.1** Where highly stressed components have been repaired by welding they should be submitted to one of the non-destructive examination tests outlined in the BL/8 series of Leaflets.
- 6.1.2** Before welding is commenced any protective treatment in the area of the repair must be completely removed and the parts prepared in accordance with the repair scheme applicable.
- 6.1.3** As prescribed in Chapter A8-10 of BCAR welders must be approved by the CAA.
- 6.2 Typical Oxy-Acetylene Welding Repairs.** The oxy-acetylene welding technique is more widely used than any of the other methods, and in the following paragraphs a brief outline of some oxy-acetylene welding repairs is given.

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6.2.1 **Welded-Patch Repair.** This type of repair illustrated in Figures 2 and 3 is often used for rectifying such damage as cracks, dents, or holes in tubes, provided certain limitations are not exceeded.

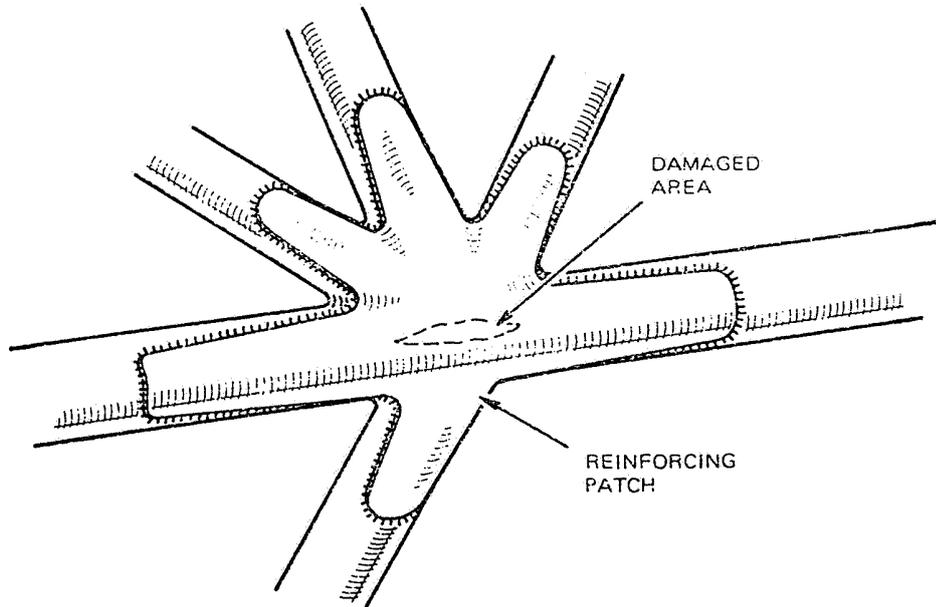


Figure 2 PATCH AT TUBE JOINT

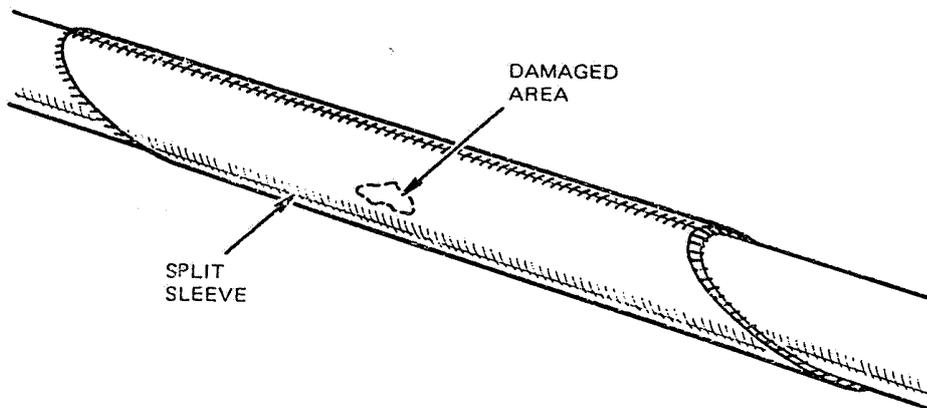


Figure 3 EXTERNAL SLEEVE REPAIR

6.2.2 **Partial Replacement—Inner Sleeves.** Fairly extensive damage to a tube is often repaired by the use of an inner sleeve splice as shown in Figure 4.

- (a) The condition and location of the associated structure should be checked and secured to prevent movement when the damaged portion is removed.

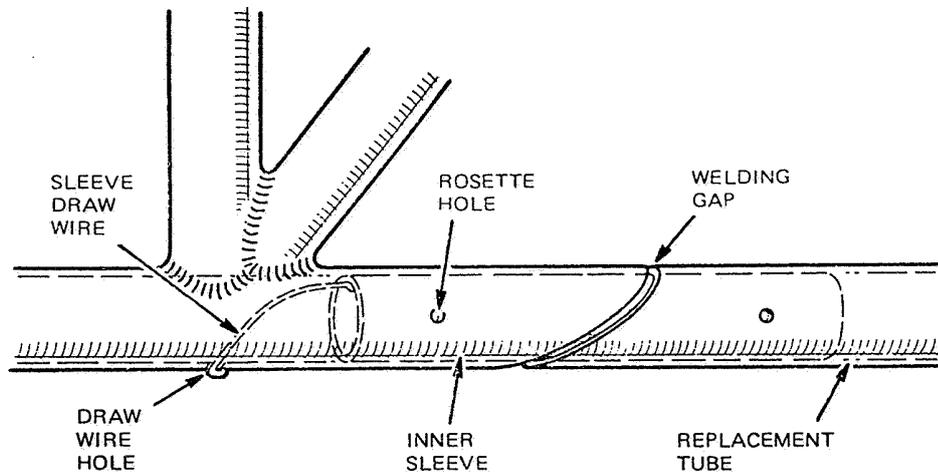


Figure 4 INTERNAL SLEEVE REPAIR

- (b) The damaged portion of the tube should be cut out using 30° or 45° diagonal cuts, and the burrs inside the tube should be removed.
- (c) A replacement piece of tube should be cut to fit where the damaged portion was removed and a gap of approximately 2.4 mm ( $\frac{3}{32}$  in) should be left for welding.
- (d) The inner sleeves should be cut to length and a check made to ensure that they slide smoothly in both tubes. If rosette holes are required they should next be cut and the burrs removed; when a draw wire is required it should be welded into position.
- (e) The inner sleeves should be marked at the half-way position, fitted into the replacement tube and positioned with the midpoint at the diagonal cut.
- (f) The repair should be completed by welding at the diagonal cuts and at the rosette holes or the draw wire hole as applicable.

**6.3 Partial Replacement—Outer Sleeves.** This method should only be used where it is impracticable to use inner sleeves. The procedure is basically the same as for inner sleeves except that the replacement tube should be cut square at both ends and the outer sleeves scarfed at 30° or 45°.

**6.4 Protective Treatment.** After welding, the parts concerned should be thoroughly descaled, cleaned, and the protective treatment restored.

## 7 GAUGING DAMAGE

**7.1** Where a score, dent, or corrosion damage in a stressed part has been removed by blending out into a smooth surfaced hollow depression, the maximum depth of the depression will have to be measured to ensure that it is within the limits given in the Repair Data. This should be done before applying any protective treatment.

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7.1.1 A method of gauging the depth of such a depression is by mounting a dial test indicator on a special adaptor block as illustrated in Figure 5. The bottom edge of the block should be straight and radiused to about 1.2 mm (0.05 in), and the dial test indicator (DTI) stem should be at right angles to this edge. The point of the conical anvil should be lightly stoned to avoid scratching the surface of the depression.

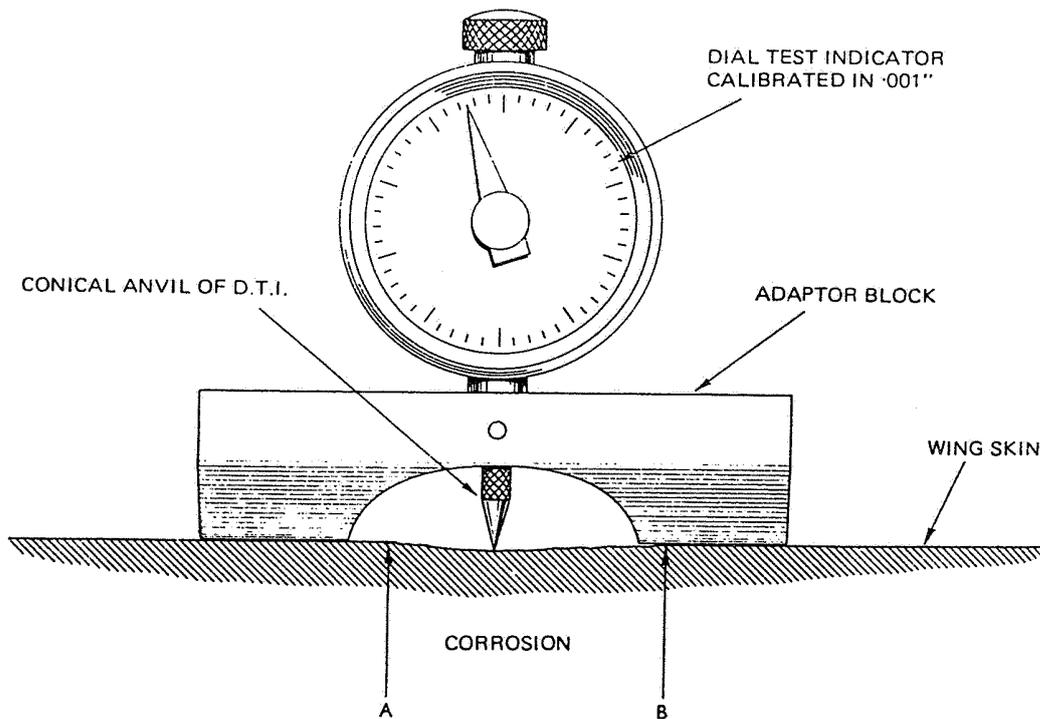


Figure 5 MEASUREMENT OF SURFACE DAMAGE

7.1.2 When gauging the depth of a depression, a reading should first be taken at two points, adjacent to but unaffected by the depression (such as A and B in Figure 5), then the maximum depth reading (D) should be taken. By subtracting the average of the two point readings  $\frac{A + B}{2}$  from the depth reading (D) the actual depth of the depression will be obtained thus: depth of depression =  $D - \frac{A + B}{2}$

7.2 **Bowing Limits.** To measure the amount of bow in a structural member (e.g. a strut), a straight edge and a set of feeler gauges can be used, providing the part to be measured is free from protruding fittings and the straight edge can be applied directly along the surface of the member. The straight edge should be placed along the entire length of the member and parallel to its axis, then by inserting feeler gauges at the point of maximum clearance the amount of bow can be calculated by the formula:—

$$\text{Bow} = \frac{\text{Clearance measured by feeler gauges}}{\text{Length of member}}$$

7.2.1 For example, if the length of the member is 2 ft and the clearance measured by the feeler gauge is 0.040 in, the amount of bow is:

$$\text{Bow} = \frac{0.040}{24.0} = \frac{4}{2400} = \frac{1}{600} \text{ or 1 in 600}$$

NOTE: In general a maximum bow of 1 in 600 is normally acceptable unless otherwise stated in the Repair Manual. However, in some instances the manual may permit tolerances for bow greater than this figure.

7.2.2 To measure a member which has protruding fittings, a trammel fitted with three pointers can be used to bridge the fittings. The three points should be checked for truth against a straight edge or surface table and adjusted if necessary. The outer points should be placed at the ends of the member and any clearance between the member and the centre point checked with a feeler gauge, the amount of bow being calculated as in paragraph 7.2.1.

7.2.3 For more accurate measurement the central trammel point can be replaced by a depth gauge in which case the neutral reading on the depth gauge in relation to the outer points should be carefully noted by checking on a surface table.

7.3 **Curved Sections.** When checking the maximum depth of a depression in a curved surface (e.g. a leading edge), the adaptor block or the trammel must be placed over a line at right-angles to the curvature of the part, i.e. parallel to the longitudinal axis of the curve.

**8 CERTIFICATION** The CAA's requirements regarding certification after repair are given in Chapter A4-3 of BCAR and are also outlined in Leaflet BL/1-8.

8.1 Full particulars of the work done should be entered in the appropriate log book and a Certificate of Compliance should be signed.

8.2 According to the nature of the repair made, the aircraft should be weighed, the Weight and Centre of Gravity Schedule should be amended or replaced by a revised Schedule, a certificate of fitness for flight should be issued and the aircraft should be tested in flight. Particulars and results of such testing must be provided.

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Issue 2

June, 1983

**AIRCRAFT****INSTRUMENTS****FLIGHT INSTRUMENTS—PITOT-STATIC SYSTEMS**

**1 INTRODUCTION** This Leaflet gives guidance on the installation and maintenance of pitot-static systems, their associated instruments and components. It should be read in conjunction with manufacturer's drawings, Maintenance Manuals, and operator's Maintenance Schedules; such documents providing details of construction, major servicing, repairs and calibration procedures relevant to specific items and aircraft systems.

**1.1** For those not familiar with the basic principles of flight instruments dependent upon pitot and static pressures for their operation, brief details of operating principles are given in the paragraphs dealing with individual instruments.

**2 SOURCES OF PITOT AND STATIC PRESSURES** Pitot pressure, which varies with air speed and air density, is the ram air pressure built up by the movement of an aircraft through the air and is sensed by a pressure head externally located at some accurately selected position (see paragraph 5). Static pressure is the ambient pressure prevailing at the altitude at which the aircraft is flying and may also be sensed by a pitot-static head or, as in some aircraft, by a separate static vent system. Both pressures are communicated to the flight instruments through pipelines; the air-speed indicator and other air-speed measuring instruments utilise pitot pressure and static pressure, while instruments such as the altimeter and the vertical speed (rate-of-climb) indicator utilise static pressure only.

**3 PRESSURE HEADS** Pressure heads are of two main types, i.e. the pitot-static type which senses and transmits both pitot and static pressures and the pitot-only type which is used in conjunction with a separate static vent system.

**3.1** Pressure head pipe connections are arranged to suit the method of installation, i.e. frontal installation, fuselage side, or under-wing installation. In the frontal installation the connections emerge in line with the head while in the other two they emerge at 90° to the axis of the head. The connections may be of the low pressure type for use with rubber grommets, or of the high pressure type for use with flared pipes and collets.

**3.2** As prevention against ice formation, pressure heads are equipped with an internal system of appropriately positioned heating elements. Pressure heads designed for fuselage side or underwing mounting have additional elements located inside the support mast. In many cases separate static vents also incorporate heating elements. The heaters are supplied with power from the aircraft electrical system and controlled from the cockpit. Display panels for open circuit detection of elements may also be fitted.

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**3.3 Installation.** Pressure heads should be examined for physical damage and freedom from obstruction, including drain holes, before installation, and it should be confirmed that the type of head is correct for the particular aircraft. Before connecting heater element cables it must be ensured that the pitot heating circuit of the aircraft is isolated from electrical power sources.

**3.3.1** Drain holes of a calibrated size are provided in the bodies of some types of electrically-heated pressure heads and these must be at the bottom when such heads are installed. Certain types of pressure head designed for mounting on the sides of a fuselage are 'handed', and the drain holes and support mast drain screw are located in such a way that they are at the lowest point compatible with the angular position of the head when installed. It is therefore important to ensure that the correctly handed pressure head is fitted.

**3.3.2** In order to prevent distortion of mounting flanges, fixing screws or bolts, pressure heads must be adequately supported during installation and not allowed to hang on their fixing screws when these are being tightened.

**3.3.3** Pressure heads should not be painted as this may impair their thermal efficiency. Furthermore, paint may cause inadvertent obstruction of the necessary orifices and result in inaccurate sensing of pitot and static pressures.

**3.3.4** After installation, the pressure connections should be checked for security and locking, and a leak test of the complete pitot-static system carried out in accordance with the requirements of the aircraft Maintenance Manual (see also paragraph 15.5). The heating elements of electrically-heated pressure heads should be checked for functioning by connecting an ammeter in the circuit and noting that the current consumed is correct for the voltage and power ratings of the pressure head installed. As pitot heads are in positions which make them vulnerable to lightning strikes, bonding should be checked for effectiveness (see EEL/1-6).

**NOTE:** Heater elements can reach very high temperatures when switched on in still air. In order not to impair their life the heating circuit should not be switched on for longer than the period recommended by the manufacturer to carry out the functioning checks.

**4 STATIC VENTS** In order to minimise the effects of position error (see paragraph 5) and to provide greater freedom from ice formation, the sensing of static pressure is by means of separate vents in the form of flat metal plates secured to the fuselage skin at pre-determined positions. There are two principal types of static vent in use, their application being governed by the size and the number of pitot-static systems required for a specific aircraft type.

**4.1** In the basic system, the static vent consists of a flat brass plate, rounded at the ends and having through its centre a 6 mm (0.25 in) diameter hole communicating with a short section of plain pipe which provides for the connection of the vent with the pipeline system. The pipe section may, in some versions, be positioned at 90° to the plate or directed upward at 30° to provide drainage for moisture. A drain tap is usually fitted in the section of pipeline immediately adjacent to vents of the former type.

**4.2** In aircraft employing several independent pitot-static systems, the static vent consists of a flat stainless steel plate through which are drilled a number of 5 mm (0.188 in) diameter holes. Each hole is connected to the pipeline of a specific system or component

requiring static pressure, by means of a threaded coupling adapter welded concentric with the hole. Holes in the fuselage skin accommodate the coupling adapters of the plate which is bolted to the skin.

**4.3 Installation.** The vents are normally fitted in a position free of turbulence from aeriels or other external fitments and located where the skin in the area of the vent is flush riveted and free of butt straps, etc., since such features would cause a varying behaviour of the boundary layer.

**4.3.1** In order to reduce errors due to pressure unbalance at the vents whenever yawing of the aircraft takes place, static vents are fitted on each side of the fuselage and are interconnected into the same static pressure line.

**4.3.2** Brass static vent plates should be provided with a stiffener plate on the inside of the fuselage skin to prevent distortion of the vent plate. On metal aircraft, a metal stiffener, similar in shape to the vent plate, should be riveted to the skin, while with aircraft having a plywood skin, a plywood stiffener should be glued to the skin. The vent plates should make complete contact at their outer edges and be secured to the fuselage skin by means of the spigots provided on the rear face, and by knurled nuts which should be tightened by hand and wirelocked; overtightening may cause the vent plate to distort. A suitable sealing compound should be used between the contacting surfaces of the vent and skin. Exuded sealant should be trimmed off by using a plastic scraper.

**4.3.3** Stainless steel vent plates should be bolted directly to the fuselage skin and, depending on the modification state of the aircraft system, are sealed either by sealing rings around the flanges of the coupling adapters, or by filling the inner surface recess with sealing compound.

**4.3.4** Smoothness of the outer surface of all static vent plates is vital to the accurate sensing of static pressure. They must therefore be kept free of scratches and other indentations, and must never be painted.

**5 PRESSURE ERROR** Pressure error may be defined as that part of the difference between the calibrated air speed and the indicated air speed due to the recorded static pressure not being equal to the ambient pressure. The error, which is strongly influenced by the position of pressure heads and static vents, is determined for each type of aircraft by conducting a series of prototype test flights over various ranges of speed, altitude, configuration, weight, etc. Details of the error so determined, and the corrections to be applied to the readings of airspeed indicators and altimeters, are presented in either tabular or graphical form and contained in an appropriate section of the aircraft's Flight Manual.

**5.1** Any subsequent alteration in the position of either pressure heads or static vents, the provisioning of additional systems, or alterations occasioned by modifications or repair to the aircraft in the vicinity of pressure heads or static vents, may affect the pressure error, necessitating further test flights and alterations to the Flight Manual.

**5.2** If a system is added or repositioned after issue of a Certificate of Airworthiness, major modification action in accordance with Section A, Chapter A4-1 of British Civil Airworthiness Requirements will be necessary.

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**6**      **PIPELINES** Pitot and static pressures are transmitted throughout systems by means of light alloy pipes (tungum pipes may also be used in some aircraft) and flexible hoses such as nylon 11, nylon 66, or rilsan, the latter being used for the connection of resilient-mounted instruments and components. In order to prevent moisture blockage and to minimise pressure lag, the inside diameter of pipelines must not be less than 6 mm (0.25 in).

6.1 The procedure for the installation and removal of pipelines depends upon the size and complexity of individual systems; reference should always be made to the aircraft Maintenance Manual. The following points, common to applied practices, are given as a general guide:

- (a) Before installation, pipelines should be blown out with a clean, dry, low-pressure air supply to ensure cleanliness and freedom from obstruction.
- (b) When tightening the end connections of flexible hoses it must be ensured that the hoses do not become twisted; a yellow or white tell-tale line running along the length of the hose will indicate any twisting.
- (c) Bending of pipes through too small a radius, and kinking, must be avoided since the resulting depressions and reduction in bore diameter will create unwanted moisture traps and erratic transmission of pressure.
- (d) Metal pipes must be securely attached to the airframe structure at regular intervals throughout their run and should slope towards points at which drain traps or drain valves are located.
- (e) Pipelines leading from static vents should be installed so that they rise continuously towards the instruments but, if this cannot be achieved, they should rise for the first 150 mm (6 in) at least. Where two static vents are inter-connected, the pipelines from each should be symmetrically disposed.
- (f) Clearance must exist between a newly installed pipe and other pipes or structural parts to avoid chafing during flight.
- (g) When pipelines are removed from an aircraft, blanks should be fitted to their end connections and all other connections in the system which become exposed by the removal. Support clamps should be returned to their original positions as soon as a pipeline has been removed to ensure their correct location.
- (h) The mating surfaces of pipe ends and connections must be clean.
- (j) When connecting pipelines employing low-pressure unions and rubber grommets, the union nuts should be tightened by hand and should then be secured by a half-turn with a spanner, since overtightening may damage the grommet and result in a leaking joint.
- (k) After installation of a pipeline, the system with which it is associated must be checked for leaks in the manner prescribed in the aircraft Maintenance Manual. On satisfactory completion of such individual checks, a leak test of the complete pitot-static system must be carried out (see paragraph 15.5).

**7**      **DRAINS** In addition to the moisture drainage of pressure heads, facilities must also be provided for the removal of moisture which might accumulate in the pipelines connecting the sources of pressure to instruments and associated equipment. Such draining facilities may take the form of either drain traps or drain valves (in some aircraft they are used in combination) located at the lowest points in pitot and static pipe runs. The design, construction and application of drains varies between manufacturers and type of pitot-static system. Reference should therefore be made to the Manuals concerning the component and aircraft type.

**8**     **ALTIMETERS** As the name implies, altimeters measure the altitude of the aircraft either above sea-level or above a point of known altitude such as an aerodrome. They are basically sensitive pressure gauges which operate on the aneroid barometer principle and indicate the changes in atmospheric pressure which occur with changes in altitude. The calibration of altimeters is in accordance with the ICAO law for the standard atmosphere, which is based on certain assumed values of pressure and temperature to provide a conventional relationship between pressure and altitude.

8.1 An altimeter mechanism consists of a stack of two or, in some versions, three aneroid capsules which are exhausted of air and sealed, and connected to a pointer mechanism via a lever and rocking shaft linkage system. The strength and resiliency characteristics of the material used in the construction of the capsules is such that they expand or contract under the influence of varying external atmospheric pressure. The complete mechanism is housed within a case which, with the exception of a static pressure connector at the rear, is completely sealed. A barometric pressure-setting device (see paragraph 8.2) also forms part of the mechanism. Static pressure is exerted on the outside of the capsules and as changes in this pressure take place the capsules expand or contract; for example, as altitude increases, static pressure decreases and the capsules expand. The small deflections thus obtained are magnified through the lever and rocking shaft linkage and gear train system to produce an indication of the pressure changes in terms of aircraft altitude.

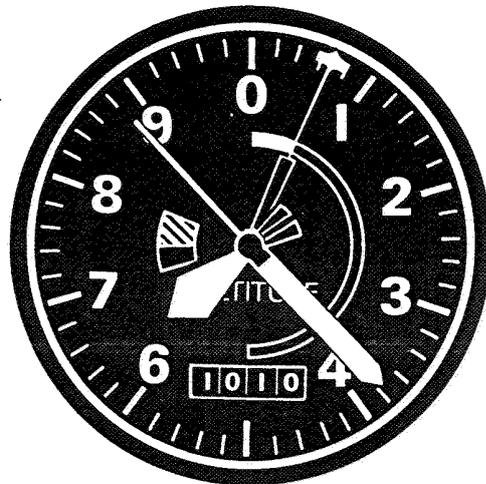
8.2 Since altimeters are calibrated to standard atmospheric conditions, any departure from the assumed values will change the pressure/altitude relationship causing errors in indication. For example, if the prevailing atmospheric pressure at a sea-level aerodrome falls below the standard value, an altimeter situated at the aerodrome will respond correctly to the pressure change and indicate that the aerodrome now stands at a certain altitude above sea-level; in other words, the altimeter over-reads. Conversely, the instrument would under-read should the atmospheric pressure increase. In order to compensate for these barometric errors, a pressure-setting device consisting primarily of an adjusting knob, a scale or digital counter and a gear mechanism, is interposed between the capsule stack and the pointers. The scale or counter may be calibrated in either millibars or inches of mercury, the readings being visible through an aperture in the main dial. When the adjusting knob is rotated, the scale or counter and the complete altimeter mechanism are also rotated, the gearing being so arranged that, for any atmospheric pressure setting, the altimeter pointer or pointers rotate to indicate the altitude equivalent of that pressure. Thus, to correct the reading of the altimeter in the example considered and so make the pointers indicate zero feet, the scale or counter must be set to the atmospheric pressure prevailing at the aerodrome.

8.3 The setting and correction of altimeters to known atmospheric pressures forms part of aircraft operating procedures and is of great importance for take-off, landing and for maintaining adequate height separation of aircraft and terrain clearance. Three settings are normally used and are signified under the ICAO Q Code for the transmission of meteorological and other operational information. They are:

- (a) Setting aerodrome atmospheric pressure so that an altimeter reads zero on landing and take-off (QFE).
- (b) Setting mean sea-level atmospheric pressure so that an altimeter reads the aerodrome altitude above mean sea-level (QNH).
- (c) Setting mean sea-level atmospheric pressure in accordance with the ICAO standard atmosphere, i.e. 1013.25 millibars or 29.92 inHg (QNE).

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- 8.4 Variations in atmospheric temperature affect the rate at which pressure changes with altitude relative to standard conditions; therefore, errors in the indications of altimeters can also occur due to such temperature variations. Correction of these errors is applied in flight by means of a height calculator based on the slide-rule principle. The effects of temperature on pressure-sensing capsules and linkage mechanisms are compensated by devices operating on the bi-metallic principle.
- 8.5 The presentation of altitude by altimeters in current use varies from the multi-pointer type to the drum and single pointer, the digital counter and single pointer, and the digital counter, drum and single pointer types. Presentations typical of those in current use are illustrated in Figure 1. In the multi-pointer type, the pointers are of different lengths and indicate 'hundreds', 'thousands', and 'tens of thousands' of feet against a common scale. In the drum/pointer type of presentation the pointer indicates 'hundreds' of feet against a fixed scale, while 'thousands' of feet are indicated by a drum which is proportionally rotated by the pointer mechanism. The drum scale is visible through an aperture in the instrument dial and is referenced against a datum marker across the aperture. In the digital counter/pointer method of presentation 'thousands' and 'tens of thousands' of feet are indicated by the incremental changes of separate counters located across the centre of the dial. The counter/drum/pointer type of altimeter presentation provides a 5-digit numerical display of altitude with the last three digits forming the drum and showing 'hundreds' of feet. The pointer displays 1000 ft for each complete revolution with 20 ft scale markings.
- 8.5.1 In order to avoid the mechanical loads which would otherwise be imposed on the pressure-sensing capsules by actuating several counters, a servo drive system may be used in altimeters employing these latter types of presentation. The movement of the capsules actuates the armature of an electromagnetic pick-off assembly producing a signal proportional to the prevailing pressure. This output signal is amplified by an external amplifier unit and supplied to a servomotor located within the indicator, to drive the pointer and counters through special gear assemblies. The amplified signal may, in some cases, also be used to drive synchros which in turn drive indicators and transponders for altitude reporting (see paragraph 8.7). In the event of electrical power failure to the instrument, a power failure warning flag is incorporated to indicate that the altimeter is inoperative.
- 8.5.2 Because of the inherent pressure error (see paragraph 5) servo altimeters generally have a built-in correction system, 'tailored' for the particular aircraft design, that minimises this error for the full range of flight speeds and altitudes. Correction for datum pressure changes in the servo altimeter is achieved by mechanically displacing the datum of the electromagnetic pick-off assembly. The pick-off senses this change and the system runs to null the datum change, thereby driving the pointer to zero.
- 8.6 The use of altimeters employing any of the three principal presentation methods, is governed primarily by the ease with which readings may be interpreted over the altitude ranges in which a specific type of aircraft must operate. Multi-pointer presentations, particularly the three-pointer type, are very susceptible to misreadings, e.g. 1000 ft for 10,000 ft, and various modifications have been incorporated to overcome this difficulty; for example, the type illustrated in Figure 1 employs distinctively shaped pointers and low altitude warning sectors. However, the use of multi-pointer altimeters as a standard for all types of aircraft is severely limited by performance characteristics and operational altitude ranges. For high-performance turbo-jet aircraft, in which misreading of altimeters may prove hazardous, the counter/pointer presentation is preferred. Information concerning altimeter presentation and the terms of their acceptance by the CAA is contained in Airworthiness Notice No.77.



MULTI-POINTER



DRUM/POINTER



COUNTER/POINTER

*Figure 1* TYPICAL ALTIMETER PRESENTATIONS

**8.7 Encoding Altimeters.** To enable the altitudes of an aircraft to be known for air traffic control purposes, an airborne radar beacon transponder can be interrogated by a ground radar. These transponders have 4,096 codes available, so the encoding altimeters not only provide the flight crews with a visible read-out of the aircraft flight level but code the transponder so that it can reply to the ground station with a signal providing a visible indication on a radar screen of the aircraft's altitude in 100 ft increments. Encoding altimeters of the non-servo type must have an extra low torque pick-off and the majority now in use employ optical encoders. In this system, the capsule drives a glass disc, etched with transparent and opaque sectors. A light source shines through the disc onto photoelectric

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cells which convert the disc's movement into coded signals for the transponder. This type of pick-off provides a high degree of accuracy with very low torque requirements.

**9 AIR-SPEED INDICATORS** These instruments are, in effect, sensitive pressure gauges which measure the difference between the pitot and static pressures, and present such differences in terms of indicated air speed. Indicators are made by various manufacturers and, although fulfilling identical roles, they may vary in their mechanical construction; however, the basic construction and operating principle is the same for all types.

**9.1** The mechanism, which is contained within an airtight case, is comprised of a pressure-sensitive capsule coupled to a pointer mechanism via a lever and rocking shaft linkage system. Two adapters, identified by the letters P and S, are located at the rear of the case and provide for the connection of the indicator to the pitot and static pressure pipelines respectively.

**9.2** Pitot pressure is transmitted to the interior of the capsule via a short length of capillary tube connected between the capsule and pitot adapter, while the static pressure is transmitted directly to the interior of the indicator case and acts on the outside of the capsule. Changes in either of the two pressures establishes a differential across the capsule causing it to expand or contract. The small deflections of the capsule are transmitted through the lever and rocking shaft linkage system via a gear quadrant and pinion to the pointer mechanism, which produces a magnified angular deflection of the pointer or pointers over a scale calibrated in knots or in miles per hour.

**9.3 Maximum Allowable Air Speed Indicators.** Another type of air-speed indicator in use is the maximum allowable air speed indicator which includes a maximum allowable needle to indicate a decrease in maximum allowable air speed with an increase of altitude. It operates from an extra capsule in the air-speed indicator which senses changes in altitude and measures this change on the dial of the instrument. Its purpose is to indicate maximum allowable indicated air speed at any altitude.

**9.4 True Air Speed Indicator.** The case of this instrument holds both an air-speed indicator which moves the pointer and an altimeter mechanism which moves the dial. The movement of the altimeter mechanism is opposed or aided by the action of a bi-metallic spring exposed to outside air flow, and, as the aircraft increases in altitude, the dial rotates in such a direction that the pointer will indicate a higher value. If the air is warmer than standard for the altitude at which the aircraft is flying, the temperature sensor will assist the altimeter to cause the true air speed reading to be higher than under standard temperature conditions.

**10 VERTICAL SPEED INDICATORS** These indicators are sensitive differential pressure gauges which are connected to the static system and sense the rate of change of static pressure and present it in terms of vertical speed (rate of climb and descent) in feet per minute. The mechanism is housed in a cylindrical case which is rendered airtight except for the static pressure connector at the rear of the case. Basically the mechanism consists of a sensitive capsule, a 'calibrated leak' assembly or metering unit, a lever and rocking shaft linkage system, and a gear type pointer mechanism. The connection of the capsule and metering unit to the pressure connector is arranged so that static pressure is fed directly to the interior of the capsule and also allowed to 'leak' at a calibrated rate to the interior of the instrument case. Thus, when the static pressure varies due to changing altitude, the metering unit has a restrictive effect causing the pressure change in the case to lag behind the pressure change in the capsule. The resulting differential pressure across the metering unit and the capsule causes the latter to expand or contract and drive the pointer via the linkage and gear mechanisms. The scale is calibrated to indicate climb and descent, in the clockwise and anti-clockwise directions respectively, from a zero graduation situated at the 9 o'clock position.

A set screw, or in some instruments an adjusting knob, is provided in the lower left-hand corner of the bezel to permit the capsule datum position to be adjusted and thus reposition the pointer to zero via the linkage and gear mechanisms within the limits set by the manufacturer.

10.1 In level flight, the pressures inside the capsule and the instrument case remain the same; therefore the mechanism is at rest and the pointer indicates zero. When the aircraft climbs, the static pressure decreases inside the capsule but, due to the metering unit, the case pressure will remain the greater and so cause the capsule to contract and drive the pointer to indicate a rate of climb. The pressure difference thus established is maintained until any further alteration to rate of change of altitude takes place. During a descent the changes in static pressure are in the opposite sense causing the capsule to expand and to drive the pointer to indicate the appropriate rate of descent until level flight is resumed and no further altitude change takes place.

10.2 **Instantaneous Vertical Speed Indicator.** The ordinary vertical speed indicator whose indication lags the pressure change would be of greater value if it had no lag, and for this reason the instantaneous vertical speed indicator has been developed. An instantaneous vertical speed indicator uses a vertical speed indicator mechanism in the case with an accelerometer-operated pump or dashpot across the capsule. When the aircraft noses over to begin a descent, the inertia of the accelerometer piston causes it to move upwards, instantaneously increasing the pressure inside the capsule and lowering the pressure at the metering unit. This gives an immediate indication of a descent. By the time the lag of the ordinary vertical speed indicator has been overcome so it will indicate, there is no more inertia from the nose-down rotation and the piston is again centred making the instruments ready to indicate instantly the levelling off from the descent.

11 **MACHMETERS** In the operation of high performance aircraft capable of speeds approaching or exceeding that of sound, it is necessary to measure air speeds which are directly related to altitude and also to the variations in speed of sound which occur with atmospheric density variations. Therefore, in addition to conventional air-speed indicators, instruments integrating both speed and altitude measuring functions and referred to as Machmeters, are installed in aircraft of this type. Machmeters indicate the air speed in terms of a Mach number which is defined as the ratio of the air speed of an aircraft to the speed of sound under the prevailing atmospheric conditions in which the aircraft is flying. The ratio may be expressed as a numerical percentage but for convenience is designated decimally and with the suffix M; thus, 0.8M means a speed that is 80% of the speed of sound under the ambient conditions in which the aircraft is flying.

11.1 The mechanism of a Machmeter consists basically of an air-speed measuring unit and an altitude measuring unit both of which are connected through calibration arms and sliding shafts to a common gear mechanism actuating a single pointer. The complete assembly is housed in a case provided with pitot and static pressure connectors at the rear. A lubber mark mounted over the instrument dial provides for the setting of the limiting Mach number specified for the aircraft in which the instrument is to be installed, and may be adjusted either by a screw or knob at the front of the instrument.

11.2 The capsule of the air-speed measuring unit expands and contracts in response to the difference between pitot and static pressure and deflects the pointer to positions related to corresponding air speeds. The altitude unit capsule expands and contracts in response to changes in static pressure only, and since it is interconnected with the air-speed

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measuring unit it determines the point of contact between the calibration arms thereby modifying the magnification ratio of the air-speed unit. Thus, the final deflected position of the pointer relates to a constant air speed at a particular altitude and, as atmospheric temperature variations are taken into account by the basic calibration formula, the Mach number as conventionally defined is therefore measured in terms of a pressure ratio.

**12 PRESSURE SWITCHES AND PRESSURE TRANSDUCERS** These units are connected in the pitot-static systems of certain types of aircraft for the purpose of actuating devices which give aural, visual or physical warning to a pilot of an approaching dangerous condition, or for controlling the operation of systems whose functions are related to speed or altitude, e.g. flight recorders and altitude recorders. In some installations switch units may be used in both the warning and controlling mode.

12.1 The mechanisms of pressure switch units are similar in basic construction and operation to those employed in air-speed indicators, Machmeters and altimeters. In place of linkage and pointer mechanisms, however, the capsules actuate special electrical contact assemblies which are supplied with power from the aircraft electrical system, and connected into the relevant warning or controlling circuit.

12.2 Pressure transducers are units designed to provide air-speed and altitude information in the form of electrical signals to flight recorder and encoding systems. The units employ pressure sensing elements connected to either d.c. potentiometer or synchro type electrical elements. The output signals which are proportional to air speed and altitude are fed to a computer unit for encoding and transmission to the recording unit.

12.3 The arrangement and setting of pressure switch contacts, operating ranges of pressure transducers and adjustment methods, depends upon the aircraft operating requirements and the design of units and recording systems adopted. Reference should therefore be made to the appropriate aircraft Maintenance Manual and manuals supplied by the equipment manufacturers.

**13 AIR DATA COMPUTERS** Air data computers are units connected to the pitot-static systems of some types of high performance aircraft for the supply of pitot-static pressure information to instruments indicating height, etc., which in this application are of the electro mechanical type. This information is also transmitted to other systems utilising these pressures as datum references, i.e. autopilots, automatic throttle control systems, etc. The units house capsules and electrical transducer elements which convert pitot and static pressures, total air temperature and possibly angle of attack, into electrical signals representing altitude and air-speed quantities and other derived quantities such as Mach number, true air speed and static air temperature, rate of climb and descent, and transmit the signals through a synchronous system. There are a number of variations in the design and method of computation within air data systems and reference should be made to the manufacturer's relevant publications for details of operation, installation and maintenance.

**14 INSTALLATION OF PITOT-STATIC INSTRUMENTS** Before installation, instruments should be inspected for damage or deterioration which might have occurred in storage or transit. New or overhauled instruments are normally kept in their special packaging containers until required and the packaging should be carefully examined for signs of damage before removing the instrument. It must be verified that the shelf life (which is

usually indicated on the container) has not been exceeded.

NOTE: The functioning of instruments must never be checked by applying the mouth and blowing into the pressure connectors. This will not only cause moisture penetration of mechanisms but also the derangement of pressure-sensing capsules due to inadequate control of pressures applied in this manner.

14.1 The dials of air-speed indicators should be checked to ensure that, where applicable, they bear coloured arcs and radial lines at various parts of the scale corresponding to the normal operating and limiting speeds laid down for specific aircraft types. It may be necessary in some instances to apply the arcs and radial lines to the cover glasses. When this is done, the precaution must be taken of painting a short white line from the glass to the bezel in a position which does not conflict with the essential operational marks. Thus, the correct position of the glass may be readily checked.

NOTE: Further information on operational markings is given in Joint Airworthiness Requirements (JAR) 25.1545 or Section D, Chapter D7-3 of British Civil Airworthiness Requirements.

14.2 In some instances instruments are fitted with cover glasses whose surfaces are 'bloomed' to reduce surface reflection. These glasses may be identified under normal daylight conditions by their bluish tint and their anti-reflection properties. Care must be taken not to scratch bloomed glasses, or to touch them unless absolutely necessary. Any finger marks or other stains should be immediately removed from the glass using a dry, clean, 'lint-free' cloth and approved isopropyl alcohol cleaning solvent. All traces of solvent should be removed with the cloth and should not be allowed to dry off naturally. Water must not be used for cleaning purposes.

14.3 The method of mounting instruments on their respective panels depends on whether the cases of the instruments specified for use in a particular aircraft type are of the flanged or flangeless design. In the former design the bezel is flanged in such a manner that the instrument is flush-mounted in its cut-out from the rear of the panel. Integral self-locking nuts are provided at the rear faces of the flange corners to receive fixing screws from the front of the panel. The mounting of instruments having flangeless cases is a simpler process in that separate fixing screws and nuts are unnecessary, and mounting of the instruments may be done from the front of the panel. A special expanding type of clamp, shaped and dimensioned to suit the instrument case, is secured to the rear face of the panel at the appropriate cut-out location by two retaining screws. Two actuating screws are connected to the clamp and are arranged to be accessible from the front of the instrument panel. The screws must be released sufficiently to allow the instrument to slide freely into the clamp. After positioning the instrument, the actuating screws are then rotated so as to draw the clamp tightly around the case of the instrument. To avoid strain or distortion care must be taken to ensure that instruments seat squarely in their cut-outs while being secured to the instrument panels. This is of particular importance when installing instruments having flanged cases.

14.4 Before connecting instruments to the pitot and static pressure pipeline system, the lines should be blown through with a clean, dry, low-pressure air supply to remove any dust or moisture that may have accumulated, and the system should be drained at the draining points provided. When installing instruments requiring electrical power, for example a servo altimeter or a pressure switch unit, the appropriate electrical circuit must be isolated from the power supply until post-installation checks and tests can be carried out.

14.5 When tightening the union nuts or adapters of pipelines onto the connectors of instruments, the connector must be held securely with a spanner to avoid undue stress upon the cases of the instruments.

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14.6 After the pipelines have been connected to the instruments, a leak test of the complete pitot-static system must be carried out (see paragraph 15.5). The electrical functioning of pressure switch units must also be checked by carrying out the tests prescribed in the relevant aircraft Maintenance Manual.

**15 MAINTENANCE OF PITOT-STATIC SYSTEMS** The following paragraphs detail the general maintenance necessary on pitot-static systems and their major components, and should be read in conjunction with the Maintenance Manuals for the type of aircraft and equipment concerned.

**15.1 Pressure Heads.** Pressure heads and their supporting tubes or masts should be inspected for security of mounting and signs of distortion. Where specifically required, checks on the lateral and longitudinal alignment with respect to the aircraft datum must be carried out to ensure that they are within the limits given in the aircraft Maintenance Manual. Checks should also be made that electrical connections at all appropriate points are secure and the insulation of cables does not show signs of cracking or chafing. The pitot pressure entry hole, drain hole and if applicable the static holes should be inspected to ensure that they are unobstructed.

**NOTE:** The size of static holes and drain holes is aerodynamically critical and they must never be cleared of obstruction with tools likely to cause enlargement or burring. In the absence of special clearing tools, which may be locally manufactured from drawings given in manufacturer's manuals, the use of a stiff non-metallic brush is recommended, taking care not to displace debris into the system and cause obstruction.

**15.1.1 Electrical Checks.** Heating elements should be checked for functioning by ensuring that pressure head casings and, where applicable, support masts and static vent plates, commence to warm up when switched on or, if an ammeter is fitted in the heating circuit, by a current consumption check. An insulation check on the resistance between the electrical leads and the appropriate component should be made by connecting a voltage supply appropriate to the rating of the heating elements, switching on the supply and allowing the component to warm up until it is just too hot to hold with the bare hand. The current should then be switched off and, while the component is hot, the insulation resistance measured, using the specified tester. The component should then be allowed to cool and the insulation resistance measured in this condition. The resistance values thus obtained should not be less than those quoted in Maintenance Manuals; a typical value is 3 megohms.

**NOTE:** Measured values less than those specified may be due to moisture penetration of the heating elements.

**15.1.2 Leakage Tests.** The method of checking pressure heads for leaks differs with the various types, and in each instance the procedures given in the relevant Manual should be followed.

**NOTE:** All pressure heads are sealed on manufacture and no attempt should be made to dismantle or tamper with them in any way. If a pressure head fails a leakage test it should be renewed.

**15.1.3 Protection Covers.** If the aircraft is to be left standing for prolonged periods, e.g. during overnight parking or hangar maintenance checks, pressure heads must be covered with a moulded protective sheath or cover to prevent the entry of foreign matter and contamination by water or other liquids. Any protective sheath or cover should be able to 'breathe', and extreme care should be taken also to ensure that pressure head heaters are not operated. The sheath or cover should be of a prominent

colour and have a streamer attached to it, to attract attention should a take-off be attempted before removal of the sheath or cover.

**15.2 Static Vents.** Static vent plates should be inspected to ensure that exposed surfaces are free from scratches, indentations, etc., and that the holes are unobstructed and their edges free of burrs and other damage. Mud and dirt should be removed from exposed surfaces with a clean 'lint-free' cloth to ensure that particles of material are not rubbed off into the vent holes. Protection of static vents during prolonged standing periods of the aircraft is effected by blanking the vent holes with special vent plugs. If plugs made from rubber are used they should be able to 'breathe' otherwise pressure differential can build-up, causing air data systems to operate when electrical power is applied. They should also be periodically inspected for signs of cracking and fracture. This is important since, if part of a fractured plug remains in the vent when the plug assembly is thought to be removed, incorrect instrument readings will result. The plugs should be of a prominent colour and have a streamer attached, to attract attention should a take-off be attempted before removal of the plugs.

**15.3 Pipelines.** Pipelines should be checked to ensure freedom from corrosion, kinking and other damage, and that the pipes are securely clamped and their connections tight and locked. Flexible hoses should be carefully inspected for security and evidence of kinking, twisting, deterioration (particularly at the joints between hose and connectors), and other defects. At the periods specified in the aircraft Maintenance Schedule, the pitot-static system should be drained at each of the draining points provided, and pipes disconnected from the instruments and blown through with a clean, dry, low-pressure air supply. To avoid contamination of adjacent parts of the structure or adjacently mounted equipment, a suitable container should be positioned at the draining points for the collection of water.

**15.4 Instruments.** The checks to be carried out on individual instruments, pressure switch units, etc., are primarily concerned with security, visual defects and calibration tests. Precise details of these checks and their frequency are given in relevant Maintenance Manuals and Schedules and reference should always be made to such documents, but the following summary serves as a guide to the general nature of the checks required:

- (a) Security of attachment to instrument panels and appropriate parts of the airframe structure.
- (b) Security of pressure and electrical connections.
- (c) Evidence of cracking of cases, bezel mounting flanges and cover glasses. The latter should always be carefully inspected as cracks caused by glancing blows struck by safety harness fittings, head sets, etc., are often difficult to detect.
- (d) Checking of dial markings, counters and pointers for legibility, discoloration and flaking.
- (e) Checking of coloured operational markings (see also paragraph 14.1).
- (f) Presence of moisture or water inside the cover glass or on the dial.
- (g) Functioning and smoothness of pointer operation during leak testing of pitot-static systems (see paragraph 15.5).
- (h) Checking of pointer direction and that pitot and static lines are connected to their respective instrument connections.

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15.4.1 The zero setting of pointers must also be checked and in particular this applies to altimeters and vertical speed indicators. At the time an inspection is carried out, the aerodrome barometric pressure should be ascertained (QFE) and set on the barometric pressure scale or counter of an altimeter by rotating the adjusting knob. With this pressure set, the instrument should read zero within the tolerances specified for the type installed. No adjustment of any kind must be made, and if a reading is not within limits the instrument must be renewed. Because of the sensitivity of altimeters, due consideration should be given to any difference in height between the level at which the prevailing barometric pressure is obtained, and the level at which the inspection takes place.

NOTE: When checking servo altimeters and altimeters connected to air data computer units, the system power supplies must be ON.

15.4.2 Under the atmospheric conditions prevailing at the time of an inspection, vertical speed indicators should indicate zero. If however, the pointers are displaced either side of the zero mark and such displacement is within the specified tolerances, the pointers may be set at zero by means of the adjustment screw provided. Indicators requiring settings outside the adjustment range specified must be renewed.

15.4.3 Calibration tests of all instruments should be carried out prior to installation, when their operation and indications are suspect, and at the periods specified in the aircraft Maintenance Schedule.

**15.5 Leak Testing of Pitot-Static Systems.** Aircraft pitot-static systems must be tested for leaks after the installation of any component parts, at any time system malfunctioning is suspected, and at the periods specified in the aircraft Maintenance Schedule. The method of testing consists basically of applying pressure and suction to pressure heads and static vents, respectively, by means of a special leak tester and coupling adapters, and noting that there is no leakage, or the rate of leakage is within the permissible tolerances prescribed for the system. Leak tests also provide a means of checking that the instruments connected to a system are functioning correctly, but they do not serve as a calibration test (see paragraph 15.4.3).

15.5.1 Specific applications of the basic method of leak testing and the type of equipment recommended depend on the type of aircraft and its pitot-static system, and as these are detailed in relevant manufacturer's and aircraft Maintenance Manuals, reference must always be made to these documents. There are, however, certain aspects of the procedures and precautions to be observed which are of a standard nature, and these are summarised for guidance as follows:

- (a) Pressure and suction must always be applied and released slowly to avoid damage to instrument capsules. In multi pitot-static systems involving the use of selector valves, pressure or suction must be restored to ambient pressure before operating the valves as specified in the tests.
- (b) If two static vents are interconnected, one vent should be blanked off before the tests are commenced.
- (c) When fitting leak tester adapters to pressure heads, care must be taken not to apply loads which tend to disturb their alignment.
- (d) In carrying out a leak test of a static pressure system an apparent leak will be indicated by the dropping back of the altimeter pointer. This is a normal

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indication which stabilises when the static pressure across the vertical speed indicator capsule has equalised.

- (e) When conducting leak tests and functioning checks of air data computer systems, the electrical power supply must not be interrupted as there is the possibility of the system becoming de-synchronised.
  - (f) When testing a system to which autopilot altitude and air-speed locks are connected, the autopilot must be powered but not engaged with the aircraft's flight control system.
  - (g) On completion of tests which have necessitated the blanking-off of various sections of a system, a check must be made that all blanking plugs and adapters have been removed.
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**AL/10-2**

Issue 2

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**AIRCRAFT****INSTRUMENTS****FLIGHT INSTRUMENTS—GYROSCOPIC SYSTEMS**

1 INTRODUCTION This Leaflet gives guidance on the installation and maintenance of flight instruments utilising gyroscopic principles and which provide primary indications of an aircraft's attitude and direction. It does not include information on instruments associated with proprietary integrated flight systems or other electronic equipment. The Leaflet should be read in conjunction with manufacturer's drawings, Maintenance Manuals, and operator's Maintenance Schedules which provide details of construction, major servicing, repairs and calibration procedures relevant to specific instruments and aircraft installations.

2 GENERAL Information on the attitude and direction of an aircraft is provided by the gyro horizon or artificial horizon, turn and slip indicator and direction indicator. These instruments depend for their operation on the fundamental properties of a gyroscope designed to establish stabilised references which, in conjunction with the indications of pitot-static instruments (see Leaflet AL/10-1), are required for various conditions of flight operations.

2.1 For those not familiar with the basic principles of these flight instruments, brief operating details are given in the paragraphs dealing with the individual instruments.

3 GYROSCOPES A gyroscope (normally abbreviated to gyro) is a rotating mass having freedom in one or more planes at right angles to the plane of rotation. It possesses two fundamental characteristics: gyroscopic inertia or rigidity, and precession. Gyroscopic inertia is the property a rotating mass has of reluctance to change its plane of rotation in space unless acted upon by an external force. (Newton's first law of motion; every body continues in its state of rest or of uniform motion in a straight line unless it is compelled by forces to change that state.) Precession is the angular change of direction of the plane of rotation, under the action of an external force.

**3.1 Definitions**

- (a) **Free Gyro:** A gyro having complete freedom in three planes at right angles to each other. This is also sometimes known as a 'space' gyro.
- (b) **Tied Gyro:** A gyro having freedom in three planes at right angles to each other but controlled by some external source.
- (c) **Earth Gyro:** A tied gyro controlled by gravity to maintain its position relative to the earth.
- (d) **Rate Gyro:** A gyro having one plane of freedom at right angles to the plane of rotation, so constructed as to measure rate of movement about the plane at right angles to both the plane of rotation and the plane of freedom.

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3.2 **Practical Applications.** Mechanically, a wheel can only be mounted so that it has complete freedom in three planes by mounting it in a system of rings or gimbals. The spinning rotor in aircraft instruments constitutes the gyro. All practical applications of the gyro are based on the two characteristics — gyroscopic inertia, and precession.

3.2.1 **Gyroscopic Inertia.** When the rotor of a free gyro is spinning it will maintain its plane of rotation fixed in space and will not be affected by movement of its outer gimbal system.

3.2.2 **Precession.** When a torque is applied to disturb the plane of rotation of a gyro, the gyro will resist angular movement in the plane of that torque, but will move in a plane at right angles to the disturbing torque; this resulting movement is called precession. The direction of the precessional movement is dependent on the direction of the disturbing force and the direction of rotation of the gyro, and can be determined by considering the applied torque as due to a force acting on a point on the rim of the gyro rotor at right angles to the plane of rotation. If that imaginary point is carried around the rotor  $90^\circ$  in the direction of rotation, that will be the point at which the force is apparently taking effect, moving that part of the rotor rim in the same direction as the disturbing force (see Figure 1).

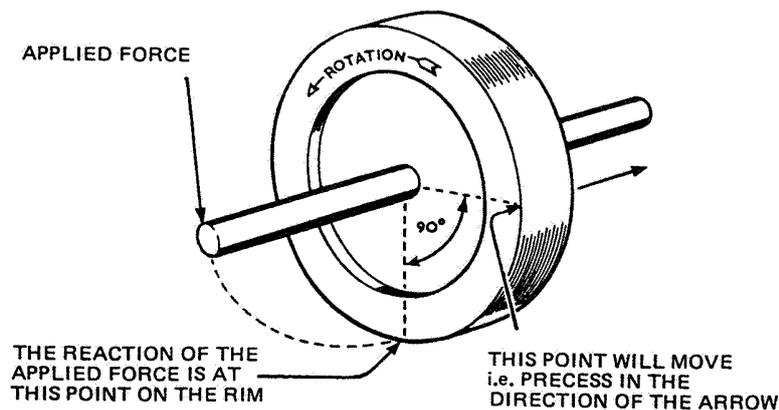


Figure 1 PRECESSION

3.3 When the gyro rotor is spinning, it maintains its plane of rotation fixed in space, but there is no definite attitude in space which the gyro will naturally assume. Therefore, if the gyro is to be used as a reference it must be controlled, so that the gyro assumes a definite attitude either in space or relative to the earth, after which it will be stabilised by its own inertia. A gyro fitted with such a device is called a 'tied' gyro. If tied by gravity control, it is called an 'earth' gyro. An example of a tied gyro is the directional gyro, which has its axis of rotation maintained in a plane at right angles to the outer gimbal ring. An example of an earth gyro, is the gyro horizon, which has its axis of rotation maintained in a vertical position relative to the earth's surface, by a pendulum control.

3.4 **Rate Gyros.** If a gyro is mounted so that it has freedom about two axes only, it can be adapted to be used as a 'rate' gyro, i.e. to measure rate of angular movement. If there is an angular movement in the plane in which the gyro has no freedom, the rotor will be precessed until its plane of rotation coincides with the plane of angular freedom and its direction of rotation coincides with the direction of the angular movement (see Figure 2).

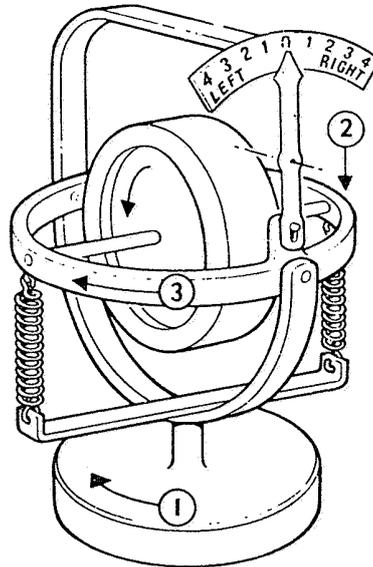


Figure 2 A BASIC RATE GYRO

3.4.1 In order to obtain an indication of rate, it is necessary to restrict precession of the rotor so as to apply a torque to it which will cause precession in the same plane as the angular movement. This is usually done by springs (see Figure 2). On turning the base, the rotor will precess until the spring applies a force to the rotor sufficient to cause it to precess about the turning axis at exactly the same rate as the base is being turned. This amount of precession against the spring will be dependent on the rate of angular movement.

3.4.2 Turning the base of the gyro illustrated in Figure 2, in the direction of arrow 1 will cause the rotor to precess so that the needle will move over to the right-hand side of the scale. The right-hand spring will now exert a force down (as shown by arrow 2). This force will precess the rotor to turn in the same plane and at the same rate as the base. Since the base and rotor axis are fixed in relation to each other, any change in the rate of angular movement of the base must cause a change in the precessional rate of the rotor. This rate of angular movement of the base must always be balanced by precession of the rotor in the same plane. This balance is achieved by precession against the spring to produce the requisite force, and any given rate of turn will be shown as a definite amount of movement of the needle over the scale provided the rotor speed is constant.

- 4 POWER SUPPLIES REQUIRED FOR INSTRUMENT OPERATION The rotors of the gyros may be driven either pneumatically from a vacuum source, or from an electrical power supply system; the application of instruments utilising either method being governed by the installation requirements for the type of aircraft. The electrical method of operation is

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most widely used in current types of aircraft gyro horizons and turn and slip indicators. Electrically-operated direction indicators usually form part of a remote-indicating compass system or of an integrated flight system, details of which are given in the appropriate manuals.

**4.1 Vacuum Supplies.** In installations using pneumatic instruments the supply of vacuum is obtained from either a venturi or an engine-driven vacuum pump.

4.1.1 The venturi is usually mounted at the side of the fuselage and is exposed to the propeller slipstream which, passing through the venturi, creates a correspondingly low pressure. The low pressure is transmitted to the instruments by a pipeline from the venturi.

4.1.2 In vacuum pump installations the pump is directly connected to a splined coupling adapter of the engine auxiliary gear drive system. The low pressure side of the pump is connected to a manifold which distributes the vacuum to the instruments via flexible hoses. An oil separator is connected to the discharge outlet of the pump and is designed to vent the pump to atmosphere and also to return the oil used for pump lubrication to the engine. In duplicate pump systems, non-return valves are installed to prevent vacuum loss in the event of failure of either pump.

4.1.3 The vacuum required for instrument operation is usually between 89 to 114 mmHg (3.5 to 4.5 inHg) when measured at the instrument case and can be pre-adjusted by a vacuum relief valve connected in the supply line. Turn and slip indicators used in some installations require a lower operating vacuum and this is obtained by means of an additional regulating valve in the individual supply lines, or, in some instances, by a section of restricted-diameter pipeline. Indication of the supply of vacuum is provided by a direct-reading vacuum gauge mounted on the instrument panel.

4.1.4 The case of a vacuum-operated instrument contains two air connections; one is connected to the vacuum source and the other is a filtered inlet open to the surrounding atmosphere and connected internally to an air jet system. In some installations a central air filter mounted adjacent to both the gyro horizon and direction indicator serves as a common inlet for these instruments. When vacuum is applied to an instrument a depression is created within its case and surrounding air enters the filtered inlet and passes through the air jet system. The air issuing from this system impinges on buckets cut in the periphery of the gyro rotor. After spinning the rotor, the air circulates through the instrument case and is then drawn off at the vacuum connection.

**4.2 Electrical Supplies.** The electrically-driven gyro horizon is designed to operate from an alternating current supply at a controlled frequency of 400 Hz. Turn and slip indicators may be designed to operate from a 400 Hz supply and/or a 28-volt direct current supply system. In duplicate instrument installations the power supply distribution system is split in such a way that the failure of a supply source does not affect both instruments simultaneously. Alternate sources of power are provided for gyroscopic instruments to ensure operation in the event of failure of the main power source.

4.2.1 The alternating current is supplied from an inverter system or from engine-driven alternators, special units being incorporated for the regulation of the voltage and the frequency within the required output values. The operating voltage is usually 115-volts three-phase, although certain types of gyro horizon operate from a 55-volts supply provided by a special inverter unit or a transformer within the instrument.

- 4.2.2 The gyro rotors are specially constructed motors designed on conventional alternating current and direct current motor principles, i.e. they are of the synchronous induction and permanent magnet types. Electrical power is supplied to the rotors via slip rings about their respective axes.
- 4.2.3 Indication of power supply failure to the instruments is provided by small warning flags which are actuated by integral electromagnetic devices. If the main supply cannot be restored, changeover facilities are incorporated in the installation to connect the instruments to an emergency supply.
- 5 **GYRO HORIZONS** Gyro horizons utilise vertical spin axis gyros and provide visual indications of any change of pitch and roll attitude of an aircraft by the attitude of fixed references relative to gyro-stabilised references. Pitch attitude is indicated by the position of a symbol, representing the aircraft, relative to a stabilised bar symbolising the natural horizon. The bar is pivoted on the outer gimbal ring of the gyro in such a way that relative positions are magnified. Simultaneously the bank attitude of the aircraft is indicated by the position of a fixed bank angle scale relative to a bank pointer which is also gyro-stabilised. The gyro assembly is pivoted about the longitudinal axis of the instrument case to provide freedom of movement about all three axes of the aircraft.
- 5.1 With the instrument in operation, gyroscopic rigidity maintains the spin axis in its normal operating position and the horizon bar with respect to the aircraft symbol. When the bank attitude of the aircraft changes, the instrument case and aircraft symbol move together with the aircraft about the longitudinal axis, and will lie at an angle to the horizon bar. At the same time the bank angle scale moves with the aircraft, indicating against the bank pointer the number of degrees of bank.
- 5.2 If the aircraft changes its attitude in pitch, the case and aircraft symbol move together with the aircraft about the lateral axis of the gyro so that the aircraft symbol will be above or below the horizon bar to respectively indicate a climb or descent.
- 5.3 The gyro assemblies of all gyro horizons incorporate a levelling device which maintains the gyro in its normal operating position. In some electrically-operated versions additional fast erection systems are incorporated which are controlled by a knob located at the front of the instrument. The operation of a fast erection system varies but, in general, it may be based on mechanical locking or caging of the gimbal system, or on the principles of increasing the current applied to the normal levelling device.
- 6 **TURN AND SLIP INDICATORS** These instruments indicate the rate of turn of an aircraft and also any slip or skid during a turn. Two separate indicating mechanisms are utilised; a turn indicating mechanism consisting of a gyro-controlled pointer referenced against a turn scale, and a gravity-controlled slip indicating mechanism which may be of the ball-in-tube inclinometer type, or of the gravity weight and pointer type. The gyro is of the two-axis type, known as a rate gyro, and consists of a single gimbal ring supporting the rotor about a horizontal axis. The gimbal ring is pivoted about the longitudinal axis of the instrument case. A calibrated rate spring is connected between the gimbal ring and the case. The pointer may be coupled directly to the gimbal ring, or coupled to it by means of a gear mechanism, depending on the manufacturer's design. Transient movements of both turn and slip indicating mechanisms are minimised by special damping devices.

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6.1 When the aircraft turns, a force is exerted on the gyro which precesses the gyro about its longitudinal axis against the tension of the rate spring until equilibrium is established. The displacement of the gyro is therefore related to the rates of performance and aircraft turn, the latter being indicated on the scale by the deflection of the pointer on the appropriate side of the scale's zero position.

6.2 The slip indicating mechanisms depend upon the effects of gravitational and centrifugal forces for their operation. During straight flight in the normal lateral attitude gravity acts vertically through the mechanism, and the ball or pointer remains at the central datum. In turning flight, centrifugal forces are added vectorially to those of gravity and the indicating mechanism will therefore indicate the resultant, or direction of, apparent gravity. When turns are correctly banked the forces are such that the apparent gravity will maintain the ball or pointer at the central datum. If a slip or skid occurs the apparent gravity will be deviated causing a displacement of the ball or pointer in the direction of slip or skid by a related amount.

7 **DIRECTION INDICATORS** Direction indicators provide a stabilised directional reference for maintaining a desired course and for turning on to a new heading. They are also used as complementary instruments to direct-reading magnetic compasses. The instrument is non-magnetic and consists of a gyro pivoted about the vertical axis of the case so that the rotor spins about a horizontal axis. A rectangular opening in the front of the case carries a fixed lubber line which is referenced against a circular card graduated in degrees and secured to the outer gimbal ring of the gyro.

7.1 With the instrument in operation, gyroscopic rigidity stabilises the gyro and circular card and a certain heading is registered against the fixed lubber line. If the aircraft heading changes, the instrument case and lubber line turn with the aircraft about the stationary gyro and card, thus giving an indication of the number of degrees through which the aircraft turns. Headings corresponding to those indicated by the magnetic compass are set in direction indicators by means of a setting knob at the front of the instrument. When the knob is pushed in, it engages a locking mechanism with the gyro assembly which can then be rotated to the desired heading by turning the setting knob. The knob has a secondary function of caging the gyro assembly to prevent damage during transit, installation and removal.

8 **INSTALLATION OF INSTRUMENTS AND COMPONENTS** Before installation, instruments and associated system components should be inspected for damage or deterioration and tested (see also paragraph 9.3.3). New and overhauled instruments are normally kept in special containers until required. The packaging should be carefully examined for signs of damage before removing the instruments. The date of manufacture which is sometimes indicated on the container of the instrument must be checked to give an indication of shelf life. Type numbers and relevant operating supply data must be verified to ensure that instruments and components comply with the requirements of the particular aircraft installation.

8.1 **Handling Gyroscopic Instruments.** The mechanisms of gyroscopic flight instruments are delicate and the importance of careful handling during installation, removal and maintenance cannot be overstressed. In addition to the items mentioned in paragraph 8, the following points should be observed when handling these instruments:

(a) All gyroscopic instruments should remain in their original packaging containers or

other well-padded shock-absorbent containers until installed in the aircraft to avoid shocks and vibration. If this is impractical, instruments should be hand carried with special care.

- (b) Electrical gyroscopic instruments should not be lifted from containers, or carried, by their power supply cables.
- (c) Instruments provided with caging facilities should be stored and transported in the caged condition. The caging device of some types of vacuum-operated gyro horizons is actuated by a screw inserted through the bottom of the case. Prior to installation this screw must be replaced by a shorter length blanking screw. When removed the appropriate screw should be retained for subsequent use. A gyroscopic instrument should never be removed or installed when the rotor is spinning as shocks on bearings could be caused by reactionary gyroscopic forces set up when removing the instrument. For example, a gyro horizon tilted more than 90° in the running condition, could develop a gimbal lock to start the complete gimbal system spinning fast enough to damage the gimbal bearings. The rotors operate at high rev/min and it is recommended that before moving an instrument in any way, at least 15 minutes be allowed to elapse after disconnecting the supply to allow the rotor to stop.

**8.2 Mounting Gyroscopic Instruments.** The method of mounting instruments on main panels is dependent on whether the case of the instrument is flanged or flangeless. In the former design the bezel is flanged so that the instrument is flush-mounted in its cut-out when fitted from the rear of the panel. Integral self-locking nuts are provided at the rear of the flange corners to receive fixing screws from the front of the panel. In gyro horizons incorporating a fast erection control device (see paragraph 5.3) the control knob is situated at one corner of the mounting flange and fixing of these instruments is by means of three screws and nuts. The mounting of instruments having flangeless cases (e.g. certain types of electrically-operated turn and slip indicators) is from the front of the panel and fixing screws and nuts are unnecessary. A special expanding type of clamp, shaped and dimensioned to suit the instrument case, is secured to the rear face of the panel at the appropriate cut-out location by two retaining screws. Two actuating screws are connected to the clamp which are accessible from the front of the instrument panel. The screws must be released sufficiently to allow the instrument to slide freely into the clamp. After positioning the instrument, the actuating screws are rotated to draw the clamp tightly around the case of the instrument.

**8.2.1** A check on the vertical position of instrument panels should be made to ensure that after installing instruments (particularly direction indicators and gyro horizons), the gyroscopic axes will be correctly aligned in their operating positions. Instruments must be seated squarely in their cut-out, thereby also ensuring alignment of axes, and cases must not be subjected to strain or distortion.

**NOTE:** The instrument panels of some types of aircraft are inclined towards the nose of the aircraft, and gyro horizons having wedge-shaped bezels are specified for such panel installations.

**8.3 Vacuum System Instruments and Components.** The procedure for the removal and installation of vacuum-operated instruments and components depends upon the size and complexity of the particular system and detailed reference should be made to the Maintenance Manual appropriate to the aircraft type. The information given in the following paragraphs is a guide to the general practices:

**8.3.1 Pipelines**

- (a) Before installation, pipelines should be blown through with clean, dry, low-pressure air to ensure cleanliness and freedom from obstruction.

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- (b) Flexible hoses must not be twisted during tightening of the end connections.
- (c) Bending of pipes through too small a radius, and kinking of the pipes, must be avoided.
- (d) Metal pipes must be properly secured to the airframe structure at the specified attachment points and there must be adequate clearance between all pipelines and structural parts to avoid chafing during flight.
- (e) When pipelines are removed from an aircraft, blanks should be fitted to the end connections and all other exposed connections in the system. Support clamps should be returned to their original positions as soon as a pipeline has been removed to ensure their correct re-location.
- (f) The mating surfaces of pipe ends and connections must be clean.

8.3.2 **Venturis.** Before installation, a venturi should be checked for damage to the threaded connector and distortion of its tubular sections and attachment bracket. The port located at the venturi throat communicating with the threaded connector should also be checked to ensure freedom from damage and obstruction. When installing a venturi it must be ensured that it is properly aligned and facing in the correct direction at the location specified for the particular aircraft type. The direction is sometimes indicated by an arrow on the venturi mounting.

8.3.3 **Vacuum Pumps.** Vacuum pumps should be checked before installation for signs of damage to the body, threaded inlet and outlet connections, and drive shaft splines. The pipe-connecting unions should be fitted to the pump before its installation and where a thread lubricant is recommended it must be applied sparingly and to male threads only. The oil passages in the pump and at the engine drive adapter should be probed to ensure that they are open and, when positioned over the mounting studs, the pump gasket should not obscure the passages. The drive shaft splines should be lightly coated with a high-temperature grease and, after alignment with the splines on the engine drive adapter, the pump should be slid into position and secured to the pad mounting studs.

8.3.4 **Valves.** In duplicate vacuum systems, non-return valves must be installed in the supply lines at the points specified and in conformity with the direction of normal air flow which is indicated on the body of the valve. Relief valves are installed in the supply line of all vacuum systems to control the amount of vacuum required for instrument operation. The type of valve may vary and reference should always be made to the relevant aircraft Maintenance Manual. The valve most commonly used has an exposed filter screen and when being installed it should be positioned with the filter screen downwards to prevent the accumulation of dust and other foreign matter. After installation, the relief valves must be adjusted to give the required vacuum (see paragraph 9.1.6).

8.4 **Electrical Systems.** The installation procedure for systems utilising electrically-operated gyroscopic instruments is simpler than that required for vacuum systems because there are fewer component parts. During installation the most common points to be observed are as follows:

- (a) Electrical power must be isolated.
- (b) Instrument circuit fuses should be checked for serviceability.
- (c) Cables should be secure and the connectors positively mated to the instruments and power supply distribution points.

8.5 After installation, instruments should be checked for proper functioning (see paragraph 9.3.2).

**9 MAINTENANCE** The following paragraphs detail the general maintenance necessary on gyroscopic flight instrument systems and should be read in conjunction with the Maintenance Manuals for the type of aircraft and equipment concerned.

### 9.1 Vacuum System Components

9.1.1 **Venturis and Pumps.** Venturis should be checked for cleanliness, freedom from obstruction particularly at the throat, security of attachment and correct alignment. Vacuum pumps should be checked for security of attachment to the mounting pads on the engine and for signs of oil leakage around the gasket.

9.1.2 **Pipelines.** These should be checked to ensure freedom from corrosion, dents, nicks and abrasions, security of supporting clamps and connections. Flexible hoses should be carefully inspected for evidence of kinking, twisting and deterioration, especially at the joints between pipelines and components located in engine nacelles (e.g. pumps and oil separators).

9.1.3 **Relief Valves.** Relief valves should be inspected for damage, and cleanliness of their filter screens. The adjusting screw should be securely locked after any adjustment of the valve during system operational checks (see also paragraph 9.1.6).

9.1.4 **Filters.** The element of a central air filter (see paragraph 4.1.4) should be inspected for signs of dirt accumulation and damage. This type of filter is usually positioned so that inspection and replacement of the element can be made without having to remove the complete assembly from the pipelines. Cleaning of the element should be carried out in the manner stated in paragraph 9.1.5.

9.1.5 **Vacuum System Cleaning.** In general, low-pressure, dry, compressed air should be used for cleaning vacuum system components. Components such as oil separators and suction relief valves which accumulate engine oil and nacelle dirt should be washed with an approved solvent (e.g. Inhibisol) then dried with a low-pressure air blast. If an obstructed pipeline is to be cleared, it should be disconnected at both ends and blown through in the direction leading to the normal source of vacuum.

### 9.1.6 Vacuum System Testing

- (a) Vacuum systems are usually checked after changing a component and at times specified in the aircraft Maintenance Schedule. Basically, the checking procedure consists of running an engine at a specified speed, testing the system for leaks and then adjusting the relief valve until the aircraft vacuum gauge indicates the value required for the installation. In duplicate systems, each relief valve must be adjusted separately. The engine speed and also the vacuum vary between aircraft types, and these details must be obtained from the relevant Maintenance Manuals which will also give the procedures to be followed.
- (b) In instances where vacuum gauge readings are too high or too low, an investigation into the condition of instrument and system filters, pipelines (obstructions and leaks), venturis and pumps should be made before adjusting a relief valve.

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**9.2 Electrical System Components.** The maintenance checks required on components of electrically-operated gyroscopic instrument systems are mainly the security and condition of power supply cables, connectors, switches, and circuit fuses. Supply voltages and frequencies should be within the limits specified for the particular electrical system but as they vary in different aircraft installations, reference must always be made to the appropriate Maintenance Manuals and Schedules.

**NOTE:** To eliminate the risks of electric shocks, arcing, burning of connector pins, etc., extreme care must be exercised when carrying out checks on components which require that sections of a circuit be 'live'.

**9.3 Instruments.** The maintenance checks to be carried out on gyroscopic instruments are mainly concerned with security, visual defects, functioning and performance tests. Precise details of these checks are given in relevant Maintenance Manuals and Schedules. The information in the following paragraphs is a guide to the general practices.

**9.3.1 Security and Visual Defects.** Checks should be made for the following:

- (a) Security of attachment to instrument panels.
- (b) Security of vacuum and electrical connections.
- (c) Evidence of cracking of cases and bezel mounting flanges. Cover glasses should always be carefully inspected for cracks which could be caused by glancing blows from safety harness fittings, head sets, etc., and are often difficult to detect.
- (d) Dial markings and pointers for legibility, discoloration and flaking.

**9.3.2 Functional Tests during Maintenance**

- (a) **Gyro Horizons.** After the vacuum or electrical power has been applied, the rotor should be allowed to run up to normal operating speed and a check made that the horizon bar settles to indicate the attitude of the parked aircraft. In electrically-operated instruments incorporating power failure warning flags, it should be checked that the flags retract from view when electrical power is applied. Fast erection systems should be checked for functioning by pushing in the control knob and checking that the gyro erects quickly to the vertical. In some gyro horizons employing a mechanical fast erection system, the power failure warning flag should retract from view when the knob is pushed in. To prevent violent hunting of the gyro assembly, the control knob of an electrical fast erection system must not be pushed in until 15 seconds have elapsed after switching on the supply. The time of holding the knob in must be kept to a minimum and must not exceed 1 minute; this will prevent damage to the levelling system while checking the fast erection.

**NOTE:** In certain types of instrument embodying electrical fast erection, the normal erection system is cut out if the gyro assembly is out of the vertical by more than 10° in pitch or roll. The gyro can then only be re-erected by pushing in the fast erection control knob.

- (b) **Turn and Slip Indicators.** With the aircraft laterally level, indicators should be checked to ensure that slip pointers or inclinometer balls are at the zero position. It is a characteristic of the rate gyros of these indicators that in their static condition the turn pointer provides no indication of the gyro having run up to normal operating speed. In order to check this, and also that the pointer mechanism is not sticking, the shock-absorbed instrument panel should be displaced at one or other corner within the limits of its mounting. This will simulate a slight turn and cause displacement of the turn pointer in the appropriate direction.

- (c) **Direction Indicators.** The caging knob should be checked for freedom of rotational and axial movement. With the gyro running and caged a slight resistance to rotation of the knob should be felt. The indicator should be set to the heading corresponding to that indicated by the magnetic compass, and after uncaging, the drift from this heading should be noted. A maximum drift of 3° in 15 minutes is usually acceptable.

**9.3.3 Performance Tests.** Performance tests of instruments should be carried out before installation, at times when their operation and indications are suspect, and at the periods specified in the aircraft Maintenance Schedule. The procedures for testing each type of instrument are given in the relevant manufacturer's and aircraft Maintenance Manuals, and reference must always be made to these documents.

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**AL/10-3****AIRCRAFT***Issue 2.***INSTRUMENTS***June, 1982.***ENGINE INSTRUMENTS**

- 1 **INTRODUCTION** This Leaflet gives guidance on the installation and maintenance of instruments employed for monitoring the operation of aircraft engines and associated systems. It should be read in conjunction with Maintenance Manuals and operators' approved Maintenance Schedules; such documents providing details of construction, major servicing, repairs and calibration procedures relevant to specific items and engine systems. Reference should also be made to the following Leaflets which contain information closely associated with the instruments covered by this Leaflet.

- AL/3-13 Hose and Hose Assemblies.
- AL/3-14 Installation and Maintenance of Rigid Pipes.
- AL/3-15 Tanks.
- AL/3-17 Fuel Systems.
- AL/10-1 Flight Instruments—Pitot Static Systems.
- EL/3-10 Turbine Engines.
- EL/3-11 Turbine Engine Fuel Systems.
- EEL/1-6 Bonding and Circuit Testing.
- EEL/3-1 Cables—Installation and Maintenance.

- 2 **GENERAL** The information given in this Leaflet is set out as follows:

	<i>Paragraph</i>
Synchronous Data Transmission Systems .. ..	3
Pressure Indicators .. .. .	4
Engine Speed Indicators .. .. .	5
Temperature Indicators .. .. .	6
Engine Vibration Indicating Systems .. ..	7
Fuel Quantity Indicators .. .. .	8
Fuel Flowmeters .. .. .	9
Installation .. .. .	10
Inspection and Maintenance .. .. .	11

For those not familiar with basic operating principles of individual instruments, brief details are given in the appropriate paragraphs.

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2.1 Many of the instruments utilise electrical elements based on the principle of measuring the required variables at source and transmitting the data through the medium of a synchronous signal link system. Various types of synchronous data transmission systems may be used and as some are applied to certain of the instruments to be described, an outline of their general construction and operation is given at this stage to avoid repetition.

3 **SYNCHRONOUS DATA TRANSMISSION SYSTEMS** All the systems consist of two principal components: a transmitting element and a receiving element, electrically interconnected through signal lines and supplied with power from the aircraft electrical system. Depending on the synchronous link adopted the power supply required may either be direct current or alternating current. The most common form of d.c. synchronous system is the "Desynn" of which there are three circuit variations; the application of each circuit being governed by the variables to be measured.

3.1 **Basic Desynn Circuit.** This circuit is applied to engine systems in which the position of a mechanical component is required to be known, e.g. a fuel trim actuator or a float mechanism of a fuel quantity indicator.

3.1.1 The transmitter unit consists of a circular wire-wound resistance or toroid tapped at three points 120° apart, and a brush assembly made up of two diametrically opposed contact arms suitably insulated from each other. The brush assembly rotates in contact with the toroid and serves to lead the d.c. supply to the system. Rotation of the brush assembly is effected by a slotted arm which engages with a crank pin connected through a mechanical linkage to the appropriate mechanical component. The type of linkage varies, but in a typical application to component position indication (e.g. fuel trim actuator position) it consists of a lever arm and spring-controlled gearing. The lever arm normally operates through 60° against a control spring, and the gear ratio between the arm and the crank pin may either be 3:1 or 6:1 so that the brush assembly can move through 180° or 360°. Stops limit lever arm movement to 70°.

3.1.2 The receiving or indicating instrument is made up of a two-pole permanent magnet rotor pivoted inside a soft-iron stator carrying a three-phase star-connected winding supplied from the threeappings of the transmitter toroid. A pointer is attached directly to the rotor spindle and rotates over a scale calibrated in the units appropriate to the required measurements.

3.1.3 When the brush assembly rotates over the toroid, the current flow to the indicator stator windings varies in magnitude and direction. The current is distributed through the windings and produces a magnetic field which rotates in synchronism with the brush assembly. The magnet aligns itself with this field thus carrying the pointer to positions indicating the amount of brush movement. When the power supply to the system is interrupted, the pointer is returned to an off-scale position by a weak pull-off magnet which attracts the main magnet rotor.

3.2 **Micro-Desynn Circuit.** The Micro-Desynn circuit is applied to systems in which less power and very small displacements of a primary actuating system is available, e.g. in the measurement of fuel or oil pressure. The circuit is a development of the basic one and the principle remains the same. In place of the toroidal resistance, however, two resistance coils are used and the brushes are arranged to move together over the whole length of their respective coils and through an angle of

about 60°. This movement, combined with the method of electrically tapping the coils, corresponds to one revolution of the contacts of a toroidal transmitter and results in 330° movement of the indicator pointer. The brushes are rotated by means of a push-rod and rocking shaft assembly coupled to a bellows type of pressure-sensing element. In applications of the circuit to liquid quantity measurement, the brushes are rotated by a mechanically coupled float mechanism. With the exception of the dial calibration markings, the receiving or indicating element is similar to that employed in the basic Desynn circuit.

**3.3 Slab-Desynn Circuit.** In both the basic and micro circuits, the voltage at each of the transmitterappings, although varying proportionally with the brush movements, produces a magnetic field in the indicator stator which causes a slight cyclic error. This deviation, plus frictional losses and contact wear, are characteristics of both circuits which can be taken into account during initial calibration. For some applications it is necessary for the effects of these characteristics to be minimised within the circuit itself and for this reason the Slab-Desynn circuit was developed.

**3.3.1** The resistance of the transmitter element is wound on a flat former, hence the term 'slab', and the power supply is connected at either end. This arrangement produces a uniform potential gradient. The pick-off assembly consists of three brushes spaced at 120° and is equivalent to the threeappings on the other types. As the assembly rotates, voltages are distributed to the indicator stator which vary according to a sine law. Another feature of this arrangement is that as each contact carries less current wear is reduced.

**3.4 A.C. Synchronous Systems.** These systems which are generally known as 'synchros' are manufactured under a variety of trade names such as "Selsyn", "Autosyn", and "Asynn" the names being contractions of the functional terms adopted, e.g. "Selsyn" is a contraction of 'self synchronous'. The operating principle of these systems is basically the same, each consisting of electrical transmitter and receiving elements. However, unlike d.c. systems, both elements are similar in construction and employ a two-pole single-phase rotor free to rotate inside a three-phase wound stator. The stator windings of each element are interconnected and in most instrument applications the rotors are supplied with alternating current (26-volts or 115-volts) via slip rings.

**3.4.1** When alternating current is supplied to the rotors a definite combination of voltages is induced in both stator windings. If both rotors are in the same position in relation to their respective stators both sets of stator voltages will be equally opposed and no current will flow in the coils. Thus, there is no magnetic field torque and the rotors remain in alignment. When the transmitter rotor is moved the induced voltages are unbalanced and currents flow in the windings of both stators producing magnetic fields which turn the receiver synchro rotor to the same position as that of the transmitter, restoring a balanced condition. There is a tendency for the transmitter synchro rotor to be turned within its stator, but as it is mechanically coupled to the appropriate measuring element, it is prevented from doing so and the receiver synchro is made to follow the transmitter.

**4 PRESSURE INDICATORS** The indicators used for the measurement of pressure in the systems of various types of engine are of two main types: direct-reading and remote indicating. A brief outline of the operating principles of typical indicators and systems is given in the following paragraphs.

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4.1 **Direct-reading Indicators.** Direct-reading indicators are mechanically operated, and as the name implies, are connected directly to the source of pressure. The most common form of indicator operates on the Bourdon tube principle. A Bourdon tube is a C-shaped tube of oval cross-section having one end closed and the other secured and open to the pressure source. When pressure is admitted to the tube it tends to straighten out causing movement of the closed end and this movement is transmitted to the pointer of the indicator via a link and gear mechanism. When applied to low pressure measurements such as manifold pressure and engine power loss, the pressure sensing elements are in the form of flexible bellows or capsules.

4.1.1 **Manifold Pressure Gauges.** Manifold pressure gauges are in most cases of the direct-reading type, designed to measure the absolute pressure at the induction manifold of supercharged engines. The principle of operation and construction of a typical indicator is as follows:

(a) The pressure sensing element consists of two metallic bellows mounted in tandem. The rear bellows is connected by a pipeline to the engine induction manifold and the front bellows is evacuated and sealed and is spring-loaded by an internal spring. The outer ends of each bellows are secured to the instrument frame and the inner ends are connected to a common distance piece. The distance piece is connected to a gear type pointer mechanism via an arm, rocker shaft and lever mechanism. Gauges are fitted with a lubber mark which may be pre-adjusted to indicate the maximum manifold pressure permitted for engines with which they are associated.

(b) When the engine is stopped and the pressure is at standard conditions, the evacuated bellows assumes a position where its tendency to collapse is balanced by the internal spring. The bellows therefore provides an atmospheric pressure datum against which induction manifold pressure is referenced. The instruments are calibrated in either pounds per square inch, or millimetres or inches of mercury. The zero position on gauges calibrated in the former units corresponds to standard pressure of 14.7 lbf/in<sup>2</sup> while on gauges calibrated in millimetres or inches of mercury, the equivalent value of 760 mm or 29.92 inHg is read directly. Under engine operating conditions variations in manifold and atmospheric pressures cause relative displacements of the bellows which are transmitted to the pointer via the distance piece, rocker shaft and lever mechanism.

4.1.2 **Power Loss, Engine Pressure Ratio and Percentage Thrust Indicators.** These indicators are sensitive differential pressure gauges designed to indicate the thrust output of turbojet engines in terms of the absolute pressure within the exhaust unit. The application of each type of indicator depends on the type of engine and installation. A typical indicator consists of two capsules connected by a lever and gear train assembly to a pointer which rotates over a scale calibrated in either in. Hg absolute (Power Loss and Engine Pressure Ratio indicators) or percentage of thrust. One of the capsules is connected by a sensing line to the exhaust unit and responds to the difference between exhaust unit pressure and static pressure supplied to the indicator case. The other capsule is of the aneroid type and is sensitive to static pressure only which, in the case of power loss indicators and percentage thrust indicators, is supplied from a static vent of the pitot-static system (see Leaflet AL/10-1 Flight Instruments—Pitot-Static Systems). In the case of engine pressure ratio indicators static pressure is supplied from a vent at the engine air intake. The deflection of the lever system

in response to displacements of both capsules is equal to exhaust unit pressure, and is transmitted to the pointer via the gear train.

**4.2 Remote-indicating Instruments.** These instruments measure pressure at source and transmit the measured values to panel-mounted instruments through the medium of either a liquid or electrical signal transmission system. Depending on the type of aircraft the liquid transmission system may either be of the closed capillary type, or pressure transmitter type. Remote indicating instruments employing the electrical signal transmission principle consist of separate transmitting and indicating units which may form part of a d.c. or a.c. synchronous data transmission system, or a ratiometer system. The pressure sensing element of a transmitter may either be a flexible metal bellows or a Bourdon tube, depending on the application of the indicating system.

**4.2.1 Capillary Type.** The capillary system consists of a transmitter unit containing a capsule which is connected by a length of capillary tubing to a Bourdon tube indicator mechanism. The capsule, capillary tubing and Bourdon tube are completely filled with a special fluid such as Heptane (a paraffin hydrocarbon having a low freezing point and very little viscosity change) the whole assembly forming a single sealed system. The transmitter unit is directly connected by means of a hollow bolt to the particular engine system (e.g. oil system) and when pressure is admitted a force is exerted on the capsule to cause displacement of the transmitting fluid. This displacement in turn tends to straighten out the Bourdon tube in the manner of a direct-reading pressure gauge.

**4.2.2 Pressure Transmitter System.** A pressure transmitter system functions in a similar manner to the capillary system, but has the advantage that the transmitting and indicating units are separate thus facilitating removal and installation, and also permitting filling of the system in situ (see paragraph 10.4.2). The transmitter unit consists of two flanged circular housings bolted together and divided into an inlet chamber and an outlet chamber by a neoprene diaphragm. The inlet chamber is connected to the pressure source, while the outlet chamber is connected via small bore tubing to a direct-reading Bourdon tube pressure gauge. A spring-loaded ball valve is teed into the gauge connection and serves as a bleed during filling operations. The outlet chamber, tubing and Bourdon tube are filled with a mineral base oil. A second spring-loaded ball valve is incorporated in a connection in the lower part of the outlet chamber, the connection being used for filling purposes. A metal centralising disc in the outlet chamber prevents distension of the diaphragm when the system is being filled, and may be re-positioned by a centralising knob.

(a) In operation, pressure is exerted on the diaphragm causing it to distend and to transmit the pressure to the fluid in the outlet chamber. The fluid tends to force itself out of the chamber, but as the system is a closed one the Bourdon tube is displaced and the indicator reads the pressure applied at the transmitter.

**4.2.3 Ratiometer Pressure Indicators.** These instruments are used principally for the measurement of pressures in engine fuel and oil systems, and depending on the type specified, operate from either a direct current or alternating current source. In both cases the ratio of currents flowing through two coils of the indicator is measured in terms of pressure. The transmitter units normally consist of a pressure sensing bellows assembly mechanically coupled to an electrical element which in the case of a direct current system takes the form of a modified Micro-Desynn element connected to a moving coil ratiometer. The

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electrical element of an alternating current operated transmitter consists of inductor coils the iron cores of which are positioned by the bellows assembly. The indicator consists of two coils connected to the transmitter coils and two cam-shaped discs free to rotate in the air gaps of the cores. The discs are mounted on a common shaft connected to the pointer. When pressure at the transmitter changes it causes an increase in current in one coil circuit and a decrease in the other, the discs rotating in a direction determined by the coil carrying the increased current. Rotation of the discs and pointer ceases when a balance is reached by the torques produced at the discs.

**4.2.4 Pressure Switches.** Pressure switches are used in conjunction with warning lights to indicate that the pressure in a particular fluid system (e.g. fuel, oil and water methanol systems) has reached a pre-determined value. Depending on the application this value may be the upper or lower limit of the safe working pressure. Some switches are also employed to initiate a sequence of controlling operations when a certain pressure is reached in a fluid system.

(a) A typical unit consists of a metal diaphragm sandwiched between the flanges of a contact box which forms the main body and a base through which the system fluid is admitted, and a fixed and moving contact switch assembly. Connection of the base to the pressure source varies but, in general, it is either of the banjo fitting type or direct flange-mounted type. The movable contact is actuated by a push-rod bearing against the upper surface of the diaphragm. The stationary contact is adjustable to provide various pressure settings. Access to the adjusting screw is gained by removal of an access plate in the cover of the contact box, or as in some units by removal of the cover itself.

(b) The pressure of the fluid entering the base of the switch unit acts against the diaphragm causing the push-rod to operate the movable contact. The contact position is thus changed to either make or break the warning or controlling circuit.

**5 ENGINE SPEED INDICATORS** These indicators measure the rotational speeds of piston engine crankshafts and compressor shafts of turbine engines. Two principal types are in use; mechanical as used in some types of single-engined aircraft, and electrical which are used in aircraft having multi-arrangements of piston engines, and in all turbine-powered aircraft.

**5.1 Mechanical Indicators.** Mechanical indicators consist of a flyweight assembly connected to the engine by a flexible drive shaft and coupled to a gear type pointer mechanism. The gear ratios at the engine and indicator are such that the flexible drive shaft rotates at a lower speed to minimise wear. As the shaft rotates centrifugal forces act on the flyweight and cause it to take up a certain angular position. The displacement is transmitted to the pointer which rotates over the scale to indicate the speed of the engine crankshaft.

### 5.2 Flexible Drive Shafts

**5.2.1** A flexible drive consists of a flexible inner shaft which is free to rotate within a stationary outer casing. The inner shaft embodies a central core of hardened steel wire over which five layers, each of four strands of finer gauge wire are wound, alternate layers being wound in opposite directions. After the inner shaft has been cut to the appropriate length a connector is secured to each end by

swaging. Both connectors incorporate squared shanks which engage the hollow squared ends of the engine drive shaft and indicator shaft respectively. The shank at the engine end of the drive is longer than that at the indicator end.

NOTE: In some types of flexible drive, the connector shank at the engine end is designed to engage with a keyway in the engine drive shaft, while the shank at the indicator end is hollow.

5.2.2 The outer casing is a continuous winding of two specially-formed steel wires and is flexible, oil tight and waterproof. Flanged collars are swaged to each end of the outer casing to provide a means of attachment to the engine and indicator. Axial movement of the inner shaft is restricted by a shoulder on the connector at the indicator end which abuts on the end of the flanged collar and also by an interposed slip washer. This arrangement permits considerable end float of the shaft in the outer casing.

5.3 **Electrical Indicating Systems.** Electrical indicating systems comprise an alternating current generator which supplies a synchronous motor-driven indicator. The generator consists of a permanent magnet rotor and a three-phase stator winding. The rotor may be driven by a short length flexible drive shaft, or as in the case of turbine engines which have high rotational speeds prohibiting the use of flexible drives, by direct coupling to a splined shaft driven by the compressor shaft via reduction gearing.

5.3.1 The synchronous motor of an indicator is coupled to an eddy current drag type of mechanism consisting of a permanent magnet, a cup-shaped or disc type of drag element, and a controlling spring. The drag element is mounted on a spindle connected to a gear mechanism which drives a large and a small pointer to indicate hundreds and thousands of revolutions per minute respectively.

5.3.2 Rotation of the generator rotor induces a three-phase voltage in the stator windings which is transmitted to the windings of the indicator synchronous motor causing the rotor to revolve at a speed proportional to the generator frequency and therefore engine speed. The permanent magnet of the drag mechanism is also rotated and induces eddy currents in the drag element tending to rotate it at the same speed as the magnet. As the controlling spring is coupled to the drag element spindle it restrains rotation of the element to a position at which spring force and drag torque are in balance. The pointers are therefore positioned to indicate the engine speed.

5.3.3 **Percentage Speed Indicators.** These indicators are designed to indicate the speed of a turbine engine as a percentage of the nominal maximum speed. The scales are graduated from 0 to 100%, the 100% indication corresponding to the nominal maximum engine speed and a specific generator drive speed which is usually 4,200 rev/min. Indicators allow for slight increases in nominal maximum engine speed by reading up to 110%. In principle they operate in a similar manner to the conventional alternating current type of indicating system.

5.4 **Synchrosopes.** Synchrosopes are designed for use in multi-engined aircraft to indicate the degree of synchronism existing between a selected 'master' engine and the remaining engines designated as 'slaves'. They form part of an engine speed indicating system, each engine being associated with a complete synchroscope unit housed within the instrument.

5.4.1 A typical unit consists of a synchronous motor having a three-phase star-wound stator and rotor. A small double-ended pointer is attached to the rotor

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shaft and is referenced against a dial marked SLOW to the left and FAST to the right. In some types of synchroscope the left and the right positions of the dial are marked INCREASE and DECREASE respectively.

5.4.2 The generator of the selected 'master' engine is electrically connected to the synchroscope rotor while the 'slave' engine generator is connected to the stator. The output from the master engine generator induces a rotating magnetic field in the synchroscope rotor at a frequency proportional to the generator speed. Similarly, the generator of the slave engine induces a rotating magnetic field in the synchroscope stator. Both fields rotate in the same direction, and under synchronised speed conditions they interact to maintain the rotor and pointer at some stationary position. When there is a difference between generator speeds field interaction causes the rotor to rotate at a speed equal to the difference, and in a clockwise or anti-clockwise direction according to whether the speed of the slave engine is greater or less than the master engine speed.

5.5 **Rotation Indicators.** In turbine engines of the by-pass type severe damage may arise if the low-pressure shaft is not free to rotate during the starting cycle; the damage being caused by the re-circulation of hot gases around the high-pressure system. In order to indicate that the low-pressure shaft has begun to rotate and that it is safe to continue the starting cycle, rotation indicators are provided.

5.5.1 The basis of an indicator is an amplifier connected to one phase of the engine speed indicator system to accept signals from it as a speed reference input. The output stage is connected to an indicator lamp located on the main instrument panel, or on a panel at a flight engineer's station. Depending on the design, an amplifier may require a power supply of 115-volts at 400 Hz, or may be completely independent of aircraft power supplies.

5.5.2 When the input reaches a critical level, the amplifier produces sufficient output current to light the indicator lamp. A typical critical input level is 6 mV, corresponding to a rotation speed of a fraction of 1 rev/min. This speed is reached in the first few degrees of rotation and the lamp starts flashing immediately the shaft begins to rotate. Input signals in excess of the critical cause the amplifier to saturate and the lamp to remain alight but without being overloaded.

5.5.3 An indicator is only required during the starting cycle and for this reason the power supply to the amplifier is fed via an engine starting circuit. For multi-engine installations, a single amplifier and indicator lamp serves to indicate rotation of each engine which is automatically selected during each starting cycle.

6 **TEMPERATURE INDICATORS** All temperature indicators are of the transmitting type and fall into three main categories:

- (a) Capillary.
- (b) Electrical Resistance.
- (c) Thermo-Electric.

6.1 **Capillary Thermometers.** Capillary thermometers are used to measure the temperature of liquids in aircraft systems such as oil and coolant and although superseded by electrical resistance thermometers are still fitted to certain types of

small aircraft. In general the construction is similar to a liquid transmission type of pressure indicator which consists of a transmitter unit joined to a Bourdon tube indicator by a length of capillary tubing. In this case the transmitter unit is in the form of a 'bulb' which is immersed in the fluid whose temperature is to be measured, the transmitting fluid contained within the system being either mercury or ethyl ether. When the bulb temperature changes the mercury expands or contracts, or in the case of ethyl ether the vapour pressure increases or decreases, causing displacement of the Bourdon tube and corresponding movement of the pointer.

**6.2 Electrical Resistance Thermometers.** Thermometers of this type are comprised of a separate bulb and moving coil indicator electrically interconnected and supplied with direct current from the aircraft electrical system. The bulb contains a coil of nickel or platinum wire which forms a variable resistance arm of a bridge circuit contained within the indicator. When the bulb temperature changes, the coil resistance increases or decreases causing current to flow through the moving coil system corresponding to the temperature resistance characteristics of the bulb material used. The circuit arrangements may be either of the Wheatstone Bridge or ratiometer type.

**6.2.1 Wheatstone Bridge Circuit.** In this arrangement a measure of the temperature at various points throughout the range, and for a given supply voltage, is obtained in terms of an out-of-balance current. By suitable arrangement of the bulb material the bridge may be balanced at a pre-determined temperature, and no current will flow through the indicator. This is known as the 'null point' and in general is used to indicate the critical temperature of the instrument since, when these conditions prevail, the indication is independent of supply voltage. At all other points on the scale the out-of-balance current depends not only on the bulb resistance but also on supply voltage; therefore, there will be an error in indicated reading if this voltage differs from that for which the instrument was calibrated. This error will be proportional to the percentage difference change in the supply voltage from that used in calibration, and to the amount by which the pointer is deflected from the 'null point'. A device for adjusting the moving coil and pointer to the 'null point' is always provided and may be set by a screw at the front of the indicator bezel.

**6.2.2 Ratiometer Circuit.** In the ratiometer circuit arrangement the moving coil system is made up of two coils rotating in a magnetic field which, unlike conventional moving coil instruments, is non-uniform. One of the coils carries a reference current while the other is connected to the resistance bulb and therefore carries a current proportional to the resistance and temperature of the bulb. The ratio of these two currents determines the position of the complete coil assembly, and the pointer, the indication being virtually independent of variations in the supply voltage.

**6.3 Thermo-electric Systems.** Thermo-electric systems are utilised principally for the measurement of air-cooled piston engine cylinder head temperatures and exhaust gas temperatures of turbine engines. The system comprises a single or multiple thermocouple arrangement located at the appropriate source of temperature, a moving coil millivoltmeter calibrated to relevant temperature/e.m.f. characteristics in degrees C, and connecting cables (see paragraph 6.3.6) of known length and resistance.

**6.3.1 Principle.** A thermocouple assembly is made up of two dissimilar metal conductors joined together to form a hot junction. The open ends of the

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conductors are connected by cables to the indicator which forms a cold junction. When the hot junction is subjected to temperature an e.m.f. is generated which causes a current to flow in the closed circuit. The magnitude of the e.m.f. depends on the materials used for the thermocouple and the difference between the hot- and cold-junction temperatures.

**6.3.2 Cold-junction Temperature Compensation.** To avoid errors in indicator readings due to the effects of temperature changes at the cold junction, automatic compensation devices are fitted to thermo-electric system indicators. Three methods are normally employed, (i) mechanical, (ii) electrical and (iii) magnetic; methods (ii) and (iii) compensating for changes in moving coil resistance to ensure proper instrument current.

- (a) The mechanical method directly compensates for cold-junction temperature changes and consists of a bi-metallic spiral, the outer end of which is connected to the outer end of the controlling hairspring. When the cold-junction temperature changes the magnitude of the circuit e.m.f. changes and causes an error in the required hot-junction temperature indications. For example, if it increases, the difference between hot- and cold-junction temperatures, and circuit e.m.f., is reduced and the moving coil and pointer tends to indicate a lower hot-junction temperature. The bi-metallic spiral is also affected by the cold-junction temperature change, but as it is wound in a direction opposite to that of the controlling hairspring it opposes the moving coil and a constant hot-junction temperature indication is maintained.
- (b) In the electrical method a neutraliser coil is connected in series with the moving coil, the characteristics of the material being such that under the same temperature conditions its resistance change equally opposes that of the moving coil material. In some instruments a thermistor shunted by a Eureka coil serves as the compensator.
- (c) The magnetic method of compensation is accomplished by means of temperature sensitive magnetic strips (magnetic shunt) clamped across the permanent magnet of the indicator. These have the effect of shunting the magnet poles so that the flux strength in the air gap is varied at a rate proportional to the rate at which moving coil resistance changes.

**6.3.3 Engine Cylinder Head Temperature Indicating Systems.** The metal combinations used for cylinder head temperature thermocouples are either copper/constantan or iron/constantan. Depending on the type of engine the hot-junction may be formed either for bolting under a sparking plug or in direct contact with a cylinder head. A thermocouple is attached to the cylinder which tests have shown to be the hottest on an engine in any particular installation. The indicators are of the semi-circular scale type usually calibrated over the range 0-350°C, and are provided with terminal type connections at the rear of their cases. The terminal identified by a positive sign is connected to a copper or iron lead depending on the thermocouple combination used. Adjustment of the pointers to prevailing cold-junction temperatures (see paragraph 11.11.2 (a)) is effected by a device located at the front of the instrument and which is adjusted by a screwdriver.

**6.3.4 Turbine Exhaust Gas Temperature Indicators.** Gas temperature is a critical variable of turbine engine operation and it is essential to provide an indication of this temperature. The two control positions in an engine at which measurements are normally taken are: (i) At the exhaust unit. (ii) Within the turbine at one of the stator positions.

- (a) Several factors have to be considered before any position is adopted; for example, temperatures related to the performance of the engine can be measured more accurately nearer to the upstream end of the turbine. The principal disadvantages of this method are that the number of thermocouples required for averaging becomes greater and the environmental temperatures in which they must operate are increased. However, as the temperature drop across the turbine varies in a known manner, it is usual to measure the temperature at the turbine outlet by locating a small number of thermocouple probes (see paragraph 6.3.5) in the area of the exhaust unit, in other words by adopting position (i). In certain types of turbopropeller engine control position (ii) is adopted by locating thermocouple probes at the leading edges of intermediate nozzle guide vanes.
- (b) Gas temperature indicators, referred to variously as exhaust gas temperature (EGT), turbine gas temperature (TGT) or jet pipe temperature (JPT) indicators, may be of the semi-circular or circular scale type calibrated over the ranges 0-800°C and 0-1000°C respectively. Terminal type connections are provided at the rear of the cases, the terminal identified by a positive sign being connected to the chromel lead of the cable system. Adjustment of pointers to the required datum temperature values (see paragraph 11.11.2 (b)) is effected by a device which depending on the type of aircraft may be positioned either by a screwdriver or special adjusting tool.

**6.3.5 Thermocouple Probes.** A gas temperature thermocouple is mounted in a ceramic insulator and encased in a metal protection sheath the whole assembly forming a probe which can be projected into the gas stream. The thermocouple is made from Chromel (a nickel-chromium alloy) and Alumel (a nickel-aluminium alloy). The hot junction protrudes into a space inside the end of the sheath which has transfer holes in it to allow the exhaust gas to flow across the hot junction. The relative positions of the transfer holes depend on whether the thermocouple is of the 'stagnation' type or the 'rapid response' type. In the 'stagnation' type which is applied to turbojet engines, the exhaust gas enters the probe through a forward facing inlet, and after circulating round the hot junction it passes through a smaller exit hole higher up and on the opposite side to the inlet hole. This arrangement allows the gas passing through to become relatively stagnant thus minimising the effects of the high velocities. The 'rapid response' type of thermocouple is designed for use in low exhaust gas velocities as in turbopropeller engines, and has equal size transfer holes arranged directly opposite each other so that gas can pass over the hot junction with minimum stagnation.

- (a) Probes may be of single, double or triple thermocouple element construction. A single element provides for temperature measurement only and a double element provides an additional identical circuit for transmitting a temperature signal to an engine temperature control system. The triple element type of probe provides for a further circuit for use in a warning system to detect a combustion fault. In some versions, the probe sheath is contained within a heat-resistant metal pitot tube which senses the exhaust unit pressure required when power loss indicators form part of engine instrumentation. A sleeve inside the lower end of the tube separates it from the probe sheath thus forming an annulus between the two. Three forward facing holes in the tube connect the annulus to exhaust unit pressure which is transmitted to the indicating system via a sensing line coupled to a union in the probe mounting flange, and a pressure manifold.

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- (b) In order to obtain a good average indication of gas temperature conditions and also to ensure functioning of the indicating system in the event an element becomes defective, a number of probes are radially disposed in the gas stream and the electrical outputs are connected to form a parallel circuit. The cables from the thermocouple probes are formed as a harness around the engine and terminate at a junction box which also provides the connecting point for the cables leading to the indicator.
- (c) In some engine installations thermocouple probes may also be positioned in the air intake to transmit signals to a temperature indicating and control system, thus giving a reading of gas temperature compensated for intake temperature variations.

6.3.6 **External Circuits.** In addition to temperature/e.m.f. characteristics, the calibration of thermo-electric system indicators takes into account certain constant external circuit resistance values. The external circuit is the section from the thermocouple probe(s) to the indicator terminals and some typical resistance values are: 2 and 8 ohms for engine cylinder head temperature indicators, and 8 and 25 ohms for gas temperature indicators. In some cases the appropriate resistance values may be found on the indicators.

- (a) The cables connecting probes and indicators may be one of the following types:
  - (i) **Extension** or those made of the same material as the thermocouple.
  - (ii) **Compensating** or those which are made of a different material to the thermocouple, but having a resistance equal to that of the equivalent extension cables.
- (b) Whichever type of lead is used a stranding is selected to make up the correct overall circuit resistance required. In some turbine gas temperature indicator installations, a trimming resistor is connected in one of the leads to adjust the external circuit resistance to the required value. The resistor is made of either Eureka (a copper-nickel alloy) or Manganin (a copper-manganese alloy) wire wound on a spool. A Eureka resistor is connected in the negative lead, while a Manganin resistor is connected in the positive lead.
- (c) In addition to the trimming resistor, the external circuit of an indicating system used with certain types of turbine engine includes a ballast resistor. The resistor is fitted because an engine may have an acceptable turbine inlet temperature but have a high exhaust temperature due to temperature scatter in the exhaust unit. The resistor reduces this scatter and brings the indicated temperature down. The value of the resistor is determined from test bed results, and because of this it must not be replaced by a resistor of a different value during the overhaul life of the engine. The specified resistance value is usually marked on the thermocouple system junction box or engine data plate and is also included in the engine log book.

**7 ENGINE VIBRATION INDICATING SYSTEMS** These systems provide continuous indication of vibration conditions normally existing when turbine engines are running, and from any sudden variations in amplitude can also provide an early warning of defects in the internal rotating parts and bearings, permitting corrective action to be taken before extensive damage occurs.

7.1 A system consists of an engine mounted pick-up unit which, in a typical application contains a spring-supported magnet and inductor coil assembly, an amplifier and an indicator mounted on the appropriate instrument panel. The scale of the indicator is graduated in units of fixed relative amplitude. A test push switch and an amber warning lamp also form part of a system. The power supply required for system operation is 115-volts single-phase, 400 Hz.

7.2 When an engine is running and electrical power is applied to the system, vibration causes relative motion between the magnet and coil and signal voltages are induced in the coil which are proportional to the velocity of vibration. These signals are applied to the amplifier where they are processed and fed to the indicator moving coil causing displacement of the pointer to positions indicating corresponding values of relative vibration amplitudes. If the vibration level exceeds a predetermined value a circuit is completed to illuminate the warning lamp. The purpose of the test switch is to check the continuity of the complete circuit. Operation of the switch connects a standard test signal, generated in the indicator-amplifier, to the pick-up unit and if the circuit is fault-free the test signal produces a standard value of vibration amplitude on the indicator.

8 **FUEL QUANTITY INDICATORS** The design and choice of a system for measuring and indicating fuel quantity is governed largely by the configuration of an aircraft fuel tank system. Most of the indicating systems in current use are based on electrical signal transmission principles, although in some types of light aircraft direct-reading indicators may be fitted. A general description of the construction and operation of typical indicators is given in the following paragraphs.

8.1 **Float Type Systems.** The transmitter or tank unit, consists of a cork or metal float attached to an arm pivoted at one end of a support assembly. The arm is mechanically coupled via a sealing unit to the electrical element which may either be of the basic or Micro-Desynn type (see paragraphs 3.1 and 3.2) or a simple wiper arm moving over a variable resistance connected to a moving coil indicator. The length and shape of individual float arms are designed to suit the tanks for which they are intended and the length of the support assembly may also vary accordingly. Stops are provided to keep the float clear of the top and bottom of the tank. The unit is assembled into a tank through an appropriately dimensioned aperture and is flange-mounted so that the electrical element is positioned externally. Leakage of fuel from the tank is prevented by a sealing washer interposed between the flange and mounting surface of the tank.

8.1.1 As the fuel level changes, the float arm moves through an angle and positions the contacts of the electrical element to produce a corresponding change of current flow through the indicator.

8.2 **Capacitance Type Systems.** These systems operate on the variable capacitance principle and consist of a number of electrical capacitance type tank units, an amplifier and an indicator. All components are interconnected by cables of the coaxial and standard type, and dependent on the particular design a system requires a power supply of either 115-volts a.c., 28-volts d.c., or both.

8.2.1 The capacitance of a capacitor is dependent on three main factors: (i) the area of its plates, (ii) the distance between them, and (iii) the dielectric constant or permittivity of the dielectric medium between the plates. In applying the capacitor principle to fuel quantity measurements the first two factors are made

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constant by constructing the capacitors in the form of either two concentric tubes or, two flat plates, the dimensions of which are fixed to suit the tank. The capacitance can therefore be varied only by changing the permittivity of the dielectric.

- 8.2.2 When such a capacitor is placed in a full fuel tank its dielectric is fuel, but as the tank empties the dielectric becomes fuel and a mixture of air and fuel vapour. Since the permittivity ratio between fuel and air varies in a known manner, then any change in fuel quantity between the tank-full and tank-empty conditions produces a corresponding capacitance change.
- 8.2.3 The method of connecting a tank unit capacitor in a gauge system varies, but in a typical version, the unit is connected in a rebalancing bridge circuit and its capacitance is compared with that of a reference capacitor. The signal proportional to the difference between them is applied to the amplifier, the output of which drives a two-phase induction motor coupled, via a gear train, to a potentiometer wiper and to the indicator pointer. The amount of motor rotation required to rebalance the bridge circuit through the potentiometer is therefore a measure of the change in tank unit capacitance and quantity of fuel in the tank. In some systems the amplifier output is converted to a d.c. signal which is measured by a moving coil ratiometer type of indicator.
- 8.2.4 Several tank units connected in parallel are used in fuel tanks to automatically compensate for aircraft attitude changes or surging of fuel. If the units are correctly sited in a tank, a gain in capacitance by some of the units resulting from a change of aircraft attitude will automatically be compensated by a loss of capacitance in others so that the total capacitance and indicator readings are unchanged. To ensure that capacitance changes are proportional to actual changes in quantity and not affected by the shape of a tank, certain of the tank units are characterised. This is effected by matching conducting surface areas to the different fuel levels resulting from the tank contour.
- 8.2.5 The permittivity of a fuel varies between different grades so that indication errors can arise when using different fuels. These errors are compensated by incorporating a reference or compensator unit in the tank. The unit is similar to a standard tank unit, but it has an additional capacitor at its lower end, and is so disposed in the tank as to be completely immersed down to very low fuel levels. It is connected into the balancing bridge circuit so that its capacitance change, due only to fuel permittivity opposes that of the standard tank units and error voltages and currents are cancelled.
- 8.2.6 Adjustment of a complete indicating system at the tank-full and tank-empty conditions is provided by two variable resistors in the sensing circuit from the tank units. Depending on the type of system installed, the resistors may be located at the rear of an indicator, within an amplifier unit or within separate adjuster boxes. In some systems a switch is provided for functional testing purposes. The switch is so connected that when depressed it unbalances the bridge circuit, and if the system is operating satisfactorily the indicator pointer rotates towards the 'tank-empty' position. On releasing the switch, bridge balance is restored and the pointer returns to its original position.
- 8.3 **Direct-reading Indicators.** Direct-reading indicators usually consist of a float contained within a metal support tube. The float engages with a spiral slot cut in the tube so that as the fuel level changes, the float moves up and down the tube and

rotates at the same time. Rotary movement of the float is conveyed to an indicating element located at the top of the tube and magnetically coupled to a spindle which passes through the float.

- 9 **FUEL FLOWMETERS** Fuel flowmeters measure and provide visual indication of the instantaneous rate at which fuel flows to an engine, and in the majority of engine fuel system installations, provide a secondary indication of the quantity of fuel consumed. A system consists of a transmitter connected in the main fuel supply line and a motor-driven indicator calibrated in either gallons, kilogrammes or pounds per hour. The transmitter contains a specially calibrated metering unit and an electrical signal pick-off unit. As fuel passes through the metering unit it drives a rotating element which is coupled to the pick-off unit. Signals proportional to the fuel flow rate are induced in this unit and are transmitted to the indicator motor which positions the pointer at the scale graduation corresponding to the flow rate.

NOTE: There are a number of variations in the design and construction of fuel flowmeter systems. For detailed information on the operating principles adopted reference should therefore be made to the relevant Manufacturer's publications.

## 10 INSTALLATION

- 10.1 **General.** Before installation, instruments should be inspected for damage or deterioration which might have occurred in storage or transit. New or overhauled instruments are normally kept in their special packaging containers until required and the packaging should be carefully examined for signs of damage before removing the instrument. It must be verified that the shelf life (which is usually indicated on the container) has not been exceeded.

- 10.1.1 The dials of indicators should be checked to ensure that, where applicable, they bear coloured arcs and radial lines at various parts of the scales corresponding to the operational limitations laid down for specific types of engine. It may be necessary in some instances to apply the arcs and radial lines to the cover glasses. In such cases, the precaution must be taken of painting a short white connecting line between the glass and the bezel, and in a position which does not conflict with the essential operational marks. Thus, the correct alignment of the glass and operational marks may be readily checked.

NOTE: Further information on operational markings is given in Chapter D7-3 of British Civil Airworthiness Requirements.

- 10.1.2 The method of mounting instruments on their respective panels depends on whether the cases of the instruments specified for use in a particular aircraft type are of the flanged or flangeless design. In the former design the bezel is flanged in such a manner that the instrument is flush-mounted in its cut-out from the rear of the panel. Integral self-locking nuts are provided at the rear faces of the flange corners to receive fixing screws from the front of the panel. The mounting of instruments having flangeless cases is a simpler process in that separate fixing screws and nuts are unnecessary and mounting of instruments may be done from the front of the panel. A special expanding type of clamp, shaped and dimensioned to suit the instrument case is secured in the rear face of the panel at the appropriate cut-out location by two countersunk retaining screws. Two round head actuating screws are connected to the clamp and are arranged to be accessible from the front of the instrument

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panel. The screws must be released sufficiently to allow the instrument to slide freely into the clamp. After positioning the instrument, the actuating screws are then rotated so as to draw the clamp tightly around the case of the instrument. To avoid strain or distortion care must be taken to ensure that instruments seat squarely in their cut-outs while being secured to the instrument panels. This is of particular importance when installing instruments having flanged cases.

10.1.3 Code numbers of instruments and associated components, etc., should be checked to ensure that they comply with installation requirements, and where electrical instruments are concerned all wiring and connections must be in accordance with relevant Manufacturer's drawings.

10.2 **Direct-reading Pressure Gauges.** Before installing a gauge the bore of the connecting union should be inspected to ensure that it is clean, free from damage and obstruction; bleeding of the system must also be carried out. With the gauge in position the rigid pipe line, or flexible hose as appropriate, should be connected to the union. The union should be held by a spanner at the hexagonal portion to prevent straining of the gauge mechanism fixing screws while tightening the pipe line or hose union nuts.

10.2.1 **Manifold Pressure Gauges.** Before installation, the lubber mark should be checked to ensure that it is set at the correct maximum permissible pressure for the engine with which the gauge is to be used. The method of adjusting the lubber mark varies; reference should therefore be made to the relevant manual for details of the procedure to be adopted. The gauze filter should be removed from the pressure connector and examined for damage and cleanliness. When replacing a filter it must be ensured that it is inserted the correct way round, e.g. certain types of filters are open at one end and must be inserted this end first. Pipelines and fuel traps where necessary, must be installed in accordance with the requirements specified in the relevant aircraft installation drawing.

10.3 **Capillary Pressure Gauges.** The installation of these instruments should be commenced at the instrument panel end by passing the banjo fitting and capillary tubing through the cut-out. The capillary tubing is normally wound on a cardboard drum and it should be reeled off from this without pulling away at sharp angles. The tubing should be disposed along its route until the gauge can be bolted to the instrument panel. Cleating of the tubing to adjacent parts of the structure is normally required at intervals of not more than 225 mm (9 in). Sharp bends should be avoided; the radius of any essential bend should not be less than 15 mm ( $\frac{5}{8}$  in).

10.3.1 Any spare length of tubing at the engine end should be formed into a coil of not less than 100 mm (4 in) diameter, the coil being cleated in at least three places to an adjacent part of the structure. A new annealed copper washer should be placed on either side of the hollow bolt attachment of the banjo fitting before connecting it to the engine.

10.4 **Pressure Transmitter Systems.** A pressure transmitter should be mounted vertically with the outlet connection to the gauge uppermost, as usually indicated by an arrow embossed on the body of the outlet housing. Four spacers screwed to the flanges of both housings provide for the mounting of the transmitter on the engine side of a fireproof bulkhead, or by means of tube clamps, on the engine

bearers. The spacers must not be disturbed as this would affect the tightness of the flanges and cause distortion of the body and subsequent leakage. When attaching the fixing screws to the spacers the latter should be held with a spanner to prevent any tendency to rotate during tightening.

10.4.1 Two pressure connections are provided in the inlet housing and the flexible hose conveying the source should be connected to the most convenient inlet. The other connection should be sealed by the blanking plug provided with the transmitter. The filler valve should be secured to the transmitter inlet housing and blanked off until filling and bleeding of the system is carried out.

10.4.2 **Filling and Bleeding.** A special filling apparatus is normally supplied for filling and bleeding, capable of applying pressure up to a maximum of  $175 \text{ kN/m}^2$  ( $25 \text{ lbf/in}^2$ ). The filling apparatus must be thoroughly clean before being filled with fluid, and all air should be expelled by operating its filling pump until bubble-free fluid flows from the end of the filling line.

- (a) Before commencing filling operations the pipeline between the transmitter and indicator should be disconnected and cleared of any dirt particles by blowing through clean, dry air at a pressure of approximately  $175 \text{ kN/m}^2$  ( $25 \text{ lbf/in}^2$ ). When it is evident that the line is completely clear it should be re-connected.
- (b) The blanking plug should be removed from the transmitter filling valve and the filling apparatus connected to the valve. The locknut and the centralising knob shaft should then be slackened off and the centralising knob pushed inward and turned by hand in a clockwise direction for about one-half turn until the shaft locks in place. This action locates the centralising disc against the diaphragm and maintains it in a central position to prevent excessive distension of the diaphragm during the filling process. If the centralising knob shaft is a little difficult to push in, it may be lightly tapped; pliers or a wrench must not be used to rotate it.
- (c) The blanking plug should be removed from the bleed valve at the gauge connection and a suitable length of flexible tubing connected to act as a bleed line. A suitable receptacle containing a small quantity of filling fluid should be positioned below the bleed valve and the free end of the bleed line immersed in the fluid. As an aid in detecting air bubbles the bleed line should incorporate an end section of transparent flexible tubing.
- (d) The filling device should then be operated to force fluid into the system, ensuring that the pressure does not exceed  $175 \text{ kN/m}^2$  ( $25 \text{ lbf/in}^2$ ), which is the pressure necessary to open the bleed valve. Pinching off the bleed line several times during filling will help in removing air. When air bubbles cease to appear at the free end of the bleed line it may be assumed that the system is filled.
- (e) On satisfactory completion of the filling operation the filler and bleed lines should be disconnected and the blanking plugs replaced on the valves. The transmitter centralising disc is returned to its normal position by turning the knob anti-clockwise and withdrawing it to its maximum extent, and then secured in this position by tightening the locknut.

10.5 **Power Loss, Engine Pressure Ratio and Percentage Thrust Indicators.** The indicators should be secured at their panel cut-out locations by the appropriate

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mounting method (see paragraph 10.1.2) and their respective connections coupled to the static and pitot pressure pipelines. After installation indicators must be tested for proper functioning under static and running conditions of their associated engines (see also paragraph 11.3.1).

**10.6 Electrical Pressure Gauges.** The code numbers of transmitters and indicators should be checked to ensure that the units are correct for use in combination. Transmitters other than flange-mounted types must be supported on an anti-vibration mounting which should be attached to the airframe or engine structure, as specified for the aircraft. When connecting pipelines to Micro-Desynn pressure transmitters care must be taken not to disturb the setting of the pressure unit. Two spanners must be used one to hold the body of the pressure connecting union while tightening the pipeline union nut. Flange-mounted transmitters must be attached to the appropriate location on the engine with the specified type of gasket fitted between the mounting faces. After the necessary electrical connections have been made and the power supply has been switched on, a check should be made that indicator pointers move from an off-scale position to zero. During engine running it must be checked that pointers move smoothly without signs of flickering. On completion of engine running, transmitters and pressure connections must be checked for signs of leakage.

### 10.7 Engine Speed Indicators

**10.7.1 Indicators and Synchrosopes.** These should be properly secured at their panel cut-out locations by the appropriate mounting method (see paragraph 10.1.2). When installing mechanical type indicators it must be ensured that the flexible drive has adequate clearance behind the panel and that any necessary bends are not sharp or would cause strain on the instrument when it is secured to the panel. Cable connections to electrical indicators and synchrosopes must be made in accordance with the relevant Maintenance Manuals and Wiring Diagrams.

**10.7.2 Generators.** Before installation, the insulation and phase resistance of generators should be checked in accordance with the procedure laid down in the Maintenance Manual for the specific type. Generators coupled to an engine by a flexible drive are normally mounted on a platform type of bracket secured to the engine. When fitting a flexible drive with square shank connectors it must be ensured that it is located the correct way round, i.e. short connector at the generator and long connector engaged with the engine drive. The union nuts should be securely tightened and wire-locked. Before installation of a spline-drive generator the face of its mounting flange and corresponding face of the engine mounting pad should be clean and undamaged and the splines should engage with the engine drive shaft without difficulty. A "Langite" or other approved gasket must be fitted between both mounting faces. After locating the generator on the mounting studs, the securing nuts must be tightened evenly and in sequence.

**10.7.3 Rotation Indicators.** For details of pre-installation checks and installation procedures, reference should be made to the relevant aircraft Maintenance Manual.

### 10.8 Temperature Indicators

**10.8.1 Capillary Thermometers.** The procedure for installing thermometers of this type is similar to that adopted for capillary pressure gauges (see paragraph 10.3).

**10.8.2 Electrical Resistance Thermometers.** Resistance bulbs should be screwed into the required position and after tightening, the union nuts should be wire-locked. Electrical connection of a bulb and indicator system must be made in accordance with the relevant Maintenance Manuals and Wiring Diagrams. After switching on the power supply a check should be made that an indicator pointer moves from a 'null' position (Wheatstone Bridge type) or an off-scale position (ratiometer type) to a position indicating the prevailing temperature of the liquid in which a bulb is immersed.

**10.8.3 Thermo-electric Systems.** The visual checks to be carried out on thermocouples, harnesses and leads and the methods of installing them, depend on the aircraft and engines with which they are associated; the instructions provided in the appropriate Maintenance Manuals must therefore be followed. Certain aspects are common to installation practices and may be summarised as follows:

- (a) Freedom from cracks at brazed joints between thermocouple element and cables in protecting sheaths and cable conduits.
- (b) Alignment of gas inlet and outlet holes in relation to the key provided for locating the probe.
- (c) Position and condition of elements as seen through gas holes.
- (d) Universal joint movement, where applicable.
- (e) Identification of positive and negative conductors and correct pairing of elements at terminals.
- (f) Condition of cable sheathing and conductors. If stranded leads are used, check for fraying and if this is evident the leads should be rejected.
- (g) When making connections ensure that continuity of polarity and conductor identity is preserved.
- (h) Before fitting thermocouples or harness systems, lightly smear the threads of captive nuts or bolts with a graphited grease; this will facilitate removal, particularly in hot zones of an engine.
- (j) Exhaust gas thermocouples should be correctly aligned in engine adaptors or mounting bosses and their securing nuts or bolts tightened to the specified torque load.
- (k) The overall circuit resistance is critical, therefore all terminals must be clean and the nuts securing the cables must be tightened to the specified torque load. When torque loading, care must be taken to ensure a direct load on the torque spanner avoiding side loads.
- (l) No alteration must be made to the length of leads, otherwise the circuit resistance will be incorrect resulting in inaccurate indications of temperature.
- (m) In order to damp the moving coil element of indicators and thus help obviate damage during transit and other handling, the terminals must be short-circuited by a piece of copper wire. It should be removed during testing, but afterwards should be replaced until an indicator is installed in the aircraft.

NOTES: (1) Thermocouple conductor leads are identified by a colour code as follows: Red-Positive-Iron, Copper and Chromel; Blue-Negative-Constantan and Alumel.

(2) In addition to the foregoing pre-installation checks, the electrical continuity, resistance and millivolt output of thermocouples, harnesses and leads should also be tested, and in the manner specified in the relevant Maintenance Manual.

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10.9 **Engine Vibration Indicating Systems.** Before installing a vibration pick-up unit it should be ensured that the internal magnet has freedom of movement. This may be done by holding the unit and checking that an audible 'click' is produced when a slight flick is imparted to the unit. The resistance of the inductor coil should also be checked to ensure that it is within the limits specified. After securing the unit to the engine, connect the cable assembly and secure it with the coupling nut provided. The unit fixing screws and coupling nut should be wire-locked. Indicator-amplifier units should be secured to the instrument panel and connected to their appropriate cables. A function test of the complete system under engine static conditions, should be carried out by switching on the power supply and noting that when the test switches are pressed the indicators read a specified standard value of vibration amplitude, and noting also that the warning lamps come on.

### 10.10 Fuel Quantity Indicators

10.10.1 **Float Type.** Before installing tank units and indicators the following tests and checks should be made:—

- (a) Insulation resistance and continuity tests of tank units, indicators and the indicating system cables in the aircraft.
- (b) Check that code numbers are correct for the particular aircraft fuel tank installation.
- (c) Check that float arms have not been accidentally bent, and that other parts of the actuating mechanism are clean and show no signs of corrosion.
- (d) Check that floats have freedom of movement where applicable, no signs of dents or flaking of fuel-resistant lacquers with which cork floats are coated.
- (e) Test the float arm freedom of movement between the 'full' and 'empty' limit stops.
- (f) Test the functioning of tank units and indicators against the appropriate Test Sets and/or Master Indicators in the manner prescribed in the Maintenance Manuals.
- (g) Ensure that the mating surfaces of a tank unit and tank are clean and fit a new sealing gasket coated on both sides with a fuel resistant sealing compound.

NOTE: When a tank is fitted with a separate inspection cover adjacent to the tank unit, it should be removed to enable the float arm position to be checked.

- (i) A tank unit should be positioned correctly in relation to the tank so that the float arm may be inserted without fouling the tank sides or baffles. After lowering it onto the tank mounting face it should be located by inserting two or three of its fixing screws, and if possible the float arm checked for clearance and freedom of movement by hand, through an adjacent inspection hole. The remaining fixing screws should be inserted and all screws tightened evenly working diametrically across the flange. The electrical leads should be connected in accordance with the relevant aircraft wiring diagram taking care to ensure correct terminal polarities, and that there are no loose strands of wire which could short-circuit the terminals.
- (ii) After installation the power supply should be switched on and the

operation of the system checked. If an inspection hole is available this may be done by moving the float arm by hand from the empty to the full position and noting that the indicator pointer moves smoothly in the corresponding direction. In all instances a functional test must be made by adding fuel in measured quantities over the total range of tank capacity. Particular attention should be paid to the accuracy of the indicator at the lower end of the scale (refer also to paragraph 11.14.1 (e)).

**10.10.2 Capacitance Type.** The method of installing components of capacitance type fuel quantity indicating systems varies particularly in connection with tank units and aircraft fuel tank systems. The instructions given in the relevant Maintenance Manuals must therefore be observed. The following gives details of certain important aspects associated with systems generally:

- (a) The code numbers of tank units must be checked to ensure that they are of the type corresponding to the location and fitting specified, e.g. centre of a tank, compensated unit, internal or external mounting. Units must be inspected for signs of damage to the electrodes and co-axial connector assemblies and if they are of the external mounting type, cleanliness of the mounting flange surface. When installing units care must be taken to pass them through the holes provided so that electrodes are not damaged or distorted, and the co-axial connectors face in the correct direction for mating with the cables. Externally mounted units are secured to the tank by means of fixing screws and sealed by a gasket and jointing compound. Internally mounted units are installed and located in their mounting brackets, through hand holes. When fitting the cables to the co-axial connectors the cable coincidence and terminal identifications must be checked to ensure that they are in accordance with the system wiring diagram.
- (b) Before installing co-axial cables they must be examined for signs of damage, erosion or other defects and tested for insulation resistance and continuity. Extreme care is essential when installing cables to ensure that the bends are not excessive (minimum permissible bend radius is 25 mm (1in) and that the cables are so placed to avoid being cut by sharp edges, etc. Precautions must also be observed in connection with the insulation of cables and ambient temperatures to which they may be subjected. For example, cables of the polythene insulated type are not suitable for location in areas subject to temperatures in excess of 60°C. Failure to observe this precaution will result in melting of the insulation and subsequent failure of the gauge system. Where temperatures in the vicinity of a cable are likely to be above 60°C, cables having PTFE (polytetrafluoroethylene) insulation must be used. Cable connector nuts must be tightened to the torque value specified in the Manufacturer's Maintenance Manual. Connector body assemblies must not be rotated during tightening of the nuts.
- (c) After the installation of a component in a tank system and any necessary adjustments, a test must be carried out in accordance with the procedures specified in the relevant Maintenance Manuals.

**10.11 Fuel Flowmeters.** The pre-installation checks of fuel flowmeter system components and the methods of installation vary between systems; reference should therefore be made to the relevant Maintenance Manuals.

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**11 INSPECTION AND MAINTENANCE** The checks to be carried out on individual instruments and associated components are primarily concerned with security, visual defects, circuit testing and calibration tests. Precise details of these checks are given in relevant instrument and aircraft Maintenance Manuals and reference should always be made to such documents. The following summary and the information given in subsequent paragraphs serves as a guide to checks of a general nature and to specific inspections and tests related to the instruments covered by this Leaflet. The summary of checks:

- (a) Security of attachment to instrument panels and appropriate parts of the airframe or engine structure.
- (b) Security and cleanliness of pressure and electrical connections.
- (c) Evidence of cracking of cases, bezel mounting flanges and cover glasses. The latter should always be carefully inspected as cracks caused by glancing blows struck by safety harness fittings, head sets, etc., are often difficult to detect.
- (d) Checking of dial markings, counters and pointers for legibility, discoloration and flaking.
- (e) Checking of coloured operational markings.
- (f) Presence of moisture or water inside the cover glasses or on the dials of instruments connected to a static pressure source, e.g. power loss indicators.
- (g) Smoothness of pointer movements during functional testing and under engine operating conditions.
- (h) At the specified maintenance check periods or at any time instruments or associated components are suspected of malfunctioning, they should be removed from an aircraft and the relevant bench checks and tests carried out.

**11.1 Manifold Pressure Gauges.** Under static conditions of an engine the readings should be checked against the prevailing atmospheric pressure reading of a barometer. For instruments calibrated in inches of mercury the reading should be the same as that of the barometer. For instruments calibrated in pounds per square inch, the barometer reading should be converted to these units and the gauge reading checked to ensure that it indicates the difference between prevailing and standard atmospheric pressures within the permissible tolerances.

**11.2 Capillary Type Pressure Gauges.** Capillary tubes should be inspected for security at their attachment points, signs of kinking or other damage. The hollow bolt attachment should also be inspected for signs of leakage of fluid from the appropriate engine system. When carrying out functional tests in situ, care must be taken to ensure that the capillary tubing is not pulled through too sharp a bend when connecting the banjo fitting to the test apparatus. The test apparatus should be supported at the same level as the point at which the banjo fitting is normally located in order to minimise 'head effects'.

**11.3 Power Loss, Engine Pressure Ratio and Percentage Thrust Indicators.** Indicators should be checked to ensure that under static conditions and also when engines are run at their governed speeds, they indicate the appropriate values within the limits given in the aircraft Maintenance Manual.

**11.3.1** At the specified check periods, or whenever indications are suspect, functioning tests should be carried out by applying air pressure from a suitable rig and noting that indicator readings correspond to the specified master gauge reading. Care must be taken never to exceed the upper limit of applied

pressure or damage to the pressure sensing capsules may result. In addition to the functioning test, water drain traps should be checked, the exhaust pressure and static pressure sensing lines should be disconnected from the engine and the indicator, and pressure tested in the manner prescribed in the relevant aircraft Maintenance Manual.

11.3.2 Filters are provided in the connections of some indicators and these should be inspected for cleanliness. If dirt is evident, the appropriate filter should be extracted from the bore of the connector and washed in a cleaning solvent such as Inhibisol. After thoroughly drying out, the filter and pipe connection should be re-connected.

11.4 **Electrical Pressure Gauges.** During engine running the correct functioning of a system should be checked by observing that the indicator pointer moves smoothly across the scale without flickering. In systems employing moving contact type transmitters pointer flicker will most often develop at the scale point where the pointer settles under normal operating conditions. This is usually owing to wear on the resistances caused by a continuous rubbing of the contacts under conditions of vibration. In such circumstances the complete transmitter should be replaced by a serviceable unit. Pressure connections should be checked for signs of fluid leakage and transmitters for security of attachment. Anti-vibration mountings should be inspected for signs of damage and also to ensure that they provide the required floating action of their transmitters.

11.5 **Flexible Drive Shafts.** The locking wire should be removed from the union nuts, the nuts unscrewed and the complete drive assembly removed from the aircraft. The flexible shaft should then be removed from the outer casing by firstly pulling out the indicator or generator end as far as possible and bending and removing the slip washer. The flexible shaft is then withdrawn by pulling out from the engine drive end. All components should be thoroughly cleaned and inspected.

- (a) It is particularly important to verify that there are no kinks, worn spots, loose or fractured strands in the flexible shaft and that the end connectors are secure. A kink may be detected by holding the complete assembly vertically at one end and slowly rotating the flexible shaft between the fingers to feel for binding and jerky motion. In instances where the flexible shaft is rejected because of loose strands, it is advisable to renew the complete drive as it is possible that the bore of the casing may have been damaged and this would result in excessive wear of the new flexible shaft.
- (b) The outer casing should be inspected for kinks, sharp bends and security. Two holes are provided in the collar at the engine end which permit surplus oil from the drive to drain away. The holes should be kept clear.
- (c) Prior to re-assembly the flexible shaft should be coated with an approved grease. With the shaft in position in the outer casing, the slip washer at the indicator or generator end should be re-assembled and using a pair of flat-nosed pliers, flattened so that it will remain on the shaft.

11.6 **Electrical Engine-speed Indicating Systems.** When an engine is running at idling speeds it may be found that the indicator pointers tend to fluctuate and read low; this is an indication that the indicator motor is not synchronising with the generator output. As the engine speed is increased the pointers should jump

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forward as the motor synchronises, and register the speeds correctly without any appreciable lag. The speeds at which synchronising takes place is governed by the upper limit of the indicator's speed range, and generator output, and these should be ascertained from the Manufacturer's Maintenance Manual for the specific type of system.

- 11.6.1 If instrument pointers oscillate at speeds above the synchronising value it should be verified that the total oscillation does not exceed the permissible ranging tolerances. Where excessive oscillation is observed it is necessary to determine whether the instrument or one of the other components in the system is at fault. If a flexible drive to the generator is employed, oscillation may be due to insecure attachment of the outer casing thus permitting the drive to 'whip' slightly. It may also be due to 'binding' of the drive as a result of lack of lubrication. If, after rectifying these faults, oscillations still persist and all electrical connections are secure, a new drive should be fitted.
- 11.6.2 With flexible drive generators and also direct-drive generators, if the drive and electrical connections have been eliminated as the source of the defect, pointer oscillation is most likely to be associated with the indicator, e.g., the drag element may be touching the rotating magnet at a certain position within the air gap. The indicator should be removed for testing and if oscillation persists, a new indicator should be installed.
- 11.7 **Synchrosopes.** Synchrosopes should be checked to ensure that during engine running pointer rotation is in the correct direction at differing speeds of master and slave engines, and that no rotation takes place when speeds are synchronised. The checks are done firstly by maintaining the slave engine or engines at idling speed and then increasing the speed of the master engine. Under these conditions it should be noted that the synchroscope pointer or pointers rotate anti-clockwise to the SLOW or INCREASE marking. The speed of the slave engine or engines should then be increased to a value higher than the master and pointer rotation noted to be clockwise to the FAST or DECREASE marking. Finally, it should be noted that as speeds are brought into synchronism, the pointer or pointers remain stationary at some position over the dial.
- 11.8 **Rotation Indicators.** The method of carrying out maintenance checks, tests and adjustments depends on the type of engine and on the systems adopted. Reference must therefore be made to the relevant Maintenance Manuals.
- 11.9 **Capillary Thermometers.** Capillary tubes and bulb fittings should be inspected for security at their attachment points, signs of kinking or other damage, and leaks. Under engine static conditions the indicator readings should correspond to the prevailing temperature conditions of the fluid in which the bulb is immersed. When carrying out functional tests of a thermometer in situ, care must be taken to ensure that the capillary tubing is not pulled through too sharp a bend when connecting the bulb to the test apparatus. The test apparatus should be supported at the same level as the point at which the bulb is normally located in order to minimise 'head effects'.
- 11.10 **Electrical Resistance Thermometers.** When electrical power is switched on instruments should be observed and a check made that pointers move from a 'null' position or an off-scale position to one indicating prevailing temperature conditions. In the event that the pointers of an indicator move to a position

beyond maximum scale reading, the power supply should be switched off immediately and a continuity check of the bulb and cables carried out, as this fault is an indication of an open circuit in the temperature sensing signal line.

**11.11 Thermo-electric Systems.** Thermocouples are not normally repairable items and if defective must be rejected for scrap or returned to the manufacturer for investigation. The mechanical condition of thermocouple units, harnesses and leads should be checked for defects paying particular attention to the following:

- (a) Fracture or erosion of thermocouple hot junctions.
- (b) Deterioration, cuts or fractures in insulation of leads.
- (c) Cracks, or damage to the leading edge of machined probes, e.g. those installed at intermediate nozzle guide vanes of turbine engines.
- (d) Blockage or enlargement of gas holes and damage to their edges.
- (e) Cracks in or distortion of sheaths and conduits.
- (f) Stiffness or seizure of universal joints in thermocouple units employing this method of attachment.

**11.11.1 Circuit Resistance Checks.** The resistance of thermocouples and external circuits of engine cylinder head temperature and exhaust gas temperature indicating systems, must always be checked to ensure that it is within the limits specified. The checks are done under ambient temperature conditions by disconnecting the thermocouple harness and external circuit leads from their junction box and connecting them in turn to a Wheatstone Bridge, or similar test instrument by means of special test leads. The test leads are of a known resistance, the value of which must always be subtracted from that obtained during the test.

NOTE: The test leads must be connected to the leads under test by clamp type connections, e.g. nuts and bolts. Crocodile clips or clamps are not satisfactory.

- (a) Depending on the modification state of certain types of turbine engines the nominal value of external circuit resistance is related to one particular ambient temperature. For conditions of ambient temperature above or below the value specified, reference must always be made to tables in the relevant engine Maintenance Manual to obtain the correct circuit resistance.
- (b) If after testing an external circuit containing a trimming resistor, it is found that the resistance is too high, the trimming resistor wire should be released from its terminal and its length reduced by unwinding the wire from its bobbin. Insulation should be removed from the wire locally and after re-connecting the wire to its terminal the total circuit resistance should be measured. This process should be repeated until the specified nominal resistance value is obtained.

NOTE: The wire should always be unwound in small increments thus working down to the required resistance and also preventing uninsulated wire being wound back on the bobbin.

- (c) If a test indicates that the resistance is too low, a new trimming resistor should be fitted.

**11.11.2 Functional Tests.** These tests are mainly concerned with checking readings against a datum temperature value and setting the pointer by means of the adjusting device provided. The procedure to be adopted and type of test equipment required, depends on the temperature measurements with which the indicating system is associated, i.e. cylinder head temperature or

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exhaust gas temperature. The following points serve only as a guide to the general nature of testing; reference must always be made to the relevant engine and aircraft Maintenance Manuals.

- (a) The datum temperature for the setting of a cylinder head temperature indicator is the temperature prevailing at the indicator itself when disconnected from the rest of the circuit, and is obtained by suspending a mercury-in-glass thermometer as close to it as possible. After allowing the temperature to stabilise, the thermometer and indicator readings should be compared. If the indicator is not reading accurately, correction should be made by rotating the adjusting device in the appropriate direction.
- (b) Exhaust gas temperature indicators are set to a datum temperature corresponding to a specific cruise temperature and require the use of a pyrometer test set. The test set is connected to the indicator, or in some installations to a special test receptacle, and its controls adjusted to inject an e.m.f. into the circuit until the datum temperature is obtained. The indicator reading is then compared with the test set and if necessary, corrected by the adjusting device.
- (c) When tests have been completed satisfactorily, indicating system leads must be re-connected at the appropriate points ensuring correct polarity and security of connections.

NOTE: After making any adjustments to indicated readings, adjustment devices should be rotated a fraction of a turn in a direction opposite to that which gave the required reading. This will relieve any stresses set up in the hairsprings and bi-metal cold-junction compensator.

- 11.12 **Engine Vibration Indicating Systems.** At the periods specified in the Maintenance Schedule and in addition to visual checks for security of components and signs of damage, a functional test of systems should be carried out (see also paragraph 10.9).
- 11.13 **Fuel Quantity Indicators — Float Type.** An indicating system should be checked when the associated fuel tank is being filled, by noting that the amount of fuel being added is correctly shown by the indicator when the aircraft is in the prescribed attitude. If the indications appear correct no additional routine maintenance is necessary. At the specified check periods, and whenever a system malfunction occurs, tank units and indicators must be removed for inspection and testing in the manner laid down in relevant Maintenance Manuals.
- 11.14 **Fuel Quantity Indicators — Capacitance Type.** As in the case of float type indicating systems, gauge readings should be checked during a refuelling operation. Where test switches are provided these should be depressed and released and a check made that indicator pointers move down-scale and then return to original readings. Some aircraft are provided with a special fuel load control panel containing an additional set of quantity indicators, and located at a point accessible from outside the aircraft. A switch is sometimes provided for changing over tank unit signals from the cockpit indicators to those on the panel enabling readings to be taken from the latter. On completion of an operation the tank units are switched back again to the cockpit indicators and a check made that they indicate their respective tank quantities.
  - 11.14.1 At the specified check periods, and whenever a system malfunction occurs, system components must be removed for inspection and testing. The number of checks to be made are greater than those related to other forms of

indicating systems, and having regard to the operating principles adopted and improved accuracy obtainable, the test procedures are of necessity more complex. The instructions given in Maintenance Manuals must therefore be strictly observed. The following summary serves as a guide to certain important aspects common to the inspection and maintenance of all capacitance type systems:

- (a) Tank units must be inspected for mechanical damage to the tubes and for faults in electrical connections. Dents or flattening of the outer tube may give an incorrect capacitance figure or cause a short circuit; faulty connections can cause intermittent readings or complete open circuit.
- (b) Externally mounted tank units should be checked for signs of fuel leakage around the flange.
- (c) If it is necessary to renew a co-axial cable connector, care must be taken in removing the defective connector to avoid damage to the cable end and the insulation. A connector must be unsoldered from a cable and not cut off since it is essential to maintain original cable length.

NOTE: The preparation of cables having an outer covering of PTFE and soldering of connectors to these cables, should only be done in a well ventilated atmosphere. As a further protection against dust particles and gases which can be produced when the cables are subjected to high temperatures, smoking should be prohibited.

- (d) In addition to continuity and insulation resistance tests, co-axial cables must be tested for capacitance.
- (e) The calibration of systems must be checked using the appropriate test sets and may be carried out either with the aircraft tanks full, or at the unusable fuel level (gauge 'zero') condition. Unusable fuel level refers to the quantity remaining when, under the most adverse conditions, the first evidence of engine malfunctioning occurs.
- (f) Adjustments at the 'empty' and 'full' positions must be made in the correct sequence and to within the permissible tolerances specified for a system.
- (g) Electrical power supplies must be isolated before coupling or decoupling cable and component connectors.

**11.15 Fuel Flowmeters.** Transmitter units should be inspected for signs of fuel leakage at metering chamber housings and at pipeline connecting unions. During engine running, indicators must be checked for correct indication of relevant fuel flow rates and fuel consumption. If a system is operative, but a fault affecting calibration is suspected, calibration checks on individual components should be carried out in the manner prescribed for the relevant flowmeter system. After installation of transmitter units, bleeding of the fuel system must be carried out.

NOTE: Reference should also be made to Leaflets AL/3-15 and AL/3-17; such Leaflets providing information relevant to fuel quantity indicators and fuel flowmeters, and on precautions to be observed when working on aircraft fuel systems.

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**AL/10-4***Issue 1.**14th May, 1976.***AIRCRAFT  
INSTRUMENTS  
COMPASS BASE SURVEYING**

**1 INTRODUCTION** In carrying out a swinging procedure for direct-reading and remote-reading compasses, the primary object is to determine the deviations caused by the magnetic field components of an aircraft. It is, therefore, necessary for swinging to be undertaken at a location where only these aircraft field components, and the earth's magnetic field, can affect the readings of compasses. The location must be carefully chosen and surveyed to prove that it is free from any interfering local magnetic fields, and also to establish it as the base on which all aspects of swinging procedures are to be carried out. The effect of interfering fields is to cause distortion of the direction and intensity of the earth's field. The effects on direction are the most critical, and, therefore, it is necessary for these to be determined during a survey. Any significant effects on the horizontal intensity will be detected as a change in direction, if suitable procedures are employed. The purpose of this Leaflet is to outline the basic requirements of a compass base, to define the accepted base classifications, and also to outline the procedures which may be adopted for surveying selected locations.

1.1 The CAA does not carry out surveys or approve compass bases, but its interest in surveying procedures lies in the fact that the accuracy of a base is a significant factor in meeting British Civil Airworthiness Requirements relevant to the overall accuracy of compasses installed in aircraft. Surveys may be carried out by an operator or by an airport authority, and in this connection, the standards set by the Admiralty Compass Observatory (ACO) are recognised by the CAA. The ACO is a Ministry of Defence department, and although it has the responsibility for surveying compass bases for military aircraft, its services in an advisory capacity, or for carrying out an entire survey, can be obtained. It should, however, be noted that the latter service is confined to airline operators and airport authorities.

1.2 This Leaflet should be read in conjunction with Leaflets **AL/10-5** and **AL/10-6** which deal with the swinging procedures for Direct-Reading Magnetic Compasses and Remote-Reading Compasses respectively.

**2 BASE REQUIREMENTS** A compass base must meet the following minimum requirements:—

- (a) It must be accessible, reasonably level in all directions, and its use should not interfere with normal aircraft movements on the airport.
- (b) It must be free from magnetic fields, other than that of the earth, which might cause aircraft compass errors. Most surface causes of errors are obvious, i.e. buildings and installations containing ferromagnetic components such as wire fences, drain and duct covers, picket points and lighting installations. The most likely underground causes of magnetic interference are:—
  - (i) Buried scrap metal and old brickwork.
  - (ii) Reinforced concrete.

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- (iii) Pipelines including drainage systems.
- (iv) Magnetic soil and rocks.
- (v) Electrical cables, conduits and airfield lighting transformers.
- (vi) Ferromagnetic pipes.

If such items are found at the selected location they should be removed if possible. Even though the area may be within permitted maximum limits of deviation (see paragraph 3) it is recommended that any ferromagnetic material present should still be removed as its magnetic effect may change with time and thereby down-grade the accuracy of the base. Where electrical cables cannot be avoided, their effects, with and without current flowing, must be checked at intervals along their length, especially around known joints. If a new base is being constructed great care must be taken to ensure that the area is not magnetically contaminated after survey and during construction. Steel reinforcing must obviously be avoided and any aggregate or hardcore used in the foundations must not be magnetic or contain magnetic items such as steel wire or drums, bricks, boiler clinker, blast furnace slag or magnetic rock. All steel shuttering and associated pins used when laying concrete must be removed. On completion of all work a full survey must be repeated.

- (c) A base should be sited so that its datum circle (see paragraph 2 (f) (iii)) is at least 50 yards away from hangars and other steel-framed buildings, and at least 100 yards away from buildings containing electrical power generation and distribution equipment, and also from overhead or underground power cables.

NOTE: Proposed building programmes should be examined to ensure that the site is not scheduled for other work.

- (d) A base must be large enough and of such load-bearing strength as to take all types of aircraft for which it is likely to be used. In this connection, some important factors to be considered are:—
  - (i) Whether an aircraft will be towed or taxied during the swing.
  - (ii) The radii of the turning circles of the aircraft.
  - (iii) The position of sighting rods and target fixtures on the aircraft and their likely path during the swing.
  - (iv) The likely positions of flux detector units of remote-reading compass systems.
- (e) The surface of the base should not preclude its use in wet weather.
- (f) The base should be clearly and permanently marked to show:—
  - (i) The base centre.
  - (ii) The central area in which a direct-reading compass, or flux detector unit of a remote-reading compass system, should remain during the swing.
  - (iii) The datum compass circle, i.e. the circle around the central area showing where the datum compass should be placed.
  - (iv) Areas of magnetic anomalies which cannot be removed.
  - (v) Nose wheel turning circles.
  - (vi) If the base is to be used for carrying out "electrical" swings a North-South line should be painted on the base, together with markings to indicate the locations of the compass calibrator monitor and turntable, and the bearing of the reference target used when sighting the monitor (see also paragraph 5.6).

NOTE: Paint is the best medium for marking concrete. The datum compass circle, which may be on grass, must be marked permanently with a narrow continuous path of non-magnetic material such as tarmac or gravel.

**3 BASE CLASSIFICATIONS** Compass bases may be established as either Class 1 or Class 2, the difference between them being only in the limits of permitted maximum deviation to be found anywhere within the base area as follows:—

- (a) **Class 1.** The maximum permissible deviation is  $\pm 0.1^\circ$ . Bases of this accuracy are required for carrying out refined swings, e.g. swinging of aircraft in which remote-reading compasses are used as magnetic heading reference systems, in conjunction with such equipment as Doppler Systems.
- (b) **Class 2.** The maximum permissible deviation is  $\pm 0.25^\circ$ . Bases of this accuracy are suitable for carrying out standard swings, e.g. swinging of aircraft in which the primary heading reference is provided by a remote-reading compass system, with a direct-reading compass serving as a standby.

NOTE: A location, the permissible deviation of which is greater than  $\pm 0.25^\circ$ , may be used where a direct reading compass is used as the primary heading reference (see paragraph 5.5).

**4 TYPES OF SURVEY** The following types of survey are normally carried out to assess the suitability of a location at which a compass base is to be finally established:—

- (a) **Initial Survey.** This is the first assessment survey of a location to determine gross errors, and should be carried out by the aircraft operator or airport authority. If the deviations obtained appear to be within the permissible limits laid down for Class 1 and Class 2 bases there is justification for carrying out an establishment survey.
- (b) **Establishment Survey.** This survey is of a more detailed nature in that measurements are taken at a greater number of more closely spaced points. The survey may also be carried out by the aircraft operator or airport authority, but, where appropriate, it is recommended that the services of the ACO be obtained (see paragraph 1.1).
- (c) **Periodic Re-survey.** After a base has been established a detailed re-survey must be carried out at the following intervals:—
  - (i) Class 1, every five years.
  - (ii) Class 2, every two years. In addition, bases of this accuracy should where possible, be surveyed by the ACO every six years.
- (d) **Annual Check.** All bases should be checked annually to ensure that markings and boundaries are clearly defined, and that no work has been done which might affect their magnetic properties, and also to take into account changes in magnetic variation. If any doubt exists, the suspect area should be given a detailed magnetic survey.
- (e) **Area Survey.** An area survey (see paragraph 5.6) is normally confined to the selection of a location which is to be used for carrying out a more specialised form of compass calibration procedure known as an "electrical" swing.

**5 SURVEY METHODS** There are two principal methods which may be adopted for the surveying of a compass base: (a) the reciprocal bearing method (see paragraph 5.3) and (b) the distant bearing method (see paragraph 5.4). In both methods, the use of accurate magnetic bearing compasses of either the medium landing type or the high-precision datum type will be required to determine the effects of interference from local magnetic fields. There is also a third surveying method (see paragraph 5.5), but being of a lower order of accuracy its adoption should be strictly limited. For the area survey referred to in paragraph 4(e) units of a specially designed compass calibrator set are used (see paragraph 5.6 and also Leaflet AL/10-6).

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5.1 **Checking and Correction of Survey Instruments.** Before carrying out a survey the appropriate survey instrument(s) should be given the full serviceability checks prescribed in the relevant operating manual, paying particular attention to checks which affect the repeatability of readings, e.g. pivot friction. Reference should also be made to any associated instrument test certificates to ascertain any instrument errors requiring correction. When the reciprocal bearing method (see paragraph 5.3) is used, bearings should be taken on a distant object with both compasses to establish a correction which can be applied to every reading taken from one of the compasses.

5.2 **Positioning of Survey Instruments.** In order that the deviation limits of a chosen location may be accurately assessed for base classification purposes from an establishment survey, the survey instrument(s) should be set up at close regular intervals, e.g. every 20 feet, to cover the area quadrant by quadrant. The instrument(s) should be at the maximum height of its tripod which is approximately 5 feet. In most types of aircraft, direct-reading compasses and flux detector units of remote-reading compasses are above this height. If a base is also to be used for an aircraft the compasses and detector units of which are below 5 feet, assessment should then be made closer to the ground.

NOTE: At certain stages of an area survey procedure, assessments are made with the tripod set at both minimum and maximum heights (see paragraph 5.6).

5.3 **Reciprocal Bearing Method.** This method is the most accurate and may be adopted for an initial assessment survey, a detailed establishment survey, and a periodic re-survey. It requires the use of two precision datum compasses, one being designated the master compass, and the other the mobile compass. The procedure is as follows:—

- (a) Following the checks for serviceability, both compasses should be aligned to a common magnetic datum. This is done by setting them up, in turn, on a tripod positioned as near to the anticipated centre of the base as is practical, and sighting the compass on a distant object and noting, for each compass, the average of several determinations of the magnetic bearing. This produces the correction referred to in paragraph 5.1 which is subsequently applied to the readings of the mobile compass. Frequent checks on the accuracy of this correction should be made throughout the subsequent stages of the survey procedure.
- (b) The master compass and tripod should be kept in its original position, and the mobile compass and its tripod should be positioned at various points around the area to give good coverage (see paragraph 5.2). At each point, the two compasses are aligned on each other's sighting telescope object lenses.
- (c) When the compasses are aligned, bearings should be taken from the bearing plates of the compasses, and the magnetic deviation between the two compass positions should be obtained by taking the difference between bearing plate readings and subtracting  $180^\circ$ . The sign convention used for the deviation is that, if the reading of the mobile compass is greater than that of the master compass, the deviation is negative. Conversely, the deviation is positive if the master compass reading is greater than that of the mobile compass.
- (d) The deviations should be recorded on an observation log, which should take the form of a scaled diagram of the area. The positions of any objects in the area such as drains, cable duct covers, lights, picketing points, etc., should also be indicated on the log. Areas in which deviations are in excess of the limits permitted by the appropriate base classification, should be investigated and, where possible, the source of magnetic interference should be eliminated. Where magnetic interference cannot be eliminated the area should also be indicated on the observation log as a prohibited area, i.e. an area which must be avoided when positioning an aircraft and datum compass for the purpose of swinging.

- (e) Care should be taken to ensure that there are no obvious magnetic objects near the chosen centre of the base. If the deviations are such that their mean is more than half the deviation limits for the class of base being surveyed, it should be assumed that there is a buried object near the base centre.

5.4 **Distant Bearing Method.** This method should be used only for initial surveys, and for gross error checks of Class 2 bases carried out because of doubts raised during annual checks. The procedure to be adopted is as follows:—

- (a) Select a distant object at least 2 nautical miles away, and accurately locate its position and the position of the compass base on a large scale map and measure the distance between them. Mark the line of sight from the centre of the compass base to the distant object.
- (b) Calculate the angular correction to be applied to bearings taken away from the base centre using the formula:—

$$\text{Correction Angle} = \frac{\text{Lateral distance from line of sight} \times 180}{\text{Distance to the object} \times \pi} \text{ degrees}$$

- (c) After ensuring that there are no objects in the area of the base centre likely to have a magnetic influence, the bearing compass, which may be of the medium landing type or precision datum type, should be set up and a datum bearing obtained by measuring the bearing of the distant object.
- (d) Take bearings of the distant object from selected points around the base area, and after applying the calculated corrections, compare the bearings with the datum bearing. Any difference obtained will be due to deviations present, assuming that the base centre is free from deviation. The deviations should be recorded on an observation log (see paragraph 5.3(d)).

5.5 **Surveying Pole Method.** This method is simpler than those already described and requires the use of two poles similar to those used by a land surveyor, and, in addition, a medium landing compass. Its survey accuracy is, however, of a lower order, principally because it does not utilize magnetic bearings of distant objects as a datum. The use of this method should, therefore, be restricted to the surveying of locations at which deviation limits outside those permitted under Class 1 or Class 2 (see paragraph 3) are acceptable; for example, a location for swinging aircraft using direct-reading compasses as the primary heading reference. It may also be used in such cases as the initial assessment of gross errors prior to a detailed establishment survey of a base, and where, in the absence of an established Class 1 or Class 2 base or more accurate surveying equipment, a swing is necessary to enable an aircraft to undertake a positioning flight. The procedure for carrying out this method is as follows:—

- (a) One surveying pole should be placed in the centre of the area chosen and the medium landing compass should be positioned and levelled 30 feet to the south of the pole. A plumb bob should be suspended from the centre of the compass to the ground, and the sighting device should be set to read due North. The second pole should be positioned 30 feet to the North of the centre pole, so that, when viewed with the compass sights as set, the two poles are in alignment.
- (b) The plumb bob position should be marked with a peg or a painted mark, and the position of the second pole and the compass should be interchanged. The compass reading with the poles as now positioned should be checked and should be within  $\pm 1^\circ$  of the reciprocal of the initial reading.

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- (c) A further check should be made by moving and sighting the compass along a line between the North and South points already obtained, taking at least four readings at approximately equidistant intervals. The compass should not deviate by more than  $1^\circ$  from the original reading at any position.
- (d) The same procedure outlined in paragraphs (a), (b) and (c) should be followed for determining the East and West positions.
- (e) The geometric location of the cardinal points should be proved by checking the chord distances between the points, as indicated by pegs or painted marks. If they are equal then the North-South and East-West lines are at right angles. In any case, the measurements should agree within  $\pm 3$  inches.
- (f) The whole of the foregoing procedure should be followed for determining deviations in the inter-cardinal areas and in the area around which the compass is to be positioned during the swinging procedure.

**5.6 Area Survey.** This survey is carried out using the monitor and console control units of a compass calibrator set which is also designed for the "electrical" swinging of remote-reading compass systems (see Leaflet AL/10-6). In this type of survey the principal objectives are (a) to determine the direction and strength of the earth's magnetic field at the locations of aircraft flux detector units (detector unit location check); (b) to select the point at which the compass calibrator monitor unit should be located in order to carry out an "electrical" swing (monitor location check), and (c) to mark out the monitor and turntable location points, and also a North-South line over which an aircraft must be positioned during a swing. The full setting-up procedures and operating instructions are detailed in the calibrator operating manual and reference to this document should, therefore, always be made. The information given in the following paragraphs is for general guidance only.

**5.6.1 Detector Unit Location Check.** The purpose of this check is to determine the uniformity not only of direction, but also the strength of the earth's field at points of the compass base which will correspond to the locations of detector units, e.g. in the vertical stabilizer, or wing tips of an aircraft. The strength of field is determined in order to obtain certain voltage values which must be set up in the calibrator control console unit, during an "electrical" swing procedure, to simulate the earth's field. The monitor and console control units are electrically interconnected by the appropriate cables, and are set up within 10 to 15 feet of each other. Magnetic direction and strength is measured in both the vertical and horizontal planes.

- (a) Measurements in the vertical plane are taken with the monitor mounted on its tripod, adjusted firstly to the minimum height position, and then to the maximum height position. Direction is determined in each position of the tripod by setting the monitor on each of the four cardinal headings, and noting the difference between these headings and the headings recorded on the control console unit. The average of the errors (the algebraic sum divided by four) is recorded as the monitor index error. The difference between the index errors at the minimum and maximum height positions is then calculated. If the difference exceeds the specified value (six minutes is a typical value) the area surveyed is unsuitable. Field strength is determined at the minimum and maximum height positions of the monitor tripod, by setting the monitor to a heading of zero degrees and obtaining voltage values from settings made on the control unit.

(b) Measurements in the horizontal plane are carried out to determine the uniformity of the earth's field direction and strength over a circle of five feet radius, the centre of which is at the location of the flux detector unit on the aircraft. The readings are taken at the centre of the circle with the monitor tripod at its normal operating height, and with the monitor set, in turn, on each of the four cardinal headings. The differences between monitor and control console unit headings are then noted, and a monitor index error obtained in the same manner as that described in (a). Readings are then taken on the cardinal headings with the monitor and tripod positioned, in turn, at four equidistant points on the perimeter of the circle, and corresponding monitor index errors are obtained. The algebraic difference between these errors and the index error at the centre of the circle is then calculated, and should be within the limits  $\pm 6$  minutes. Field strength is determined by setting the monitor to a heading of zero degrees and obtaining voltage values with the monitor at the centre of the circle and at the four equidistant points on its perimeter.

**5.6.2 Monitor Location Check.** The purpose of this check is to select the location for the monitor in order to measure the earth's field during the "electrical" swinging procedure. The location selected should be such that with an aircraft positioned on the base, the monitor readings will not be influenced by magnetic effects of the aircraft itself. A distance of 75 to 100 feet is normally sufficient. The direction and strength of the earth's field is determined at the selected location and corresponding monitor index error and voltage values, calculated. The bearing of a reference target at least one-half mile distant from the location is also obtained. As this target is to be used during a compass swing it should be ensured that it will be visible from the monitor location when an aircraft is positioned on the base. The suitability of the selected monitor location is then determined by re-positioning the monitor at the flux detector unit location and measuring the direction and strength of the earth's field, and then calculating the algebraic difference between values at each location. The readings at each location should be taken within a time of 30 minutes of each other to lessen the possibility of a change in the earth's field.

**5.6.3 Marking of Base.** On completion of the foregoing checks, markings must be permanently set out on the base to indicate the following:—

- (a) **Location of Flux Detector Units.** For aircraft the flux detector units of which are installed in the vertical stabilizer, the marking is made on the North-South line (see (c)), and for aircraft the flux detector units of which are installed in each wing tip, the markings are made each side of the North-South line at distances corresponding to those from the aircraft centre line.
  - (b) **Location of Monitor.** In addition to this marking, the bearing of the reference target used during the survey should also be marked at the monitor location.
  - (c) **North-South Line.** This line should be marked out from a point which is used as a reference in determining the flux detector unit location. The monitor is set up over this point, and by lowering the monitor telescope so that its gratitudes are observed against the base, several other points are marked out; firstly, with the monitor on a corrected zero degree heading and then on a heading of 180 degrees. The points are then joined by a painted line.
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**AL/10-5**

Issue 3.

14th May, 1976.

**AIRCRAFT****INSTRUMENTS****DIRECT-READING MAGNETIC COMPASSES**

**1 INTRODUCTION** This Leaflet gives general guidance on the installation of direct-reading magnetic compasses which are used as either primary or standby heading indicators, and also on the methods of compensating for deviation errors. It should be read in conjunction with Leaflet AL/10-4 Compass Base Surveying, relevant compass and aircraft Maintenance Manuals, and approved Maintenance Schedules. Reference should also be made to certain relevant information contained in Chapters D6-8 and K6-1 of British Civil Airworthiness Requirements and British Standard BS 3G.100 Part 2.

- 1.1 Deviation is the angular difference between magnetic and compass headings, and is caused by magnetic influences in or near the aircraft. It is called Easterly (positive deviation) or Westerly (negative deviation) dependent on whether the North-seeking end of the magnet system is deflected to the East or the West of the magnetic meridian.
- 1.2 The technique of deviation compensation is known as "swinging" and consists of (a) observing the compass readings on different headings of the aircraft, (b) calculating the deviation errors and determining coefficients, (c) neutralizing the magnetic fields of the aircraft by adjustment of permanent-magnet compensator devices and (d) recording any residual deviations on a deviation or "steer by" card.

**NOTE:** This Leaflet describes one of the methods used for swinging, calculating deviations and applying corrections. There are other procedures in use which adopt different calculation sequences.

**2 COMPASS ERRORS AND METHODS OF COMPENSATION** In connection with the compensation of direct-reading compasses, the following principal errors have to be taken into account:—

- (a) **Index Error.** This error, which is also known as Coefficient "A" error, results from malalignment of a compass in its mounting and has the same magnitude on all headings. The error is calculated by averaging the algebraic sum of the deviations on each of the cardinal and quadrantal headings. Compensation is effected by rotating the compass in its mounting through the number of degrees calculated, and relative to the longitudinal axis of the aircraft.
- (b) **One-cycle Errors.** These refer to the deviations produced in compass readings as a result of the effects of components of permanent or hard-iron magnetism of the aircraft's structure. The deviations vary as sine or cosine functions of the aircraft's heading, the maximum deviations being termed Coefficients "B" and "C" respectively. Other sources of these errors are components of soft-iron magnetism induced by the earth's field, the hard iron itself, and the effects of electric currents from cables or equipment which may be mounted in the vicinity of the compass. The Coefficient "B" error is calculated by averaging the algebraic difference of the deviations on the East and West headings, while the Coefficient "C" error is calculated by averaging the algebraic difference of deviations on the North and South headings. Compensation is

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effected by a permanent magnet type compensator unit, which, depending on the type of compass, is either secured direct to the compass bowl or is mounted separately on the compass support bracket. The unit contains two pairs of magnets, the axes of which are so disposed that their fields neutralize the effects of the magnetic components producing "B" and "C" deviations. Each pair of magnets can be rotated by a shaft provided with either a screwdriver slot or a shaped end requiring the use of a key.

**3 TYPES OF COMPASS** Two types of direct-reading magnetic compass are in use, the card type and the grid-steering type. The major differences between the two are in the magnet system arrangement, the method of heading presentation, and the arrangement of the deviation compensator devices.

**3.1** Card type compasses, which are designed for mounting on an instrument panel or on a coaming panel, indicate magnetic headings by means of a graduated card affixed to the magnet system and registering against a lubber line in the front of the bowl. The deviation compensator device is usually secured directly to the compass bowl.

**3.2** Grid steering type compasses employ a needle and filament type magnet system which is referenced against a grid-ring located over the compass bowl. The grid-ring, which may be rotated and clamped in any position, has a graduated scale and two pairs of parallel grid wires in the form of an open T. Magnetic headings are indicated by the number of degrees read against a lubber line in the compass bowl, when the needle and filaments lie parallel to the grid wires, and the North-seeking filament points to the North mark on the grid ring. These compasses may be designed for mounting on a bracket below an instrument panel or for inverted mounting in a cockpit roof. In the latter case, heading indications are observed by means of a mirror attachment. Deviation compensator devices are normally separate and are mounted on the compass supporting bracket.

**4 LOCATION** The location of a compass in an aircraft is important and factors such as angle of observation, illumination, vibration, and in particular, the effect of magnetic disturbances, require careful consideration. The location is determined during the aircraft's design stage and should not be altered unless authorized by the Airworthiness Authority.

**4.1** Compensation may be made for a reasonable amount of permanent magnetism, but variable sources of deviation must be kept distant in order to minimize their effects.

**4.1.1** Where practicable, magnetic steel parts, especially movable parts, should not be positioned near the compass.

**4.1.2** Electrical cables carrying uni-directional current produce a magnetic effect on the compass magnet system which is governed by the current and distance from the compass. All such cables should be positioned, if possible, at least 2 feet away from the compass. If double pole cables are used (i.e. supply and return cables run closely together) the magnetic effects of the cables are usually insignificant.

**4.1.3** To minimize the effect on the compass of items of equipment with magnetic fields, such items should not be located closer to the compass than the relevant compass safe distance specified for each item by the manufacturer.

**NOTE:** Compass safe distance is defined as the minimum distance from a compass at which an item of equipment may be located to produce a maximum deviation of 1° under all operating conditions. This distance is measured from the pivot of the compass magnet system to the nearest point on the surface of the equipment.

4.1.4 The possibility of magnetic fields generated by electric currents passing through windscreen pillars and frames, or through instrument mountings, should not be overlooked.

4.1.5 The effect of modifications to instrument installations, radio installations, electrical control panels or wiring in the vicinity of the compass must be considered, and tests should be made to determine whether any deviation will be caused under operating conditions.

NOTE: The most adverse combinations of electrical loads must not cause deviation in excess of 2° (5° for light aircraft).

4.1.6 In some instances, particularly in light aircraft, certain components and parts of the structure, e.g. control columns, control arches, tubular frames, may exhibit residual magnetism in varying amounts which cannot be corrected by compass deviation compensating devices. The origin and cause of such magnetism must be investigated and the appropriate remedial action must be taken. A simple practical detection method is to position a small pocket compass near suspect components or parts and to note any deflections of the needle.

5 INSPECTION AND TESTS BEFORE INSTALLATION Compasses are particularly susceptible to damage in transit and to deterioration during storage. They should be stored in the transit boxes supplied by the manufacturer, and should be handled carefully to avoid shocks which might impair the pivot action or cause other damage. Compasses should not be stored on steel racks or shelves, or in steel cupboards. Each compass should be inspected for serviceability before installation as follows:—

- (a) The compass glass, anti-vibration devices and all movable or working parts, where appropriate, should be inspected for condition.
- (b) In grid steering compasses, the grid-ring locking device should function correctly and the grid-ring should rotate freely when unlocked. The grid wires should be undamaged and the graduations should be legible.
- (c) The compass bowl must be free from dents, and the card and liquid must not be discoloured.
- (d) The liquid must be free from sediment and bubbles. There should be no sign of leakage from the bowl as indicated, for example, by staining of the bowl exterior.
- (e) In compasses in which the deviation compensator devices are built in, the magnet adjusting screws or spindles should be slowly rotated through their full range of movement to check for roughness, "hard spots" and backlash in the gearing. There should be sufficient inherent friction to prevent disturbance of compensator settings by shock or vibration. On completion of these checks, the compensators should be returned to their magnetic neutral positions as indicated by the alignment of indicator lines or dots engraved on the spindles with their fixed datum marks.
- (f) Compasses with integral lighting should be tested to ensure that no deflection of the magnet system is caused when the lighting is switched on.

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- 5.1 **Pivot Friction\***. This should be checked with the compass in a level position. The magnet system should be deflected through approximately  $10^\circ$  and held for 30 seconds by placing magnetic material near the compass. The magnetic material should then be removed and the settling position of the magnet system noted. The system should then be deflected approximately  $10^\circ$  in the opposite direction, held there for 30 seconds, then released and the settling point noted. The angular difference between the two settling positions should not exceed the limits specified in the relevant manuals. During this test no tapping of the compass bowl is permissible.
- 5.2 **Damping Test\***. The magnet system should be deflected with an external magnet through  $90^\circ$  and held for 1 minute. The deflecting force should be removed. The time taken for the magnet system to return through  $85^\circ$  should not exceed the limits specified in the relevant manuals.
- 5.3 **Defect Rectification**. The rectification of defects, such as might be revealed by the inspections and tests referred to in this paragraph 5 may only be undertaken by an organisation approved by the CAA for such work.

**6** **INSTALLATION** The compass should be so mounted that a line passing through the lubber line and the vertical pivot support is either on, or parallel to, the longitudinal axis of the aircraft. The lubber line in grid steering type compasses should always point forward. With card type compasses the lubber line faces aft. Compasses provided with adjustment slots and scale for index error (coefficient "A") correction, should be positioned so that the centre zero mark on the scale is aligned with the datum mark on the compass mounting.

- 6.1 When not integral, the compass deviation compensator device should be mounted as close as possible to the compass, and should be centrally disposed about the magnet system pivot support with the AFT engraving positioned aft.
- 6.2 Brackets, or other forms of compass supporting structure, should be made of non-magnetic materials; this also applies to all nuts, screws, washers and the tools used for mounting.  
  
NOTE: In aircraft employing a direct-reading compass as a standby heading indicator, the instrument is usually installed adjacent to the central support frame of the windscreen panels. In such cases the retaining nuts and bolts used in this frame should also be of non-magnetic material.
- 6.3 The compass deviation or "steer by" card should be positioned so that it may be easily read during flight.
- 6.4 If the compass has an integral lighting system the wiring should be properly connected to the appropriate terminals. The lighting circuit should then be switched on and a check made to ensure that this does not cause a deflection of the magnetic system.

**7** **COMPASS SWINGING AREA** Since the compass swinging procedure determines deviations caused by magnetic fields of an aircraft, it is necessary for the swinging to be undertaken at a location where only these fields and the earth's magnetic field can affect the compass readings. The location must, therefore, be carefully chosen and surveyed to prove that it is free from any interfering local magnetic fields (see Leaflet AL/10-4 Compass Base Surveying).

\*These paragraphs deal only with pre-installational checks on compasses which have passed their schedule of tests. The tolerances given are general and vary in accordance with the type of compass, the compass specification, the latitude at which the test is made, temperature variation and the strength of the earth's magnetic field.

**8 PREPARATION BEFORE SWINGING** A check should be made to see that all airborne equipment is installed in the aircraft. Loose items or tools made from magnetic materials should not be left in the aircraft or carried by the personnel engaged in the swinging procedure. Any detachable cockpit mechanical control locks which might be magnetic should be removed and placed in their flight stowages. Where towing arms and towing vehicles are to be used for manoeuvring the aircraft, their possible magnetic effect should be investigated, and if significant they should be disconnected and moved clear before taking any compass readings.

- 8.1 Ensure that all equipment required for the swing is available, e.g. appropriate datum compass, sighting equipment and non-magnetic tools needed for deviation compensations.
- 8.2 Where appropriate, landing gear ground locks should be in position and landing gear shock struts should be checked to ensure that they are properly inflated. In some types of aircraft, a landing gear lever latch is employed which is solenoid-operated. The solenoid is normally energized in flight, and since its magnetic field may have an effect on the accuracy of the standby direct-reading compass, it should also be energized during the swinging procedure.
- 8.3 The flying controls should be in the normal straight and level flight positions when taking the readings, and should then be operated to ascertain that the movements have no adverse effect on the compass readings. Flaps, throttles, etc., should also be set to their "in flight" positions.
- 8.4 Electrical equipment, e.g. radio, instruments and pitot tube heaters, should be switched on to ascertain that there are no adverse effects on the compass. In this connection, reference should always be made to the relevant aircraft manuals for details of the electrical loads to be selected appropriate to the aircraft operating conditions, e.g. normal day or night operation, or operation with emergency power.
- 8.5 Deviation compensator devices should be set to their magnetic neutral positions after installation, or after replacement of a compass or deviation compensator device where this is a separate unit.

**9 COMPASS SWINGING PROCEDURE** Where compasses are to be compensated on a base with marked headings, the longitudinal axis of the aircraft must be aligned either on, or parallel to, the markings, usually with the aid of plumb lines dropped from points fore and aft along the axis. A datum compass such as the medium landing compass may also be used, whether or not a concrete or tarmac base is available. The datum compass should be aligned with the aircraft's longitudinal axis and positioned on the datum circle, or if this is not marked, at a specified distance from the aircraft (typical distances are 50 to 150 feet). In order that the longitudinal axis of the aircraft may be accurately determined, datum points on the aircraft and directions from which they are to be sighted, must be carefully selected (see also Leaflet **AL/10-6**). Some aircraft have provision for the fitment of sighting rods to aid determination of the longitudinal axis. The most straightforward direction for sighting is from the rear; the heading then corresponds to the datum compass reading. If the view from this aspect is unsatisfactory the view from ahead of the aircraft should be considered, bearing in mind that reciprocal headings will be indicated. It is not advisable to take sights from positions at angles to the longitudinal axis.

**NOTE:** When using a datum compass to position an aircraft, it is not necessary for the aircraft to be set exactly on the cardinal and quadrantal points; settings within 5° are acceptable.

- 9.1 Compasses installed in aircraft with fuselage-mounted engines should be compensated with engines running. If this is not practical then they should at least be re-checked on four equally spaced headings with the engines running, on completion of the swinging procedure.

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9.2 **Compensating and Recording.** When taking compass readings a brief pause should be allowed after placing the aircraft on each heading and the compass should then be tapped gently while the magnet system is allowed to settle. A check should always be made on each heading to ensure that interference from each individual item of electrical equipment and its associated wiring, or the interference from the most adverse combination of the possible electrical load, has not been increased. For card type compasses, the readings are taken against the vertical lubber line. If the compass is of the grid steering type, the grid wires should be aligned parallel to the magnet system, North on North, and the reading against the lubber line should be observed. In both cases, observations should be such that parallax errors are avoided.

NOTE: When more than one direct-reading compass is fitted in an aircraft, or when a direct-reading compass serves as a standby to a remote-reading compass, all readings and subsequent adjustments should be made simultaneously on each heading.

9.2.1 All observed readings and associated deviation calculations obtained during swinging should be recorded on properly prepared record forms. The layout of forms varies for different compensation methods but, in general, their composition follows that associated with the method described in this Leaflet and as set out in Table 1.

9.2.2 The aircraft should first be headed N and the compass reading should be noted in column 2 of the Table, e.g. 006°. The deviation is the difference between the compass reading (column 2) and the magnetic heading indicated by the datum compass or compass base (column 1); the sign is plus or minus according to whether it is necessary to add the deviation to, or subtract it from, the compass reading in order to obtain the magnetic heading. In this example it is -6° and this should be recorded in column 3.

TABLE 1

Points	(1) Datum Compass or Base* Reading	(2) Aircraft Compass Cardinal Readings	(3) Deviation	(4) Devia- tions Corrected for C or B, as appli- cable	(5) Aircraft Compass Quad- rantal Readings	(6) Deviation	(7) All Devia- tions Corrected for A	(8) Finally Corrected Readings for Card
N	000	006	-6	-4	—	—	—	—
E	090	088	+2	+1	—	—	-2	002
S	180	182	-2	-4	—	—	+3	087
W	270	270	0	+1	—	—	-2	182
NW	315	—	—	—	—	—	+3	267
NE	045	—	—	—	317	-2	0	315
SE	135	—	—	—	048	-3	-1	046
SW	225	—	—	—	138	-3	-1	136
					227	-2	0	225

\*A compass base was used in this example.

$$C = \frac{\text{Deviation on N} - \text{Deviation on S}}{2} = \frac{(-6) - (-2)}{2} = \frac{-6 + 2}{2} = \frac{-4}{2} = -2^\circ$$

$$B = \frac{\text{Deviation on E} - \text{Deviation on W}}{2} = \frac{(+2) - (-0)}{2} = \frac{+2}{2} = +1^\circ$$

$$A = \frac{\text{The sum of the Deviations on N E S W NW NE SE SW}}{8} = \frac{-4 + 1 - 4 + 1 - 2 - 3 - 3 - 2}{8} = \frac{-18 + 2}{8} = \frac{-16}{8} = -2^\circ$$

- 9.2.3 The compass reading on E should next be checked, and the deviation obtained and recorded, e.g.  $088^\circ$  and  $+2^\circ$ .
- 9.2.4 The aircraft should now be headed S and the compass reading and deviation also recorded, e.g.  $182^\circ$  and  $-2^\circ$ . Coefficient "C" should be calculated algebraically from the formula shown in the Table; thus, from the example readings, "C" is  $-2^\circ$ . This should be applied, with its sign unchanged, to the deviation noted on S and the result recorded in column 4, i.e.  $-4^\circ$ . The sign of the coefficient should then be changed and applied to the deviation on N, the result being  $-4^\circ$ , which should also be recorded in column 4. The appropriate adjusting spindle of the compensator device should be rotated until the compass indicates the corrected reading, i.e.  $184^\circ$ . The compass should be tapped gently whilst making the adjustment.
- 9.2.5 The compass reading on W should be checked next, and the deviation recorded, e.g.  $270^\circ$  and  $0^\circ$ . Coefficient "B" should be calculated algebraically from the formula shown in the table; thus, from the example readings, "B" is  $+1^\circ$ . This should be applied, with its sign unchanged, to the deviation noted on W and the result recorded in column 4, i.e.  $+1^\circ$ . The sign of the coefficient should then be changed and applied to the deviation on E, the result being  $+1^\circ$ , which should also be recorded in column 4. The appropriate adjusting spindle of the deviation compensator device should be rotated until the compass indicates the corrected reading, in this case  $269^\circ$ . The compass should be tapped gently whilst making this adjustment. This completes the compensation of deviation on the cardinal headings.
- 9.2.6 The aircraft should again be headed on each cardinal heading and any residual deviations noted. A check should then be made on the compass reading, and deviation, at each quadrantal heading and these should be recorded in column 5 and column 6 respectively.
- 9.2.7 Coefficient "A" should be calculated from the formula shown in the table (after correction for coefficients "C" and "B"). It will be noted from the example readings that coefficient "A" is  $-2^\circ$ . Corrections should be made by adding this coefficient (sign unchanged) to the compass reading on any aircraft heading, and by adjusting the mounting position of the compass (e.g. rotating it about bolts in slotted mounting lugs) through the appropriate number of degrees until the lubber line is aligned with the corrected heading.
- 9.2.8 After correction for coefficient "A", residual deviations should be calculated in order to obtain corrected readings for entry on the deviation card (column 8). The deviations, which should not exceed  $3^\circ$  ( $5^\circ$  for light aircraft) on any heading, are calculated by subtracting coefficient "A" from the deviations noted in columns 4 and 6, recording the values as in column 7, and then finally subtracting these values from the datum compass or base readings (column 1).
- 9.3 **Deviation Card.** A deviation or "steer by" card (see Figure 1) should be compiled to show deviations related to standard headings at intervals of  $45^\circ$  ( $30^\circ$  for light aircraft) and should be secured in a position adjacent to the respective compass. The card readings are those which the compass must indicate in order that the aircraft may be flown on correct magnetic headings, e.g. in order to fly on a magnetic heading 000 (North) the compass must indicate  $002^\circ$ . In cases where radio equipment is installed in instrument panels, it should also be stated whether the compass was swung with the equipment switched on or off. Details should be given on the back of the card to indicate aircraft type and registration, compass type and serial number, place and date of swing, signature and authority of the compiler. A record of the swing should be entered and certified in the aircraft log book.

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For Magnetic Heading		Steer by Compass
N	000°	002°
NE	045°	046°
E	090°	087°
SE	135°	136°
S	180°	182°
SW	225°	225°
W	270°	267°
NW	315°	315°

Figure 1 TYPICAL DEVIATION CARD

**10** COMPASS SWINGING IN SERVICE Swinging and compensation as detailed in paragraph 9 must be carried out whenever a direct-reading compass or separate deviation compensator device, if appropriate, is installed. On other occasions a check-swing is sufficient. A check-swing consists of placing the aircraft on four headings 90° apart, and comparing the deviations with those on the existing deviation card. If there is any difference between these deviations it will be necessary to carry out a complete swing. Compasses should be check-swung on the following occasions:—

- (a) After a check inspection if required by the approved Maintenance Schedule.
- (b) Whenever inaccuracies in heading indications are reported.
- (c) After any modification, repair or major replacement involving magnetic material, particularly in aircraft the engines of which are mounted in the fuselage or wing nacelles.
- (d) Whenever a compass has been subjected to shock, e.g. after a heavy landing.
- (e) After the aircraft has passed through a severe electrical storm, or has been struck by lightning.
- (f) Whenever the aircraft has been subjected to a magnetic crack detection examination.
- (g) Whenever the sphere of operation of the aircraft is changed to one of different magnetic latitude.
- (h) Whenever a significant change is made to the electrical or radio installation, particularly to circuits in the vicinity of the compass.
- (j) Whenever a freight load is likely to cause magnetic influence and thereby affect compass readings.
- (k) After the aircraft has been in long term storage.

- II . ROUTINE INSPECTION The security of the mounting of each compass and deviation compensator device should be checked, and any adjustment or tightening should only be done by an organization approved by the CAA for such work or by an engineer licensed in the appropriate category. The compass should be inspected for bubbles in the liquid, discoloration, sediment, clarity of scale, liquid leakage, cracked glass and the effectiveness of the anti-vibration mounting where fitted. In compasses of the grid steering type, the functioning of the grid ring locking device should also be checked, and when in the unlocked position it should permit complete rotational freedom of the grid ring. The deviation card must be legible and secure in its holder.
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**AL/10-6**

Issue 1.

14th May, 1976.

**AIRCRAFT****INSTRUMENTS****REMOTE-READING COMPASSES**

**1 INTRODUCTION** This Leaflet gives general guidance on the methods of compensating for deviation errors which can occur in remote-reading compasses. Brief details of the operating principle of compasses are also included, but as there are so many variations in application to systems in current use, such details are only of a fundamental nature. The Leaflet should be read in conjunction with Leaflet AL/10-4—Compass Base Surveying, relevant compass and aircraft Maintenance Manuals, and approved Maintenance Schedules. Certain relevant information is contained in Chapters D6-8 and K6-1 of British Civil Airworthiness Requirements and British Standard BS 3G.100 Part 2; reference should, therefore, be made to these publications.

1.1 Deviation is the angular difference between magnetic and compass headings and is caused by magnetic influences in or near the aircraft. It is called Easterly (positive deviation) or Westerly (negative deviation) dependent on whether the signals induced in the compass flux detector unit on any one heading are influenced to produce a change in heading indication to the East, or to the West of the magnetic meridian.

1.2 The technique of deviation compensation is known as "swinging" and consists of, (a) observing the relevant compass system indicator readings on different headings of the aircraft, (b) calculating the deviation errors and determining coefficients, (c) neutralizing the aircraft's magnetic fields by adjustment of compensator devices and (d) recording any residual deviations.

**2 PRINCIPLE OF REMOTE-READING COMPASS SYSTEMS** The principal component of any system is a flux detector unit, sometimes called a flux valve or fluxgate. It is located in an area relatively free from any disturbing magnetic fields of the aircraft itself (e.g. a wing tip or vertical stabilizer) so that the horizontal component of the earth's magnetic field can be more accurately detected by the sensing element within the unit. The sensing element forms part of a synchro type of transmission system which, in most compasses, is coupled to a horizontal-axis directional gyro contained within either a heading display indicator mounted on the main instrument panel, or a master gyro unit from which heading data is transmitted to a separate indicator. In some aircraft using an inertial navigation system, the flux detector sensing element is connected to a compass coupler unit instead of a directional gyro, the purpose of the unit being to develop a stabilized magnetic heading reference from both sensing element and inertial navigation system signals. The sensing element is pendulously suspended in such a way that it has a limited amount of freedom in the pitching and rolling planes, but has no freedom in the yawing plane. In one currently used system the element is stabilized by a vertical gyro.

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2.1 The sensing element is made up of material having high magnetic permeability wound with an exciter or primary coil and three pick-off or secondary coils. The exciter coil is supplied with a low-voltage single-phase a.c. at a constant frequency (typical values are 26 V, 400 Hz) and this produces an alternating flux in the sensing element material. In addition to this flux, the horizontal component of the earth's magnetic field is also introduced; its effect being to change the total flux cutting the pick-off coils in such a manner that an e.m.f. is induced in them which, in terms of amplitude and phase, represents the magnetic heading.

2.1.1 The induced e.m.f. causes current to flow to the stator windings of a receiver synchro within either the display indicator, master gyro unit or compass coupler, as appropriate, and a field is set up across the stator in a direction determined by the current flow in the windings. If the detector sensing element and receiver synchro are in synchronism, the synchro rotor is in its 'null' position and no signal voltage is induced in its winding by the stator field cutting it. When a change in aircraft heading takes place, however, the position of the detector sensing element with respect to the earth's field also changes with the result that the current flow in the receiver synchro stator changes, causing the stator field to rotate. This, in effect, is the same as a rotor displacement from the 'null' position, and although the rotor itself always tends to rotate with the stator field it is restrained momentarily by the mechanical coupling between it and the gyro. Thus, an error voltage is induced in the rotor winding; the phase and amplitude of which being dependent on the direction and magnitude of displacement of the rotor from the 'null' position. The voltage is fed to an amplifier and finally to a slaving system which produces a torque to precess the gyro and its indicating element to indicate the heading change. At the same time, the synchro rotor rotates in synchronism with the stator field.

### 3 COMPASS ERRORS AND METHODS OF COMPENSATION In connection with the swinging and compensation of remote-reading compasses, the following principal errors have to be taken into account:—

- (a) **Index Error.** This error, which is also known as Coefficient "A" error, results from malalignment of the flux detector unit and has the same magnitude on all headings. The error is calculated by averaging the algebraic sum of the deviations on each of the cardinal and quadrantal headings.
- (b) **One-cycle Errors.** These refer to the deviations produced in compass readings as a result of the effects of components of permanent or hard-iron magnetism of the aircraft's structure. The deviations vary as sine or cosine functions of the aircraft's heading, the maximum deviations being termed Coefficients "B" and "C" respectively. Other sources of these errors are, components of soft-iron magnetism induced by the earth's field, the hard iron itself, and electric currents from cables or equipment which may be mounted in the vicinity of the flux detector unit. The error due to Coefficient "B" is calculated by averaging the algebraic difference of the deviations on the East and West headings, while the Coefficient "C" error is calculated by averaging the algebraic difference of deviations on the North and South headings.
- (c) **Two-cycle Errors.** These errors result from imperfections in the transmission of heading data and are usually referred to as transmission errors. They can be caused by impedance or voltage unbalance in the flux detector sensing element or in the synchros of the compass system. Another source of two-cycle error is soft-iron magnetism.

- (d) **Crosstalk Errors.** These errors occur particularly during an "electrical" swinging procedure (see paragraph 4.5) when the d.c. signals simulating the earth's field are applied. They are caused by different sensitivities of the flux detector unit coils and by unequal air gaps separating the flux collector horns; the overall effect being to produce quadrature components which offset the field from that originally intended.

3.1 **Methods of Compensation.** Typical methods of compensating errors are described in the following paragraphs.

3.1.1 **Index Error Compensation.** The error to be compensated is calculated from the Coefficient "A" formula (see 3(a)). In the most commonly used method, compensation is effected by rotating the flux detector unit in its mounting through the number of degrees so calculated, relative to a datum parallel to the longitudinal axis of the aircraft. The flux detector unit is rotated clockwise (when viewed from above) for a +A error and anti-clockwise for a -A error. In some compass systems the flux detector is first aligned with the centreline of the aircraft, and the "A" error is removed by providing an electrical differential by means of a differential synchro between the flux detector unit and its synchro.

3.1.2 **One-cycle Error Compensation.** The errors to be compensated are calculated from the Coefficient "B" and Coefficient "C" formulae (see 3(b)). Depending on the type of compass system installed, compensation may be effected by one of the methods described in (a) and (b).

(a) **Mechanical Methods.** In several types of compass systems, a permanent magnet type compensator unit is secured to the top of the flux detector unit. The compensator contains two pairs of magnets, the axes of which are so disposed that their fields neutralize the effects of the magnetic components producing "B" and "C" deviations. Each pair of magnets can be rotated by a shaft containing a screw-driver slot, and associated gearing. In one particular type of compass system, mechanical compensation is effected by screws, a metal cam and cam follower; the complete device being incorporated within the compass indicator. For details of this method of compensation reference should be made to the relevant Maintenance Manuals.

(b) **Electrical Methods.** Electrical compensation is normally effected by a compensator unit connected to, and located remote from, the flux detector unit. A compensator unit contains two adjustable potentiometers, one for each coefficient. Depending on the compass system installed, the potentiometers can be adjusted to vary either the electromagnetic fields produced in two coils mounted on top of the detector unit, or they can be adjusted to produce the correcting electromagnetic field within the flux detector pick-off coils, by supplying direct current to the coils themselves. In this latter case, the coils have the dual and simultaneous function of picking-off voltages resulting from heading changes and of deviation compensation. In certain types of compensator unit, test points are provided to permit measurement of the d.c. voltages across the two potentiometers.

3.1.3 **Crosstalk Error Compensation.** Compensation is effected during an "electrical" swing procedure, by applying d.c. signals to the flux detector unit coils and generating fields which oppose the quadrature components in the North-South and East-West directions.

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**4 COMPASS SWINGING PROCEDURES** The procedure to be adopted depends primarily on the type of compass and the method by which magnetic heading reference datum is obtained, i.e. from a base having headings marked out on it, from a datum compass, or from a base established for carrying out "electrical" swinging as outlined in paragraph 4.5. Details of the procedure appropriate to a specific system and aircraft type are given in the Maintenance Manuals, and reference must, therefore, always be made to such documents. The information given in the following paragraphs is intended to serve only as a general guide to procedures and to certain associated important aspects.

**4.1 Compass Swinging Area.** Since the swinging procedure determines deviations caused by the magnetic fields of an aircraft, it is necessary for it to be undertaken at a location where only these fields and the earth's magnetic field can affect the compass readings. The location must, therefore, be carefully chosen and surveyed to prove that it is free from any interfering local magnetic fields (see Leaflet AL/10-4—Compass Base Surveying).

**4.2 Aircraft Sighting Points.** In all swinging procedures it is necessary to determine the position of the longitudinal axis of the aircraft with respect to a magnetic heading reference datum, and for this reason, two datum points on the aircraft (e.g. the aircraft nose and tip of the vertical stabilizer) and directions from which they are to be sighted, must be carefully selected. If the datum points are at different heights above the ground, and if the aircraft is rolled out of a level plane as a result of the compass base not being level, then an error can occur in the measured datum heading. Roll angles are normally small and the error approximates to:—

$$\text{Heading Error} \dots \frac{\text{degree}}{\text{degree of roll}} \dots \text{is } \frac{\text{Vertical distance between two points}}{\text{Horizontal distance between two points}}$$

In several types of large transport aircraft, sighting is facilitated by the provision of sighting devices which are attached to the aircraft prior to carrying out the appropriate swinging procedure. Some examples are described in the following paragraphs.

**4.2.1 Sighting Rods.** In this example, front and rear sighting rods are attached to corresponding points provided along the centre line at the underside of the fuselage. An extension rod is also provided for attachment to either the rear sighting rod, if datum compass sightings are to be taken from the front of the aircraft, or the front sighting rod, if sightings are to be taken from the rear.

#### **4.2.2 Telescopic Target Fixture**

(a) A typical fixture is shown in Figure 1. It is attached to the bulkhead of a main landing gear wheel well so that the scale and crosshair are on the inside of the turning circle of the aircraft. The setting of the fixture with respect to the longitudinal axis of the aircraft, is determined by sighting the telescope on a target mark located at the underside of the front fuselage, in this case at the forward jack pad position. The scale is of the centre-zero type, angles to the right being positive and angles to the left being negative, when sighted from the datum compass. Magnetic heading of the aircraft is determined during the swinging procedure by sighting the datum compass on the crosshair and scale of the target fixture, and calculating the difference between the scale reading and the datum compass reading, the latter being the bearing of a pre-selected reference target located at some distance from the base.

(b) Another example of a target fixture is shown in Figure 2. In this case the fixture is attached to the underside of the front fuselage, and its telescope is sighted on a target ball mounted on a cable, the ends of which are secured to the up-lock rollers of each main landing gear strut. When the cable is in position, the ball is situated to the left of the aircraft centreline. Magnetic heading of the aircraft is determined in a similar manner to that described in (a).

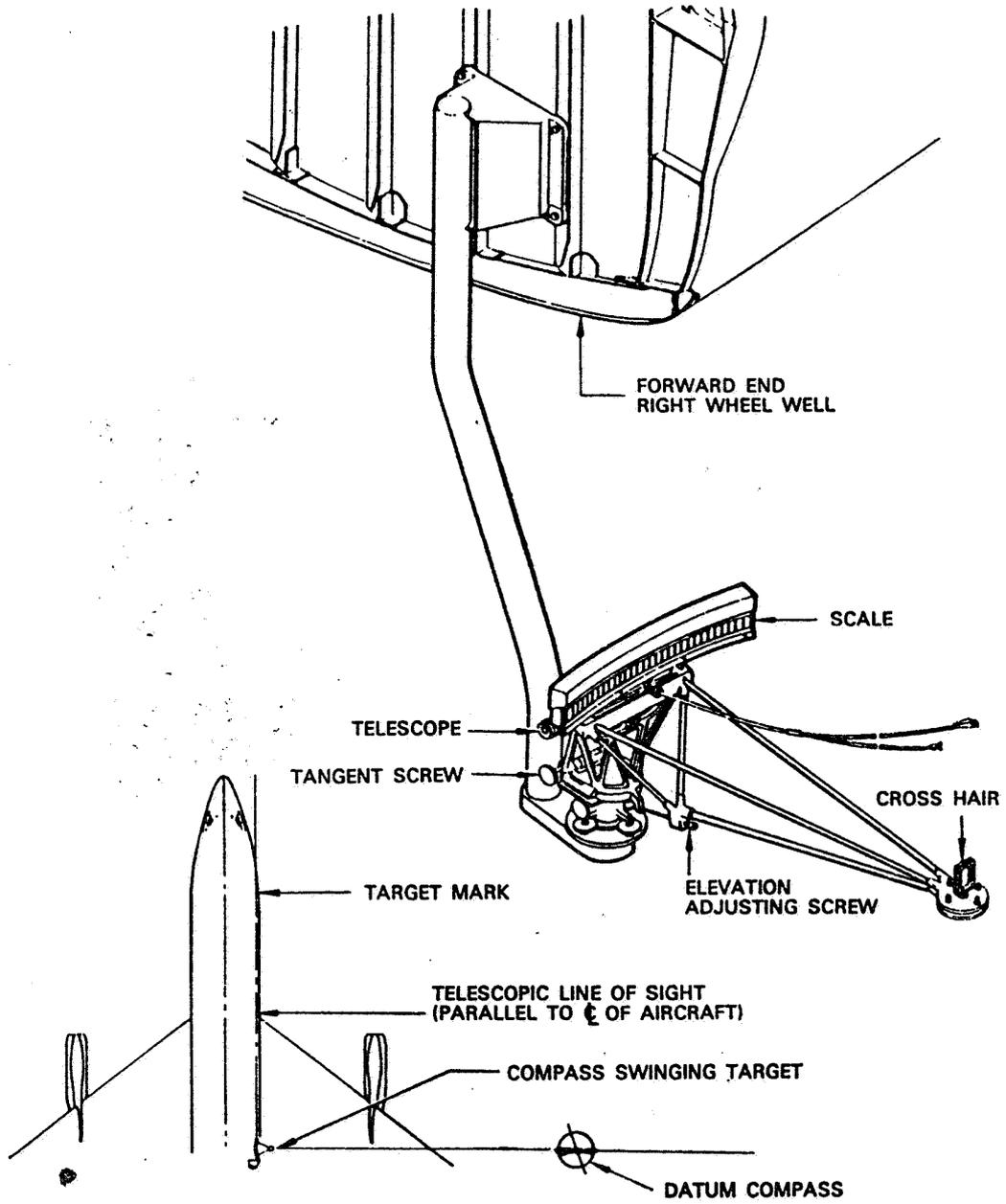


Figure 1 TELESCOPIC TARGET FIXTURE

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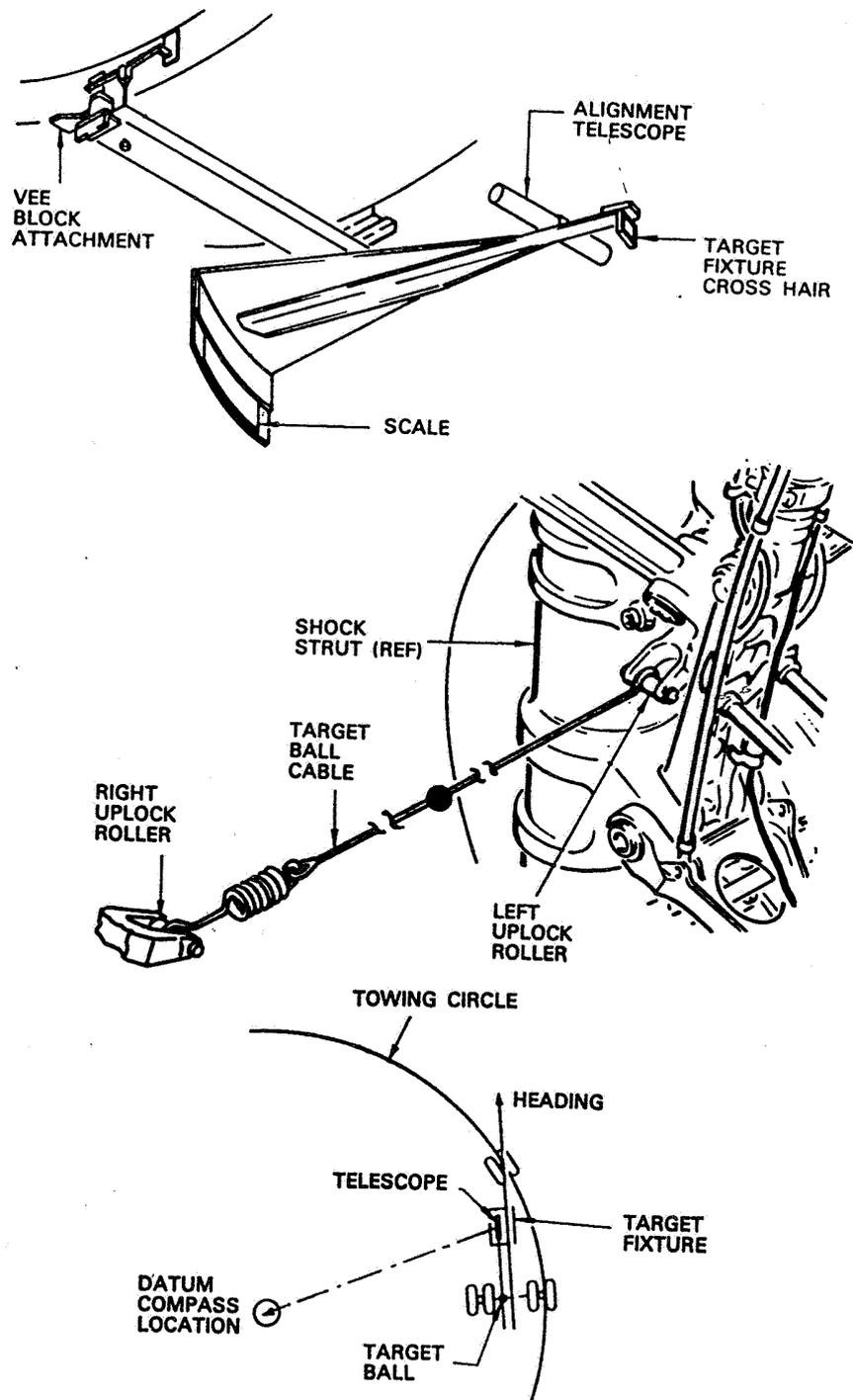


Figure 2 TARGET FIXTURE AND BALL

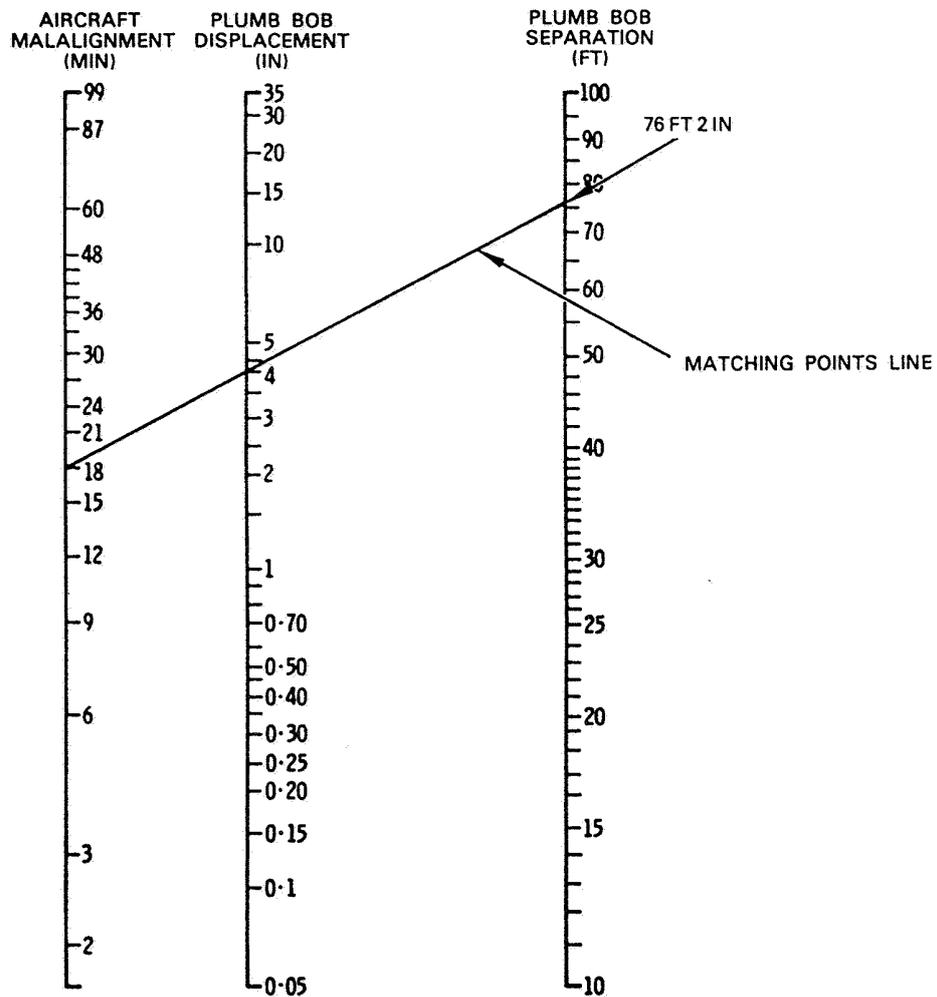


Figure 3 AIRCRAFT MALALIGNMENT NOMOGRAPH

4.2.3 **Plumb Line Sighting.** In this method, the longitudinal axis of an aircraft is indicated by the alignment of two plumb bobs suspended individually from fore and aft points at the underside of the fuselage. The use of the plumb bobs as a means of sighting depends on the compass swinging procedure adopted. If a swing is carried out on a base on which cardinal and quadrantal heading lines are marked out, the aircraft heading is determined by the position of the plumb bobs with respect to the marked lines.

- (a) In the case of an "electrical" swinging procedure, the plumb bobs are used only for ensuring that the aircraft is aligned with the North-South line marked out on the base. Malalignment should not exceed a specified amount, usually 1 degree, and this is calculated from a nomograph comprising three scales corresponding to the separation between plumb bobs, to plumb bob displacement from the North-South line, and to aircraft malalignment. An example based on an aircraft in which the plumb bob suspension points are 76 ft. 2 in. apart is shown in Figure 3.

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- (i) When the aircraft is positioned over the North-South line, with its nose pointing North, the points where the plumb bobs come to rest are marked on the ground and the lateral displacement of each from the edge of the line is measured. If the displacement is West of the line it is negative, and if it is East it is positive. The algebraic difference between the two values is then obtained as a reference point on the plumb bob displacement scale, and aircraft malalignment is read off the appropriate scale at the point intersected by a line projected through the known points on the plumb bob separation and projection scales. Thus, in the example shown, the known points are 76 ft. 2 in. and 4 in., and a projected line intersects the malalignment scale at a value of 18 minutes. In the event that malalignment is greater than the maximum specified for the aircraft, the aircraft should be repositioned.

4.3 **Preparations Before Swinging.** The following aspects of preparation are generally applicable to all compass systems:—

- (a) Carry out a serviceability test of the system in accordance with the procedure prescribed in the relevant Maintenance Manual.

NOTE: Throughout the serviceability test and other preliminary checks, and also subsequent swinging procedures, it is most important that power supplies to systems be continually monitored to ensure that voltage and frequency values remain constant within their prescribed limits.

- (b) Ensure that all equipment required for the swing is available, e.g. appropriate datum compass, sighting equipment, test voltmeters and milliammeters, non-magnetic tools for adjustment of deviation compensators, and external power supply equipment.
- (c) Check that all normal equipment is installed in the aircraft. In this connection, reference should also be made to the relevant aircraft manuals for details of electrical equipment which could influence compass system readings and, for this reason, must be in operation during a swinging procedure.
- (d) Ensure that landing gear ground locks are in position and that relevant towing equipment is readily available.
- (e) Check that main landing gear shock struts are properly inflated.
- (f) Check that brake system pressure is normal for the appropriate type of aircraft.
- (g) Ensure that personnel responsible for carrying out the swinging procedure remove from their person all metallic objects which are likely to cause deviation.
- (h) Obtain appropriate clearance to tow the aircraft to the compass base.

4.4 **Conventional Swinging Procedure.** The term “conventional” is used here to signify a procedure in which the magnetic heading reference datum is obtained, either from a compass base with heading alignment marks painted on it, or from a datum compass. In the former case, and with the aid of plumb line sighting, an aircraft can be aligned precisely on the cardinal and quadrantal headings. When using a datum compass, such precise alignment is not essential since the compass is always positioned to sight on the aircraft. It is usual, therefore, for positioning of both aircraft and datum compass to be within certain permissible limits. Limits commonly specified are within the range  $\pm 3$  degrees to  $\pm 5$  degrees. A typical swinging sequence is outlined in the following paragraphs.

4.4.1 When the aircraft has been towed onto the base, the appropriate sighting equipment should be fitted (see paragraph 4.2) and the aircraft positioned so that it is heading North.

4.4.2 External power supply should be connected to the aircraft, and after the compass systems have been energized and their gyros allowed to run up to normal operating speed, carry out the preliminary checks specified in the appropriate Maintenance Manuals. The following checks are typical of those normally required for systems in current use:—

- (a) Synchronizing of heading indicators against annunciator devices to ensure that magnetic monitoring by flux detector units, has ceased before taking readings. In certain types of compass system this check is effected by plugging a centre-zero milliammeter into "monitoring current" sockets provided in a unit (e.g. an amplifier) of the system. If the gyro has no drift, monitoring has ceased when the meter oscillations are evenly balanced about the indicator "null" position within the tolerances specified for the particular system. In some cases, a monitoring meter forms part of a compass indicator, thereby obviating the need for a centre-zero milliammeter.
- (b) Slaving of compass system indicators and associated system indicators, e.g. radio magnetic indicators.
- (c) Check heading signals to auto-pilot and other associated navigational systems after selection of appropriate system switch positions.
- (d) Operational check of power failure warning and other indicating flags on all heading indicators.
- (e) Drift rate check of gyros.
- (f) Setting of deviation compensators to their neutral positions. This is normally only done during an initial swing procedure, and whenever a new flux detector unit or a deviation compensator is installed (see also paragraph 5). If a compensator is of the permanent magnet type, the slots of the adjustment screws should be aligned with datum marks on the compensator body. In the case of a potentiometric type compensator, the potentiometers should be adjusted until a "null" position, as indicated by a test meter plugged into the compensator, is obtained. If a new flux detector unit has been installed its index error scale should also be aligned at the zero datum.

NOTE: It is recommended that if no new components have been installed, compensators should remain at their previous settings so that with each subsequent adjustment procedure, some indication of how coefficients change with time can be obtained.

4.4.3 With the aircraft still heading North and compass indicators synchronized, the deviation, i.e. the difference between the indicated reading and the magnetic datum, should be calculated. The sign is plus or minus according to whether it is necessary to add deviations to, or subtract them from, the compass readings in order to obtain the magnetic heading.

NOTE: The procedures for swinging the compass systems of some types of aircraft, also require at this stage, the calculation and compensation of an initial four-point Coefficient "A" error. After noting the deviations on North, therefore, the aircraft is then positioned on the other cardinal headings and the average of the algebraic sum of the four deviations is determined.

4.4.4 Position the aircraft so that it is heading East and after allowing the compass indicators to synchronize, the deviation should be calculated and its sign determined as noted in paragraph 4.4.3.

4.4.5 Position the aircraft so that it is heading South and after calculating the deviation, determine the Coefficient "C" error by calculating the average of the algebraic difference between the deviations on the North and South headings. The sign of the coefficient should then be changed and added algebraically to the indicated readings

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to establish the corrected heading indications. The Coefficient "C" section of the appropriate deviation compensation devices (see also paragraph 3.1.2) should then be adjusted until, with the indicators synchronized, the corrected heading is indicated.

4.4.6 Position the aircraft so that it is heading West and, after calculating the deviation, determine the Coefficient "B" error by calculating the average of the algebraic difference between the deviations on the East and West headings. The corrected heading indications are established and applied in a similar manner to that described in paragraph 4.4.5, except that adjustments are made at the Coefficient "B" section of the appropriate compensation devices.

4.4.7 On completion of the Coefficient "B" correction, the aircraft should be positioned successively on the cardinal and quadrantal headings (starting at West) in order to calculate the Coefficient "A" error. The error is calculated by taking the average of the algebraic sum of the deviations on eight headings, and is corrected in the manner appropriate to the compass system installed (see also paragraph 3.1.1). After applying the Coefficient "A" correction, the compass indicator readings on the cardinal and quadrantal headings should again be noted and the residual deviations should be recorded.

NOTE: Where appropriate, the eight-point Coefficient "A" compensation is additional to that referred to in the Note to paragraph 4.4.3.

4.4.8 All observed readings and associated deviation calculations obtained during swinging should be recorded on properly prepared record forms, and a record of the swing should be entered and certified in the aircraft log book. A record should also be made of compensator settings. A deviation or "steer by" card should also be compiled from recorded residual deviations, to show the readings which a compass must indicate in order that the aircraft may be flown on correct magnetic headings. The deviations should be related to standard headings at intervals of 45 degrees; in some cases an interval of 30 degrees may be specified. Details should be given on the back of the card to indicate aircraft type and registration, compass type, place and date of swing, signature and authority of the compiler. On completion, the card should be displayed in the appropriate holder in the aircraft cockpit.

4.5 "Electrical" Swinging Procedure. An "electrical" swinging procedure is one in which the earth's magnetic field is simulated by electrical signals in such a way that it is unnecessary to rotate the aircraft onto the various headings as in the conventional forms of swinging. The aircraft is positioned heading North with its fore-and-aft axis coincident with a North-South line marked on the selected compass base, and with its flux detector units positioned over marked location datum points (see also paragraph 4.2.3 and Leaflet AL/10-4). The electrical signals are in the form of varying d.c. voltages, the values of which are determined during the appropriate compass base survey procedure (see Leaflet AL/10-4) and also during the swinging procedure. The signals are designated as  $E_1$  and  $E_2$  voltages, and are applied respectively to the A-leg pick-off coil, and the B-leg and C-leg pick-off coils of the flux detector sensing elements, by adjusting the controls of a console unit forming part of a special calibrator set which can be connected into the flux detector circuit. The electromagnetic fields produced by the  $E_1$  and  $E_2$  voltages, alter the effective magnitude and direction of the earth's field passing through the legs of the detector sensing element, resulting in a magnetic vector which rotates to various headings, thereby simulating rotation of the aircraft and detector unit relative to the earth's field. These simulated headings are compared with the actual headings indicated by the aircraft compass system to determine the deviation errors to be compensated.

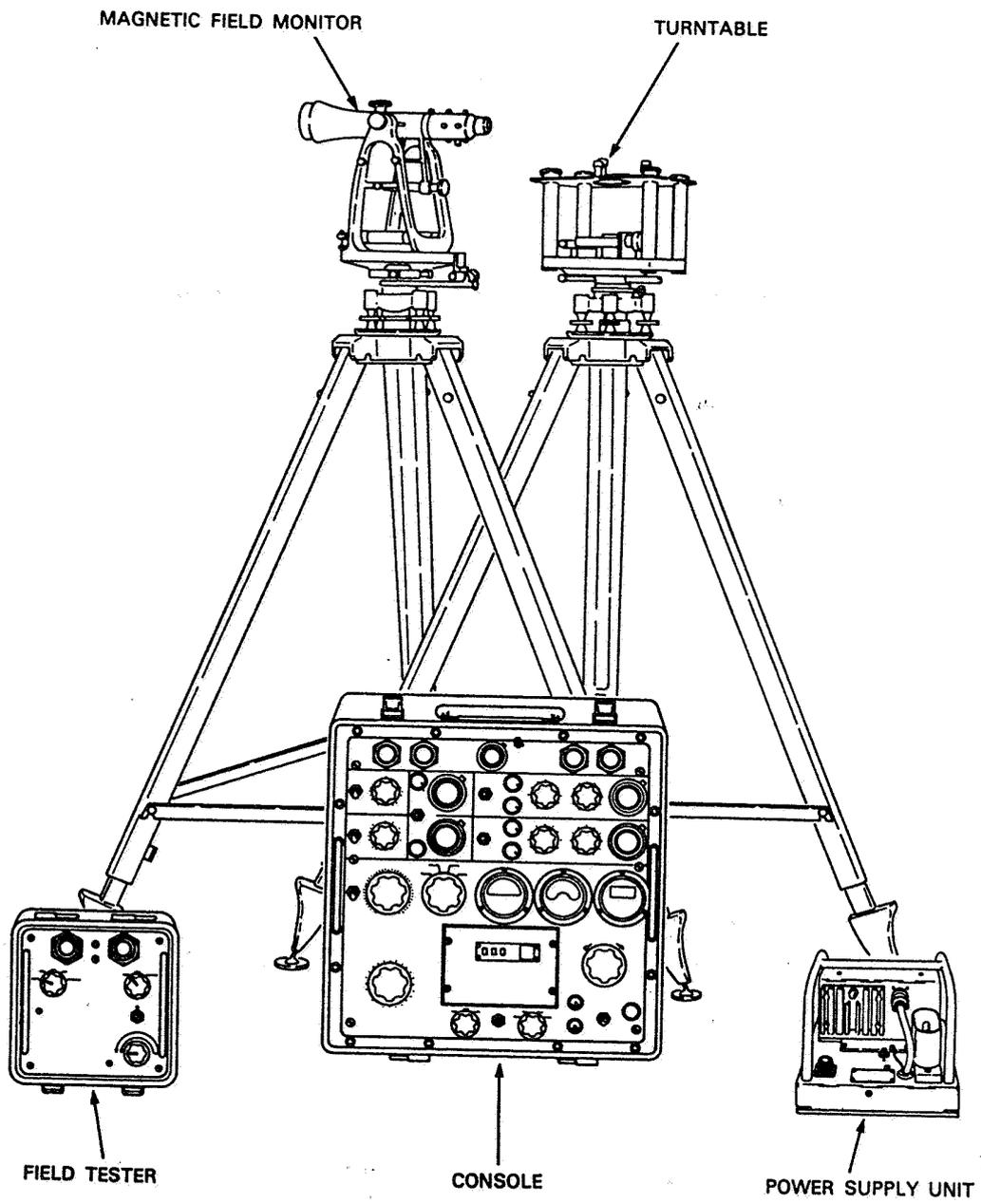


Figure 4 COMPASS CALIBRATOR SET

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**4.5.1 Compass Calibrator Set.** It is beyond the scope of this Leaflet to go into the complete details of the compass calibrator set and its use in the "electrical" swinging procedure, reference should, therefore, always be made to the relevant manufacturer's operation manual. The information given in the following paragraphs serves only as a general outline.

- (a) A compass calibrator set consists of the major components shown in Figures 4 and 5. The magnetic field monitor is a theodolite with a 22x telescope and a magnetic sensing element, and in conjunction with the console unit, it measures the strength, and determines the direction, of the horizontal component of the earth's field. It is used for the magnetic survey of areas required for swinging (see Leaflet AL/10-4) and also to monitor changes in magnetic conditions during a compass swing. The magnetic sensing element is similar to that employed in a remote indicating compass flux detector unit, except that it is non-pendulous.
- (b) The turntable is also a theodolite but without a telescope and magnetic sensing element. It is used for calibrating and aligning certain types of flux detector unit (see paragraph 4.5.2 (b)) with magnetic North, and for determining the index or Coefficient "A" error before installing a unit in the aircraft.
- (c) The console unit is the central control unit of the calibrator and contains all the switches, controls and indicators for programming the  $E_1$  and  $E_2$  voltage signals and for determining the errors in aircraft compass system indications to be compensated. The console also provides interconnection of the magnetic field monitor, turntable and power supply unit. The power supply unit is a solid-state inverter which converts a 28V d.c. input into a 115V 400 Hz a.c. output required to operate the calibrator.
- (d) The optical alignment unit (see Figure 5) consists of a fixed-focus 8x telescope and appropriate adjustment devices, and is used for aligning certain types of flux detector unit in an aircraft during its transfer from the turntable, thereby ensuring that the index error compensation is maintained (see paragraph 4.5.2 (e)).

**4.5.2 Swinging Procedure.** The procedure for carrying out an "electrical" swing depends primarily on whether a flux detector unit is of the pre-indexed type, or of the master type (pre-calibrated and pre-indexed). Basically, however, the procedure consists of the following sequence of operations:—

- (a) **Check on the Direction of Magnetic North.** This is done to determine whether there has been any shift from that obtained when the base survey was carried out. The check is carried out by sighting the calibrator monitor, from its location point on the base, on the pre-determined reference target, and then determining errors on the cardinal headings, and thus obtain an area compensation value for setting on the console control unit.
- (b) **Magnetic Alignment of Detector Unit.** The purpose of this operation is to check the Index or Coefficient "A" Error, and thereby the amount by which the detector unit is to be offset in its mounting with respect to magnetic North. If the detector units are of the pre-indexed type, the check is done with the unit mounted on the calibrator turntable at its location on the base, and before the aircraft is towed onto the compass base. In the case of master type detector units, the aircraft can be towed onto the base at the outset of the swing procedure, since the units, being pre-calibrated on the four cardinal headings for a specific compass system and aircraft installation, are already installed and the use of the turntable is thereby eliminated.

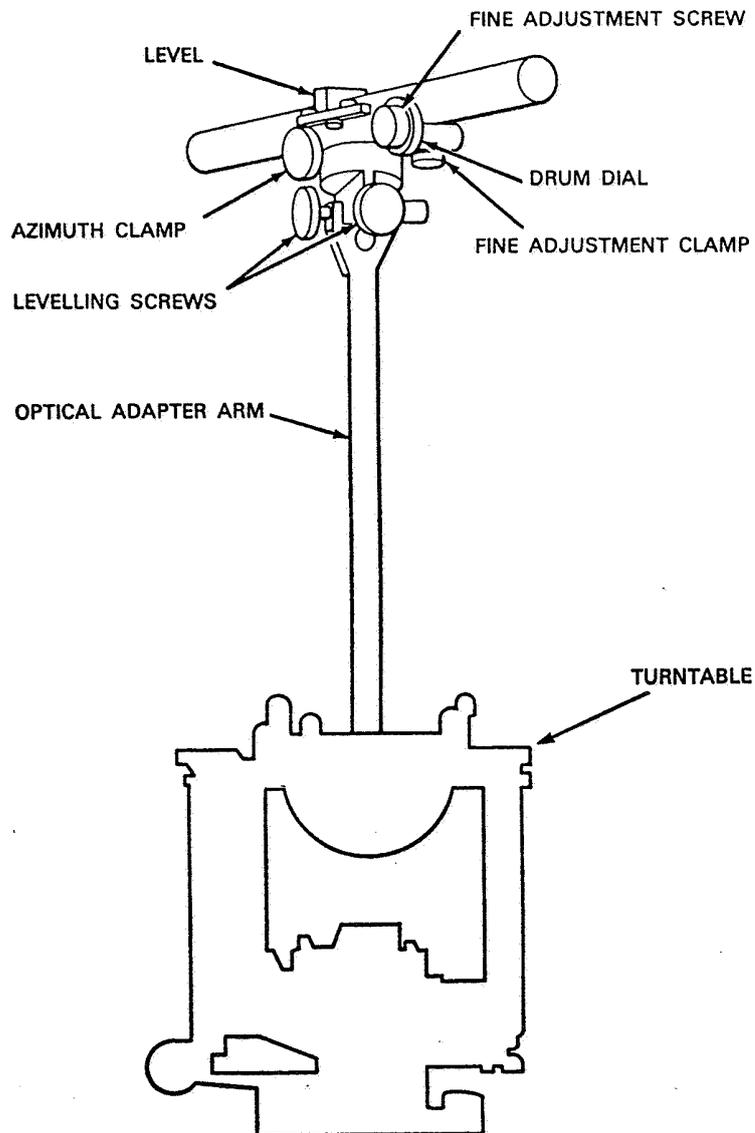


Figure 5 OPTICAL ALIGNMENT UNIT

- (c)  **$E_1$  and  $E_2$  Voltages Check.** The purpose of this check is to determine the voltages required to simulate the earth's field effects which would be obtained if the aircraft and its detector units were rotated onto various headings. The check also determines the adjustments which are necessary to compensate for one-cycle errors, i.e. Coefficients "B" and "C", during the compass swing operation. The check applies to both pre-indexed and master type flux detector units, except that in the former case, voltage values are obtained by selecting headings on the calibrator turntable, while for master units selections are made on the calibrator monitor.

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- (d) **Determination of Crosstalk Errors.** These errors (see paragraph 3 (d)) are measured at headings of 90, 180 and 270 degrees. Crosstalk error does not occur at 0 degrees since no voltages are applied to the flux detector unit to simulate this heading.
- (e) **Optical Transfer of Flux Detector Unit.** This operation is applicable only to flux detector units which have not been pre-indexed or pre-calibrated. It is carried out by means of the calibrator optical alignment unit, and is necessary in order to ensure that a detector unit will be installed in the same position with respect to magnetic North, as that determined by the calibrator turntable magnetic alignment check. The aircraft is towed onto the base and positioned so that not only is the longitudinal axis coincident with the North-South line with the nose pointing North, but also the flux detector unit access location is directly over that of the calibrator turntable. The optical alignment unit is then attached to the detector unit and a reference bearing is obtained by sighting the telescope on a target which is at least half-mile distant from the base. The values of aircraft malalignment, and flux detector unit index error, are then set into the optical alignment unit, and the detector unit, with equipment attached, is transferred to its mounting bracket in the aircraft and is rotated until the telescope is again aligned with the distant reference target. At this setting the detector unit is secured to its mounting bracket and electrically connected to its compass systems. The optical alignment unit is then removed.

NOTE: Optical transfer is a critical operation in "electrical" swinging procedure, and extreme care should be taken to prevent the telescope from being jarred or knocked out of adjustment before a flux detector unit is fully secured in its mounting bracket.

- (f) **Compass Swinging.** This operation, which applies to all compass systems irrespective of the type of flux detector unit employed, is the one in which compensations are made for one-cycle (Coefficients "B" and "C") and two-cycle (transmission) errors. Before compensating, a final check on  $E_1$  and  $E_2$  voltage values should be made, and adjustments should, where necessary, be carried out to allow for any possible changes in the earth's field strength. On completion of all adjustments, a final swing through increments of 15 degrees should be carried out.

NOTE: Variations between compass system compensation can occur depending principally on the type of compensator used. Reference should, therefore, always be made to the relevant system and aircraft Maintenance Manuals.

**4.6 Swinging by Inertial Navigation Systems.** With the introduction of Inertial Navigation Systems (INS) into certain types of public transport aircraft, the use of system display unit heading information, as the datum for compass swinging, became a possibility. The swinging procedure, although basically similar to that employing an external magnetic datum, does however, require that the effects of diurnal changes in local magnetic variation be taken into account in order to minimize compass deviation errors.

**4.6.1** Variation is the horizontal angle between the true and magnetic meridians, and in the United Kingdom it normally increases Westerly during the morning and decreases during the late afternoon. These diurnal changes, as they are called, are in the order of 0.1 degrees in the winter, and 0.3 degrees in the summer. During periods of high sunspot activity however, the changes become random and may increase in amplitude to 0.5 degrees, and have been known to be as large as one degree. In the case of a compass swing using an external magnetic reference datum, the diurnal changes do not affect the swing since both the datum compass and the aircraft compass are affected by the same changes and the correct deviations are calculated. Furthermore, as long as the compass base has a constant value of variation over it, an accurate compass swing can be carried out irrespective of the value of local variation. In using INS heading information as a datum, diurnal changes will, however, affect only the aircraft

compass, thereby giving rise to false deviation errors which require the application of variation corrections. An outline of a method of applying the corrections, based on that prescribed for a particular type of aircraft using three inertial navigation systems, is given in the following paragraphs.

- (a) The aircraft is positioned within two degrees of North using the readings of the INS display units, and the average of the three readings is noted. The aircraft's magnetic heading is then determined by applying the value for the local magnetic variation to the average of the display unit readings. For Westerly variation the value is added and for Easterly variation it is subtracted.
- (b) The heading indications of the compass systems are then noted, after allowing each system to synchronize, and the deviations of each system on the North heading are calculated.
- (c) The foregoing procedure is repeated on the other three cardinal headings, and the deviation coefficients are calculated and compensated in the manner prescribed for the particular compass systems.

4.6.2 Although the method described in paragraph 4.6.1 takes into account local variation on all cardinal headings, it should be noted that it is still possible for false deviations to occur as a result of diurnal changes taking place, for example, during the time required for compass systems to synchronize. Unless continuous calculations are made, or the aircraft headings are checked with the aid of an external datum compass, it is unlikely for local variation to be known accurately for the duration of the swing. Serious consideration should, therefore, be given to the maximum compass error which might occur during an INS datum swing compared with one using an external magnetic datum, and whether such error can be accepted for the aircraft compass systems concerned.

**OCCASIONS FOR COMPASS SWINGING** The swinging procedures described in paragraph 4 should normally be carried out after installation of a complete compass system, and whenever standard type, or pre-indexed type, flux detector units are changed. Changing of a master type detector unit does not usually downgrade the performance of its associated system unless alignment of the unit in its mounting bracket, or alignment of the bracket itself, has been altered. Normally, a complete swinging procedure should also be carried out after a deviation compensator device has been changed, although in some systems this may not be necessary provided that compensating voltage settings are properly transferred to the replacement unit. On all other occasions it is sufficient only to carry out a check swing by placing the aircraft on four headings 90 degrees apart, and comparing any deviations with those recorded on the previous calibration swing. If there is any difference between these deviations, a complete swinging procedure should be carried out. Occasions for a check swing are as follows:—

- (a) After a check inspection if required by the approved Maintenance Schedule, or at any time that the accuracy of a system is in doubt.
- (b) After any modification, repair or major replacement involving magnetic material.
- (c) After any modification or repair to wing tips, or vertical stabilizers, in the vicinity of flux detector units.
- (d) Whenever a compass has been subjected to shock, e.g. after a heavy landing.
- (e) After the aircraft has passed through a severe electrical storm, or has been struck by lightning.

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- (f) Whenever the aircraft has been subjected to a magnetic crack detection examination.
  - (g) Whenever the sphere of operation of the aircraft is changed to one of different magnetic latitude.
  - (h) Whenever a significant change is made to the electrical or radio installation, particularly to circuits in the vicinity of flux detector units.
  - (j) Whenever a freight load is likely to cause magnetic influence and thereby affect compass system readings.
  - (k) After the aircraft has been in long term storage.
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Issue 4

September, 1988

**AIRCRAFT****ICE PROTECTION****PNEUMATIC DE-ICING SYSTEMS****1 INTRODUCTION**

1.1 The purpose of this Leaflet is to provide general guidance and advice on the installation and maintenance of pneumatic aerofoil de-icing systems. The Leaflet should be read in association with Aircraft and Aircraft Component Maintenance Manuals, and Maintenance Schedules relevant to the specific items and aircraft installations.

1.2 Subject headings are as follows:—

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**2 STANDARD OF PROTECTION**

2.1 The Air Navigation Order 1985, requires that aircraft in the Public Transport Category (Passenger or Cargo) registered in the United Kingdom, shall be provided with 'adequate equipment' to prevent impairment of the lifting surfaces through ice formation, where, meteorological forecasts indicate at the time of departure, the possibility of encountering weather conditions conducive to icing.

2.2 Aircraft ice protection certification acceptance standards are detailed in British Civil Airworthiness Requirements (BCAR) Section D Chapter **D4-7**, and Joint Airworthiness Requirements (JAR) Paragraphs 25.1416 and 1419. These requirements cover such considerations as, aircraft stability, flying control balance characteristics, jamming of flying controls and continuous engine(s) operation in icing conditions. However, certain basic standards have also to be complied with by all aircraft, which are intended to provide a reasonable protection if the aircraft is flown unintentionally for short periods in icing conditions.

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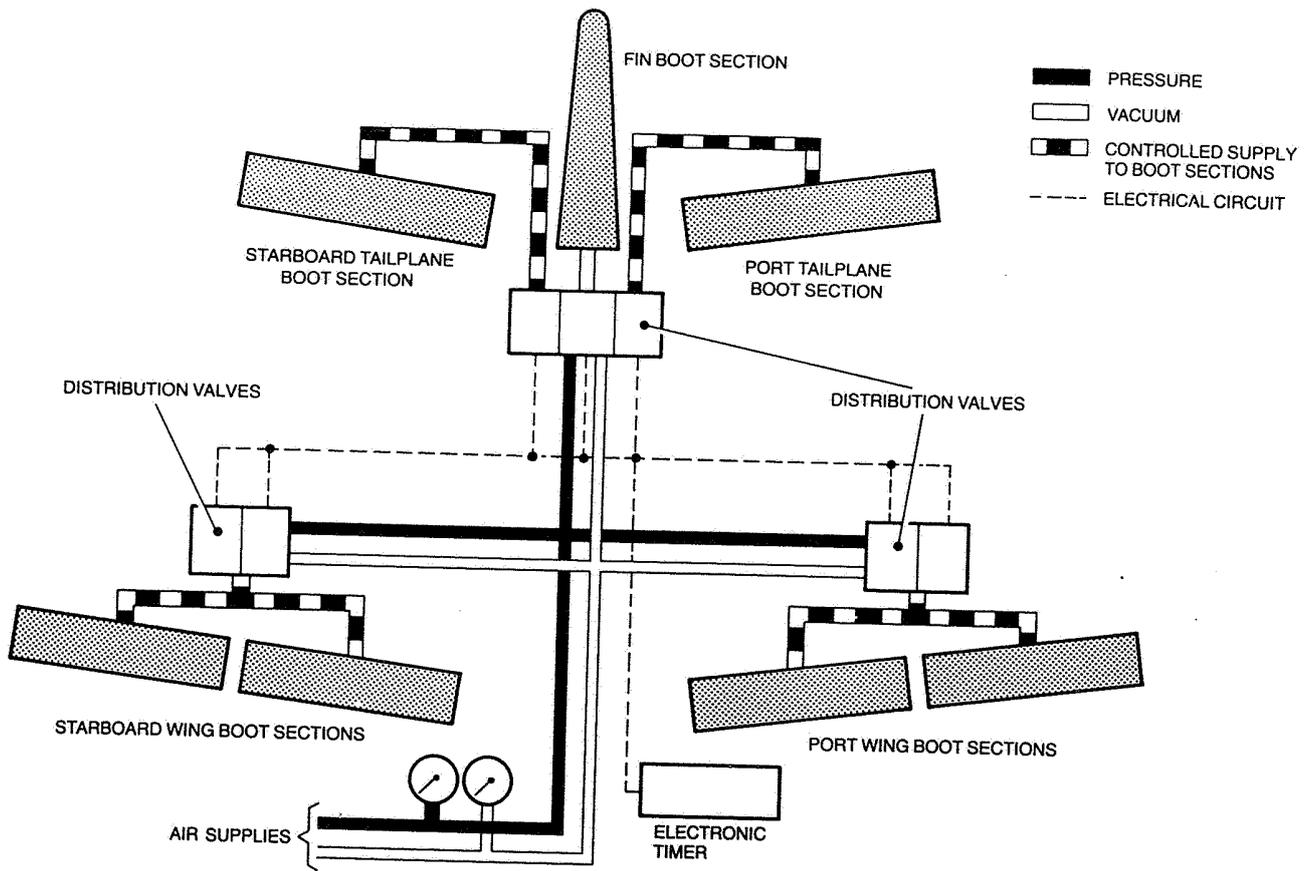


Figure 1 SCHEMATIC DIAGRAM OF A PNEUMATIC DE-ICING SYSTEM

### 3 THE PNEUMATIC DE-ICING SYSTEM

3.1 **General.** Pneumatic de-icing systems are employed in certain types of piston-engined and twin turbo-propeller aircraft. The number of components comprising a system varies with the operating principle. The typical de-icing system schematically illustrated in Figure 1 comprises the following:—

- (a) The air supply system.
- (b) The air distribution system.
- (c) The pneumatic de-icer boots.
- (d) The controls and indicators.

#### 3.2 Operation

3.2.1 When the system is switched on, pressure is admitted to the pneumatic de-icer boot sections to inflate the tubes. This weakens the bond between the ice and de-icer boot surfaces, causing the ice to break away. At the end of the inflation stage of the operating sequence, the air in the inflation tubes is dumped to atmosphere through automatic opening valves, the tubes are then fully deflated by the vacuum supply. This inflation and deflation cycle is repeated whenever the system is in operation. When the system is switched off, vacuum is continually supplied to all inflation tubes within the de-icer boot sections to hold them flat against the wing and tail unit leading edges, thereby minimising aerodynamic drag.

3.2.2 The method of sequencing usually varies with the method of air distribution as referred to in paragraph 3.3. In most installations, sequencing control is effected by means of an electronic device, however reference should always be made to the relevant Aircraft Maintenance Manual for details of the method of control and operating time cycles.

#### 3.3 Air Supplies and Distribution

3.3.1 The tubes in a pneumatic de-icer boot section are normally inflated by one of the following methods:—

- (a) Air pressure from the pressure side of an engine-driven vacuum pump.
- (b) Air pressure from a high pressure air reservoir, or
- (c) as fitted to some types of turbo-propeller aircraft, air pressure from a tapping at an engine compressor stage.

3.3.2 Whenever the system is switched 'OFF' or at the end of the inflation stage of the operating sequence, the de-icer boots are deflated by vacuum derived from either a vacuum pump, or, in systems utilising an engine compressor tapping, from the venturi section of an ejector nozzle.

3.3.3 The method of distributing air supplies to the de-icer boots, depends on the type of de-icing system adopted for a particular type of aeroplane, but in general, there are three methods in use. One method employs shuttle valves which are controlled by a separate solenoid valve. The second method distributes air to each de-icer boot by individually solenoid-controlled valves; in the third method, distribution is effected by a motor-driven valve.

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## 3.4 Pneumatic De-icer Boots

3.4.1 Pneumatic de-icer boots, or overshoes, consist of layers of natural rubber and rubberised fabric between which are disposed flat inflatable tubes that are closed at the ends. The inflatable tubes are made of rubberised fabric which are vulcanised inside the natural rubber layers. When the de-icer boots are in position on a wing, or tailplane leading edge, the tubes either run parallel to the span, or as in other arrangements, parallel to the chord. The inflatable tubes are connected to the air supply pipelines from the distribution valves by short lengths of flexible hose. These in turn are secured to connectors on the de-icer boots and air supply pipelines, by hose clips. The external surfaces of the de-icer boots are coated with a film of conductive material to discharge any accumulations of static electricity.

3.4.2 A de-icer boot may be attached to the leading edge of an aerofoil either by, screw fasteners (Rivnuts), or adhesive cement. To cover the edges of a screw-fastened de-icer boot, metal fairing strips are used on the upper and lower surfaces. To secure and prevent inward creep of the de-icer boot, end strips are also fitted. The strips are secured by the same screws and Rivnuts as those used to secure the edges of the de-icer boots to the leading edge.

3.5 **Controls and Indicators.** The controls and indicators required for the operation of a de-icing system depend upon the type of aircraft, and the particular arrangement of its de-icing system. In the basic arrangement, a main ON-OFF switch, pressure and vacuum gauges, or indicating lights, form part of the controlling section.

## 4 INSTALLATION

4.1 **General.** For full details of the checks to be carried out on pneumatic de-icing system components prior to installation, and the installation methods to be adopted, reference should always be made to the relevant Aircraft and Aircraft Component Maintenance Manuals. The information provided in the following paragraphs is therefore of a general nature, and intended only as a guide to installation practices.

### 4.2 Pneumatic De-icer Boots

4.2.1 **Screw-fastened De-icer Boots.** The following points should be observed when installing de-icer boots of this type:—

- (a) The mating surfaces of the leading edges should be clean and free from projections or rough edges which may chafe the undersurfaces of the boot. Projections such as rivets may be covered with adhesive tape.
- (b) Leading edges should be painted with a mixture of French Chalk and lead-free petrol or Methylated Spirit and allowed to dry thoroughly. This will leave a smooth even film of French Chalk on the leading edge skin to lubricate movement of the rubber de-icer boot.
- (c) The undersurface of the de-icer boot should also be thoroughly dusted with French Chalk.

NOTE: The liquid mixture as applied to leading edges should not be used.

- (d) To prevent chafing of the aerofoil surfaces, a narrow strip of adhesive tape should also be placed on the underside of the trailing edges of the fairing strips, taking care to ensure that the tape does not extend beyond the edge of the fairing strips.
- (e) The de-icer boot should then be positioned adjacent to leading edges, and the hoses from the air supply system fitted to the correct de-icer boot connections.

- (f) When fitting a screw-fastened de-icer boot, it is immaterial whether the upper or lower edge is attached first. The edge chosen should be the one most convenient to reach and perform the stretching operation described in paragraphs (g) and (h). The de-icer boot and a fairing strip should be loosely secured, along one edge, to the aerofoil. The screws should not be tightened until the other edge has been secured.
- (g) To assist the ice shedding action and deflation, de-icer boots are secured under tension. This is effected by stretching the second edge into position. A special tool for gripping the edge of the de-icer boot is normally used to facilitate stretching, together with a number of pegs to locate the de-icer boot mounting holes over the rivnuts.
- (h) When the de-icer boot is stretched back over the rivnuts, a peg should be forced through the de-icer boot mounting hole and into the appropriate rivnut. At least two additional pegs should be inserted in adjacent rivnuts, before releasing the tension. This operation should be repeated until the entire edge of the de-icer boot is attached. As the tension and pegging operation progresses, there may be a tendency for wrinkling to develop, this may be worked out by slapping the de-icer boot surface with the gloved hand which will also help to keep lengthwise shrinkage of the de-icer boot to a minimum.
- (i) When all the pegs have been inserted, the fairing strip should be installed over the pegs, and working from one end, the pegs replaced with the appropriate attachment screws. These, together with those screws securing the other edge of the de-icing boot, should then be tightened and the end fairing strips fitted.

**4.2.2 Cemented De-icer Boots.** The following points should be observed when installing de-icer boots of this type:

- (a) All paint should be removed from the complete leading edge skin surface of an aerofoil, which together with the undersurfaces of the de-icer boot, should be cleaned by swabbing the skin surface with a clean, lint-free cloth soaked in Toluol and then wiped dry with a clean dry cloth before the solvent has had time to evaporate. Cloths should be changed frequently to avoid re-contamination of the cleaned areas, and to ensure a completely clean surface, cleaning operations should be carried out at least twice.
- (b) Immediately after the final drying operation, an even coat of the cement specified for use should be applied to the leading edge skin surface and undersurface of the de-icer boot. The surfaces should then be allowed to dry before a second coat of cement is applied and left to dry until completely tack-free. Drying times depend on temperature and humidity conditions. At 15°C or above with a relative humidity of up to 75%, a minimum of one hour drying time should be allowed. When the relative humidity is between 75% to 90%, a drying time of two hours between coats should be allowed.
- (c) Before cementing a de-icer boot to the leading edge, it should be rolled up (undersurface outwards) and a check made to ensure that its air supply connecting tubes do not foul the edges of the holes provided in the leading edge. A check should also be made that when unrolled from this position, the de-icer boot will be correctly aligned with the entire leading edge. This second check is facilitated by marking a centre line down the length of the de-icer boot on the cemented surface, and a corresponding centre line along the front of the leading edge.

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- (d) The de-icer boot should be folded back at the air connection end, over a distance of 229 mm (9 in) to 305 mm (12 in), and tacky surfaces reproduced in this area on the de-icer boot and leading edge, by swabbing with a clean lint-free cloth moistened with Toluol. Excessive swabbing should be avoided to prevent removal of cement from the surfaces. The two tacky surfaces should be positioned together and the de-icer boot rolled down firmly with a 51 mm (2 in) wide rubber covered hand roller.

NOTE: Two sizes of hand roller are normally specified for use, a 51 mm (2 in) wide roller for main rolling and a 19 mm (¾ in) wide roller for rolling between the inflatable tubes. All rolling must be carried out parallel to the inflatable tubes.

- (e) The de-icer boot should then be rolled back from the free end, and tacky surfaces reproduced over the de-icer boot and leading edge. The surfaces should then be joined and rolled together, working progressively in strips 305 mm (12 in) wide, until the de-icer boot is attached to the leading edge. If the de-icer boot becomes attached to the leading edge in an incorrect position, the de-icer boot should be pulled up smartly and repositioned immediately avoiding any twisting or bending.

NOTE: If a blister appears during rolling operations a piece of wire should be gently inserted between the open end of the de-icer boot and the leading edge until it enters the blister. The wire should then be removed and the air rolled out along the "tunnel" formed by the wire. In areas clear of the inflation tubes, a blister may be dispersed by inserting a hypodermic needle into it.

- (f) In some installations, fairing strips are fitted along one edge of a de-icer boot surface to permit flush fitting of the strip. Care must be taken when cutting to ensure that it is not done too deeply; a cut should be made one layer at a time.
- (g) When the de-icer boots are finally cemented in position, the air supply connections should be made secure, and the ends of de-icer boots trimmed so that they lie flush with the end of the fairing strips and all excess cement cleaned away from the de-icer boot and metal surrounds. Additionally the de-icer boots should be sealed along their edges and ends by applying a special sealing cement. Reference should be made to the Aircraft Maintenance Manual for preparation details of the cement and the number of coats to be applied. When the final coat of sealing cement is dry, it should be 'capped' by the application of cement to the same specification as that to restore the conductivity of the surface (see paragraph 5.3).
- (h) Finally, a test for the satisfactory adhesion of the de-icer boots to leading edge sections should be carried out in the manner specified in the relevant Aircraft Maintenance Manual, which also includes a check to ensure that the forces required to separate the specially prepared test pieces are within permissible limits.

4.2.3 **Other Components.** The methods of installing pressure and vacuum regulating valves, distributor valves, electronic timers, indicators and such other components appropriate to the de-icing system of a specific aircraft type, are detailed in the relevant Maintenance Manuals, and reference should therefore be made to these documents.

## 5 INSPECTION AND MAINTENANCE

5.1 **General.** The majority of inspection and maintenance procedures associated with pneumatic de-icing systems are related to the de-icer boots, since their location on an aircraft makes them vulnerable to damage which may be caused under actual operating conditions or during ground handling and servicing operations. Therefore, the information on inspection and maintenance procedures detailed in the following

paragraphs is primarily concerned with de-icer boots and is intended to serve only as a general guide. Reference should therefore always be made to the relevant Aircraft and Component Maintenance Manuals and Approved Maintenance Schedules appropriate to the specific aircraft type.

5.2 At each inspection careful consideration should be given to the overall condition of de-icer boots. This applies particularly to the soft pliable rubber which may easily be damaged during servicing operations. The following are general precautions which should be observed:—

- (a) Refuelling hose and other equipment must not be dragged over the surfaces of the de-icer boots.
- (b) Ladders or service platforms which are placed near the de-icer boots during servicing operations must have sponge-rubber pads fitted to prevent damage.
- (c) Oil or grease found on the surface of de-icer boots must be removed as soon as possible with soap and water or with a clean rag moistened with a lead-free petrol. Petrol should not be allowed to dry on the surfaces; it should be wiped off immediately with a clean cloth.

NOTE: Surfaces should not be rubbed hard during cleaning as damage to the conductive film may result.

- (d) Personnel must not tread on de-icer boots during servicing operations.
- (e) In tropical areas de-icer boots should not be exposed to sunlight for long periods.

### 5.3 Conductive Surface Deterioration

5.3.1 The conductive surface of cemented de-icer boots (paragraph 3.4.1) deteriorates slowly in service through general abrasion and this will be evident by the abraded condition and rough appearance of the surface. The method of restoring the conductivity of the surface is as follows:—

- (a) Carefully clean the outer surface of the de-icer boot using soap and water or a clean lint-free cloth moistened with lead-free petrol. Liquids should be used sparingly and surfaces dried off immediately.

NOTE: The de-icer boot surfaces should not be rubbed hard during cleaning or damage to the conductive surfaces will result.

- (b) Apply one coat of the conductive cement specified for the de-icer boots, ensuring that the identification and serial reference number details printed on a small part of the de-icer boot surface, are not obliterated. The cement should be applied evenly and sparingly over the surface, care being taken to prevent excess quantities running down and forming rippled ridges across it. While the cement is drying, the aircraft should remain in a warm, dry area. In dusty conditions, the de-icer boots should be covered loosely with paper which is sealed with tape at the edges.

NOTE: Conductive cement normally requires about 24 hours to dry. Therefore, whenever possible, de-icer boots should be resurfaced soon after the start of any periodic maintenance check on the aircraft.

5.4 **De-icer Boot Deterioration.** Continued operational use and exposure to intense sunlight causes the surface of de-icer boots to deteriorate by general crazing. If the surface is extremely crazed, with the cracks extending to the fabric reinforcing, the de-icer boot should be replaced. If the damage due to crazing does not extend into the natural rubber plies of the de-icer boot, then a coating of conductive cement will normally suffice in restoring the de-icer boot to a serviceable condition.

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## 5.5 Repairs

5.5.1 **General.** Damage to de-icer boots found during inspections will vary from minor cuts, holes and scratches; which may be easily repaired, to extensive splitting of the tube areas which are beyond repair. Minor tears and holes can usually be detected by visual means or the sound of escaping air, or by system pressure not building up to the required operational value as indicated by the system pressure gauge. If there is difficulty in locating a leak, the de-icer boot should be inflated, and a soap solution applied to the suspected area.

5.5.2 **Repair Methods.** Repair schemes are devised, and detailed in Maintenance Manuals and in some cases, Structural Repair Manuals, for the relevant aircraft type. The repair methods to be adopted and the nature of the work involved, depends largely on the extent of the damage to the de-icer boot. Kits are provided for carrying out cold patch repairs in-situ which are normally confined to two size ranges of damage; cuts, holes or cracks up to 19 mm ( $\frac{3}{4}$  in) long, and from 19 mm ( $\frac{3}{4}$  in) to 51 mm (2 in) long. The kits normally contain moulded rubber patches of various sizes, cements, rubber and rubberised fabric sheets, and the appropriate tools. Where larger cuts, holes, or cracks have occurred, or where a portion of a de-icer boot has been torn away, a temporary emergency repair may be made with the aid of a cold patch repair kit.

5.5.3 Numerous cold patches greatly affect the efficiency of a de-icer boot, therefore these repairs must only be regarded as a temporary measure. When a de-icer boot has been extensively patched it must be removed from a leading edge in order that permanent repair by a vulcanising process may be carried out. Some important aspects of de-icer boot repair methods are summarised as follows:—

- (a) Patches should be approximately 16 mm ( $\frac{3}{8}$  in) larger all round than the cut. In the case of cuts which range in size from 19 mm ( $\frac{3}{4}$  in) to 51 mm (2 in), and for the emergency repair of more extensively damaged areas, the rubber or rubberised fabric sheet material should be cut 38 mm ( $1\frac{1}{2}$  in) larger all round.
- (b) Care should be taken to remove only the conductive coating from an area of the de-icer boot surface slightly larger than the patch required. To assist in this operation, a special buffing shield (supplied with the repair kit) with various sized apertures is held over the damage area in the selected position.
- (c) After the removal of the conductive coating, the cleaned surface should be roughened with a wire brush and then smoothed as evenly as possible with an emery buffing stick. The surface should be finally cleaned with lead-free petrol and allowed to dry.
- (d) The patch and damage area should be coated with cement, and after the specified air-drying time has elapsed, the patch should be applied to the de-icer boot. To ensure that the patch adheres centrally over the damage, one corner should be lightly applied and the remainder pressed down at the same time exerting a slight pulling action. The tension thus created will help to close up the puncture in the de-icer boot surface when the patch is finally in position.
- (e) Patches should be pressed down carefully to prevent entrapment of air and rolled thoroughly with the steel roller supplied with the repair kit, ensuring that the edges of the patch have adhered closely to the de-icer boot surface.
- (f) After allowing the appropriate time for setting, the patch and surrounding area should be wiped with a clean lint-free cloth moistened with lead-free petrol to remove all surplus cement. When the surfaces are thoroughly dry and clean, a coat of conductive cement should be applied to restore the conductive surface.

- (g) If the damage to a de-icer boot is such that an inflatable tube is cut completely through, the inside surface should be patched first and then the outside. The patches must be cut from rubberised fabric sheet which is manufactured such that it stretches in one direction only. When in position, the patches should stretch normal to the inflation tubes, i.e. for de-icer boots using spanwise inflation tubes, the fabric stretch should be chordwise and vice versa.

NOTE: A pressure test must be carried out on the de-icer boot in accordance with the procedures specified in the Aircraft Maintenance Manual after repair to the inflatable tubes.

**5.6 Functioning Tests.** Functioning tests must be carried out at the check periods specified in the Approved Maintenance Schedules, or when a system malfunction occurs, or a major component (e.g. a distributor valve, regulator valve or de-icer boot) has been replaced, and also after repairs to a de-icer boot. The method of testing a system depends mainly on the type of aircraft and precise details must therefore be obtained from the relevant Maintenance Manual. The checks which in general form part of functioning test methods, are outlined as follows:—

- (a) Tests may be carried out using either the aircraft engines or by deriving the requisite air supplies from a ground test trolley. If a system which uses engine compressor bleed air is to be tested by using a test trolley, the air supply must be clean, moisture-free and at a delivery pressure approximating that normally obtained at the engine compressor tapping.
- (b) Pressure and vacuum indicators should be checked to ensure that supplies are maintained at the specified values. Adjustments should be made, where necessary, to relevant regulating and relief valves.
- (c) With a system selected 'ON', de-icer boots should be checked to ensure that they inflate and deflate in the correct sequence and for the correct periods of time determined by the appropriate timing device. During this check it should also be noted that the pressure gauge pointer fluctuates simultaneously with de-icer boot inflation and deflation.
- (d) If the de-icer boot section inflates and deflates sluggishly; even though the correct pressure is indicated, it may be the result of an obstruction in certain of the pipelines (e.g. those leading to the de-icer boot sections or to the distributor valves). If the distributor valves are of the electrically controlled type, sluggish inflation and deflation may also be due to sticking solenoids.
- (e) Joints and sections of pipelines should be checked for leaks under operating conditions.
- (f) When the system is selected to the 'OFF' position, the de-icer boot sections should deflate completely and lie flat against the leading edge of the appropriate aerofoil.

**6 STORAGE OF DE-ICER BOOTS** Before storing, the surface conditions of the de-icer boot should be inspected carefully, to establish that there are no operating defects. They should be cleaned and repaired, and where necessary (see paragraph 5.5) lightly dusted with French Chalk. Connectors should be blanked off and the de-icer boots rolled up commencing at approximately 153 mm (6 in) diameter. Rolling should be commenced at the end remote from valve connectors so that they are on the outside of the finished roll. Where connectors are located near the centre of the de-icer boot, a pad of corrugated paper should be placed over the connectors to protect the contacting surface. The rolled de-icer boot should then be thoroughly wrapped up in a heavy paper to exclude all light, and stored in a cool, dry, dark

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place, where it will not be crushed or wrinkled. In cases where de-icer boots are precemented to detachable leading edge sections, the latter should be wrapped up and stored in such a manner that they are supported on their trailing edges.

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Issue 3

June 1986

**AIRCRAFT****ICE PROTECTION****THERMAL (HOT GAS) DE-ICING SYSTEMS**

- 1 **INTRODUCTION** This Leaflet gives guidance on the installation and maintenance of the thermal systems used for the de-icing of wings and tail units. It should be read in conjunction with Maintenance Manuals and approved Maintenance Schedules; such documents providing details of construction, major servicing, repairs and test procedures relevant to specific aircraft installations and components.
  
- 2 **GENERAL** In systems of this type, the leading edge sections of wings and tail units are usually provided with a second inner skin positioned to form a small gap between it and the inside of the leading edge section. Heated air is ducted to the wings and tail units and passes into the gap, providing sufficient heat in the outer skin of the leading edge to melt ice already formed and prevent further ice formation. The air is exhausted to atmosphere through outlets in the skin surfaces and also, in some cases, in the tips of wings and tail units. The temperature of the air within the ducting and leading edge sections is controlled by a shutter or butterfly type valve system the operation of which depends on the type of heating system employed.
  
- 3 **AIR SUPPLIES** There are several methods by which the heated air can be supplied and these include bleeding of air from a turbine engine compressor, heating of ram air by passing it through a heat exchanger located in an engine exhaust gas system and combustion heating of ram air.
  - 3.1 In a compressor bleed system the hot air is tapped directly from a compressor stage and after mixing with a supply of cool air in a mixing chamber it passes into the main ducting. In some systems, equipment, e.g. safety shut-off valves, is provided to ensure that an air mass flow sufficient for all de-icing requirements is supplied within pressure limits acceptable to duct and structural limitations.
  - 3.2 The heat exchanger method of supplying warm air is employed in some types of aircraft powered by turbo-propeller engines. The heat exchanger unit is positioned so that exhaust gases can be diverted to pass between tubes through which outside air enters the main supply ducts. The supply of exhaust gases is usually regulated by a device such as a thermostatically controlled flap fitted in the ducting between the exhaust unit and the heat exchanger.
  - 3.3 In a combustion heating system ram air is passed through a cylindrical jacket enclosing a sealed chamber in which a fuel/air mixture is burned, and is heated by contact with the chamber walls. Air for combustion is derived from a separate air intake and is supplied to the chamber by means of a blower.

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- 4 DUCTING The type of ducting, materials used, methods of inter connection and disposition in an aircraft vary between de-icing systems, and reference should therefore always be made to the relevant aircraft Maintenance Manual for details.
  - 4.1 Light alloy and stainless steel are materials normally used in construction, stainless steel being adopted principally in compressor bleed systems. Flanged and bolted end fittings, or band-type vee-clamps with interposed sealing rings are common methods of connecting duct sections together, and in some cases an additional means of sliding duct sections one end into the other and securing by adjustable clamps may be adopted.
  - 4.2 In some installations in which ducting passes through the fuselage, joints between duct sections are sealed to prevent loss of cabin air pressure. Fuselage ducting may, in some types of aircraft, comprise an inner stainless steel duct surrounded by an outer fibreglass duct. The two ducts are approximately 13 mm ( $\frac{1}{2}$  in) apart and the interspace is filled with glass wool to provide thermal insulation. The purpose of this ducting arrangement is to serve as a leak warning system by venting interspace air through venturis which operate pressure switches and a warning light.
  - 4.3 Expansion and contraction of ducting is catered for by bellows or gimbal type expansion joints and in aircraft having variable incidence tailplanes and other moveable aerofoil surfaces such as leading edge slats and Kruger flaps, swivel joints and telescopic joints are fitted in the ducts supplying air to these surfaces.
  - 4.4 In some installations, ducting in certain areas is lagged with a fire-resisting, heat-insulating material, normally fibreglass held in place by glass-cloth bound with glass cord.
- 5 TEMPERATURE CONTROL The control of the air temperature within ducting and leading edge sections is an important aspect of thermal de-icing system operation and the methods adopted depend on the type of system.
  - 5.1 In a typical compressor bleed system, control is effected by temperature sensing units which are located at various points in the leading edge ducting and by valves in the main air supply ducting. The sensing units and valves are electrically interconnected so that the valves are automatically positioned to regulate the flow of heated air to the system thus maintaining the temperature within a predetermined range. Indications of air temperature conditions are provided by resistance type temperature sensing elements and indicators, temperature sensitive switches and overheat warning lights. On some aircraft the electrical supplies to the valves are interrupted by landing gear controlled relays when the aircraft is on the ground. Under these conditions, valve operation is accomplished by holding the system control switch to a 'TEST' position.
  - 5.2 When heat exchangers are employed, temperature control is usually obtained by the use of adjustable flaps and valves to decrease or increase the supply of heating and cooling air passed across the exchangers. The method of controlling the flaps and valves varies with different aircraft, but a typical system incorporates an electric actuator, which is operated automatically by an inching device controlled by a temperature sensing element fitted in the duct on the warm air outlet side of the heat exchanger. In some systems, actuators are directly controlled by thermal switches, so that the flaps or valves are automatically closed when a predetermined temperature is reached. Indications of air temperature conditions are provided by resistance type temperature sensing elements and indicators, temperature sensitive switches and overheat warning lights.
  - 5.3 In systems incorporating combustion heaters, the temperature is usually controlled by thermal cyclic switches located in the heater outlet ducts, so that when the temperature reaches a predetermined maximum the fuel supply to the heaters is automatically switched off.

**6 INSTALLATION** The arrangements for the installation of thermal de-icing system components depends primarily upon the type of system and also upon the particular type of aircraft. The information given in the following paragraphs is of a general nature only, and is intended as a guide to the procedures associated with the installation of principal components. Full details are contained in the Maintenance Manuals for specific aircraft types and reference must always be made to these documents.

**6.1 Heat Exchangers.** Before installation, heat exchangers should be inspected to ensure that no foreign matter has entered the various connections, that there are no visible cracks or other damage and that ram air passages are free from obstruction. In some installations, exhaust gas and hot air ducts must be assembled to a heat exchanger prior to its installation.

**6.1.1** Heat exchangers must be adequately supported during installation to prevent fouling of ducting, or other adjacent components and parts of the aircraft structure.

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

**6.1.3** New sealing gaskets and O-rings should be fitted to the joints between system ducts, ram air inlet and outlet flanges, and exhaust gas inlet and outlet flanges. This is also essential whenever a joint is broken down for any reason. All joints should be correctly aligned and in tightening the appropriate nuts, bolts or clamps, care should be taken that distortion of the connection flanges and damage to brazed joints of a heat exchanger does not occur through overtightening. Nuts, bolts or clamps should be locked in the appropriate manner specified in the relevant aircraft Maintenance Manual.

**NOTE:** Particular care must be taken when making connections between engine exhaust units and heat exchangers to ensure that exhaust gases cannot enter the main ducting of the de-icing system. If the ducting has leaks, gases may be introduced into the cabin of the aircraft resulting in dangerous levels of carbon monoxide concentration (see Airworthiness Notice No. 40).

**6.1.4** If disturbed during installation of a heat exchanger, flaps or valves should be tested and adjusted as necessary. Moveable parts should operate freely throughout their full range of travel.

**6.2 Combustion Heaters.** Before installation, combustion heaters should be inspected for evidence of damage and, when necessary, pressure tested in the manner prescribed in the manufacturer's Maintenance Manual to ensure that no fuel or combustion products can leak into the air supply of the system (see Airworthiness Notice No. 40).

**6.2.1** Heaters should be installed in the manner specified in the Maintenance Manual concerned, taking care that air and fuel leakages do not occur at duct joints or connections.

**6.2.2** 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.

**6.2.3** 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).

**6.3 Ducting.** The methods of installing ducting vary between de-icing systems and it is therefore necessary to refer to the relevant aircraft Maintenance Manual for details of the procedure to be carried out.

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6.3.1 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) New sealing gaskets and O-rings should be fitted between jointing faces of duct end fittings. This is also essential whenever a joint is broken down for any reason. The jointing faces should also be checked for excessive ovality or gapping.
  - (c) When fitting band-type vee-clamps, the sealing rings must be correctly positioned to ensure that the seal bears evenly against, and is compressed by, the adjacent joint flange.
  - (d) Band-type vee-clamps should be lubricated with the lubricant prescribed in the Maintenance Manual and torque-tightened to the loads specified.
  - (e) In some installations requiring the supply of hot air to moveable aerofoil surfaces, flexible couplings are used to join duct sections and are sealed by twin sealing rings between inner and outer sleeves of the coupling. When such a coupling or associated duct section is to be replaced it is important to fit new sealing rings in pairs.
  - (f) When installing sections of ducting supplying air to moveable aerofoil surfaces, care must be taken to ensure that sealing rings are correctly positioned with respect to swivel joints to permit full freedom of movement and to prevent leakage of air.
  - (g) New locking washers should be fitted to bolts which secure flanged type end fittings.
  - (h) When assembled on ducts, silicone rubber sleeves should be in a free condition, i.e. they should not be twisted, stepped or collapsed.
  - (j) Bedding tape or metal clips must be correctly located between rubber sleeves and adjustable clamps to prevent damage to the sleeves when tightening the clamps.
  - (k) Lagging, where fitted, should be inspected to ensure freedom from tears, damage and evidence of deterioration.
  - (l) Electrical bonding leads must be properly secured and tested electrically.
- NOTE: Information on bonding and testing is given in Leaflet EEL/1-6.
- (m) Expansion bellows, gimbal joints, sliding clamps or swinging link assemblies where installed, should be checked for full and free movement.
  - (n) In installations employing ducting having both inner and outer sections, threaded blocks are normally incorporated for attaching the ducting to the aircraft structure. When installing such ducting it is essential that the correct bushes, washers and bolts are assembled in the appropriate positions on the mounting bracket to prevent penetration of the inner duct skin by the mounting bolt.
  - (o) After replacement of a duct, the disturbed joints and appropriate section of ducting should be tested for leaks in the manner described in the relevant aircraft Maintenance Manual.

NOTE: The pressures specified for test purposes must not be exceeded and adequate safety precautions must be taken when inspecting ducts under pressure.

**6.4 Temperature Control Components.** The method of controlling the air temperature within the ducting of a system and within wing and tail unit leading edge sections, varies between systems and aircraft types; relevant Maintenance Manuals must therefore be consulted for the appropriate procedures for installing components. The details given in the following paragraphs are of a general nature only.

**6.4.1** Temperature sensing elements for control and indication purposes should be inspected before installation for cleanliness, signs of damage and should be checked for proper functioning. New sealing rings, gaskets and retaining washers, as appropriate, should be fitted.

**6.4.2** In some types of aircraft, the temperature control system employs a sensing element and a control valve which after bench setting are given the same serial number and must always be installed as a matched pair.

**6.4.3** Cables interconnecting components must be of the rating specified by the manufacturer. All connections should be checked against the relevant wiring diagrams, and plugs, sockets and terminal screws properly secured.

**6.4.4** All valves should be inspected for cleanliness, signs of damage and freedom of movement. New sealing rings and gaskets, as appropriate, should be fitted between valve jointing faces and ducting.

**6.4.5** Before installation, functional checks should be carried out on electric actuators employed for the operation of butterfly valves, jet pipe flaps etc., to ensure that limit switches are correctly adjusted at the extremes of valve travel.

**6.4.6** In certain systems deriving hot air from an engine compressor stage, shut-off valves of the electro-pneumatic type are employed. When installing these valves care must be taken to ensure that pressure sensing lines are undamaged and that they are correctly and securely coupled to the valve connecting unions.

**6.4.7** Certain valves are often marked with arrows to indicate the direction of flow, particular care is therefore necessary to ensure that they are installed in correct relation to the flow.

**6.4.8** The attachment of valves to their respective mountings and duct sections must be securely made and torque loadings strictly observed.

**6.4.9** Electrical bonding leads must be properly secured after the installation of a component.

**6.4.10** Mechanical linkages between electric actuators, inching control units, butterfly valves and flaps should be correctly adjusted to ensure that, after installation of a component, all movements are free and within the required range of travel. Where specified, linkages, exposed surfaces of actuator plungers, etc., should be lubricated with a low temperature grease.

**6.4.11** On completion of the installation of a component associated with temperature control, an in-situ functional test should be carried out in accordance with the procedure specified in the relevant aircraft Maintenance Manual. Any limitations as to the duration of complete system functional checks must be strictly observed.

**7 INSPECTION AND MAINTENANCE** The information given in the following paragraphs on inspection, maintenance and functional testing, is only of a general nature and should be read in conjunction with Maintenance Manuals and approved Maintenance Schedules for the components and aircraft concerned.

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- 7.1 **Heat Exchangers.** These units should be inspected for security of attachment to the aircraft structure, security of duct connections, evidence of engine exhaust gas leaks, evidence of overheating, and freedom from damage.

NOTE: Careful examination of connections is necessary to ensure that no leakage of exhaust gases into the main ducting of the de-icing system can occur (see Airworthiness Notices Nos. 40 and 41).

- 7.1.1 The external surfaces of a heat exchanger matrix must be clean and the ram 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 an air blast applied in a direction opposite to the normal air flow.
- 7.1.2 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 is suspected, the heat exchanger should be removed for cleaning and repair and replaced by a serviceable unit.
- 7.1.3 Heat exchangers should be pressure tested at the periods and at the test figures recommended in the approved Maintenance Schedule.
- 7.2 **Combustion Heaters.** Heaters should be examined for security. The fuel system should be carefully checked for evidence of leakage and drain pipes 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.
- 7.2.1 Electrical wiring and associated electrical components should be checked for security, loose connections, chafing of insulation, etc. The sheath of the igniter plug cable should be examined for any possible indications of arcing, evident by burning or discolouration of the sheath.
- 7.2.2 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.
- 7.2.3 System operation should be checked at the periods specified in the approved Maintenance Schedule and in the manner prescribed in the relevant aircraft Maintenance Manuals.
- 7.3 **Ducting.** All ducting should be inspected for security of attachment to the relevant parts of the aircraft structure, freedom from damage and overheating. Attention should be paid to weak and critical areas most likely to be found around bends and bifurcations where the gauge may be locally reduced by deformation during manufacture.
- 7.3.1 Joints between duct sections, and adjustable clamps should be secure and where appropriate tightened to specified torque values. Expansion bellows, flexible couplings and gimbal joint assemblies should be examined for freedom from cracks, distortion, corrosion and damage. Checks should also be made for free movement and, where necessary, manufacturing clearances should be checked to ensure they are within the limits specified for the installation.
- 7.3.2 Rupture disc and blow-out disc assemblies, where fitted, should be inspected for security and freedom from damage and a check made to ensure that the blow-out disc lies flush with the aircraft skin. In the event that a rupture disc has operated (indicated by protrusion of the blow-out disc), or if there is any cause to suspect the application of excessive duct pressure, the rupture disc assembly must be replaced and the duct inspections detailed in the aircraft Maintenance Manual carried out. It should be noted that manual re-setting may require the replacement of a shear device which forms part of the blow-out disc assembly.

7.3.3 When specified, ducts should be tested for leaks in the manner prescribed in the relevant aircraft Maintenance Manual. The test pressures and rate of leakage should not exceed the limits quoted for the system.

NOTE: Adequate safety precautions must be taken when inspecting duct sections under pressure.

7.3.4 It is usually more convenient to test a complete duct 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 stop valves, non-return valves, etc., where these provide convenient boundaries between sections.

7.3.5 Air leaks can be detected by sound and where ducts are lagged, leaks are sometimes revealed by discoloration and holes blown in the lagging material. If there is any difficulty in locating leaks, the soap and water method is recommended.

7.3.6 Lagging should always be properly secured and free from oil, hydraulic fluids, etc.

**7.4 Temperature Control Components.** All components should be inspected for security of mounting, mechanical and electrical connections, signs of damage, deterioration of electrical cables, etc.

7.4.1 Moveable flaps, linkages and actuators associated with engine exhaust units and with heat exchangers, should be inspected for freedom of movement and where specified, lubricated with the oil or grease recommended in the relevant aircraft Maintenance Manual. Inter-connecting linkages, flap hinges, etc., should be checked for excessive play and evidence of lost motion.

7.4.2 Maintenance of valves, inching control units, etc., associated with temperature control is usually confined to inspection for cleanliness, security of mounting, ducting attachments and, where applicable, security of electrical connections, functioning tests and lubrication specified in the particular component Maintenance Manual.

7.4.3 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. Valve seats and valve faces should be kept free of dust or traces of lubricant.

7.4.4 Temperature sensing elements, indicators and overheating warning devices should be checked for proper functioning and that the correct indications appropriate to system operating conditions are obtained. In the event that the pointer of an indicator moves to a position beyond maximum scale reading, the power supply should be switched off immediately and a continuity check of the sensing element and cables carried out, as this fault is an indication of an open circuit in the temperature sensing signal line.

7.4.5 The combined operation of components comprising a temperature control system should be checked during specified ground tests to ensure that they respond correctly to the selected operating conditions. The test procedures which must be carried out at the periods specified in the approved Maintenance Schedule vary, and the extent to which a system can be tested may, in some cases, be limited, particularly in relation to the duration of a test and the air temperature to be attained in leading edge sections. On the other hand, full-range temperature control of a system in some aircraft may be checked on the ground. Reference should be made to the relevant aircraft Maintenance Manual for the procedure to be adopted and limitations to be observed.

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**AL/11-3**

Issue 3

December, 1985

**AIRCRAFT****ICE PROTECTION****GROUND DE-ICING OF AIRCRAFT\***

- 1 INTRODUCTION This Leaflet gives general guidance on the removal of frost, ice and snow from aircraft before flight. In-flight de-icing is dealt with in Leaflets AL/11-1, AL/11-2, AL/11-4 and AL/11-5.

2 GENERAL

- 2.1 The presence of frozen deposits on an aircraft may be the result of direct precipitation (rain, snow, frost etc.) or accretion of frost or ice on external surfaces of integral fuel tanks after prolonged flight at high altitude, or accumulations on the landing gear and forward surfaces or undersurfaces following taxiing through snow or slush.
- 2.2 Any deposits of ice, snow or frost on the external surfaces of an aircraft may drastically affect its performance. This can be due to reduced aerodynamic lift and increased aerodynamic drag resulting from the disturbed airflow over the aerofoil surfaces, or due to the weight of the deposit over the whole aircraft. The operation of an aircraft may also be seriously affected by the freezing of moisture in controls, hinges and microswitches, or by the ingestion of ice into the engine. Furthermore, since the in-flight de-icing system may not become effective until the aircraft is established in the climbout, the measures taken to remove frozen deposits on the ground must also be such as to provide adequate protection during the initial stages of flight.
- 2.3 Neither the use of currently available Freezing Point Depressant (FPD) types of de-icing/anti-icing compounds, nor the use of manual techniques of de-icing with such compounds should be thought of as producing reliable anti-icing qualities for a definable period of time because the number of variables involved make it impractical to estimate that time. Only in the sense that under certain conditions FPD anti-icing compounds are known to be effective in retarding the formation of frost, snow or ice may they be considered to have anti-icing qualities for a period of time thus making the process of de-icing simpler and in many cases obviating the need for further de-icing or treatment during that period. It is emphasised, however, that the need for a close inspection of an aircraft prior to take-off still remains.

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\*CAP 512, entitled Ground De-icing of Aircraft is also available from CAA Printing and Publication Services, PO Box 41, Cheltenham, Glos. GL50 2BN Price £1.45 + 45p postage and packing. This CAP covers the text of this Leaflet, together with operational aspects and common practices or suggested practices for safe cold weather operation and general information relating to ground and flight operations in conditions conducive to aircraft icing.

## AL/11-3

- 2.4 The aircraft de-icing systems are designed to remove or prevent the accretion of ice on a specific area of the wings, tail and engine nacelles in flight and would not normally be effective in removing deposits which have accumulated while the aircraft is stationary. Their use on the ground may, in some instances, also cause a different type of unsatisfactory situation by melting parts of the deposit which would then freeze elsewhere. The use of cabin heating to remove deposits from the fuselage is also not recommended for the same reason.
- 2.5 When aircraft are moved so as to be under cover during inclement weather, any melted snow or ice may freeze again when the aircraft is subsequently moved into sub-zero temperatures. Complete protection could be provided by placing aircraft in heated hangars, but due to the size of modern transport aircraft and the need to meet schedules involving quick turnaround times this is not often practicable. Removal of frost, ice and snow from aircraft is therefore often necessary and maintenance crews need to be familiar with the methods of ground de-icing in current use.
- 2.6 There are two main types of de-icing/anti-icing fluids:-
- (a) **Type I fluids (unthickened).** These fluids have a high glycol content and a low viscosity. The de-icing performance is good, however, they provide only limited protection against refreezing.
  - (b) **Type II fluids (thickened).** These fluids have a minimum glycol content of approximately 50% and due to the thickening agent have special properties which enable the fluid to remain on the aircraft surfaces until take-off. The de-icing performance is good and, in addition, protection is provided against refreezing and/or build-up of further accretions, when exposed to freezing precipitation.

### 3 PRE-FLIGHT PREPARATION

- 3.1 The whole aircraft should be inspected to ensure that it is free from deposits of frost, ice and snow. When necessary, a de-icing fluid should be used. The objectives of using such fluids are to achieve effective removal of any frost or ice and to provide a measure of protection against any further formation. Only fluids approved for the purpose should be used.
- 3.1.1 The ability of the fluid to achieve the above objectives under varying atmospheric conditions is dependent upon the correct mixture strength and methods of application, both of which should be strictly in accordance with recommended procedures. For example, while fluid diluted with water may effectively remove ice, its ability to prevent further formation will be significantly reduced, and under certain conditions the fact that the aircraft surfaces are wetted may actually enhance the accumulation of wet snow.
- 3.1.2 Where adequate advice on approved fluids, mixture strength and methods of application is not given in the relevant aircraft Maintenance Manuals, guidance should always be sought from the aircraft manufacturer and from the suppliers of the fluid. The following information is only intended as general information and should not be used to override that which is contained in the aircraft Maintenance Manuals.

3.1.3 Advances in the composition of de-icing fluids have led to the production of a dual purpose anti-icing barrier fluid (DTD 900/4907) which is capable of removing ice and snow and delaying deposits re-forming. When used as a de-icing agent, this fluid should be mixed with the required volume of water and applied at a temperature of approximately 70°C by the method described in paragraph 5.2. It is however, strongly recommended that refractometer readings be taken so that the precise concentration of the solution can be determined.

NOTE: Pocket refractometers are available which permit on-site measurement of fluid concentration as a refractive index which can be converted to fluid/water proportions accurately by means of a chart.

3.1.4 Table 1 gives a guide to some typical maximum times during which the residual film of fluid may be effective in providing protection from re-freezing. It must be appreciated, however, that the period of protection will vary dramatically, depending upon the severity of the particular condition. Visual checks of the aircraft external surfaces are therefore always required to confirm the actual condition of the aircraft in extreme conditions of snow and freezing rain.

TABLE 1  
GUIDELINE TO HOLDOVER TIMES

Ambient temperature °C	Weather conditions					Probable safe period of protection			
	Steady snow	Frost	Freezing fog	Freezing rain	Rain	Kilfrost ABC 100%	Kilfrost ABC or Hoechst 1704 + water 70/30	Kilfrost ABC or Hoechst 1704 + water 60/40 or 50/50	Any other approved fluid + water
+3 and above	*					4 hours	3 hours	2 hours	1 hour
+3 to zero	*	*	*	*	*	2 hours 10 hours 3 hours 45 mins 1 hour	1¼ hours 6 hours 2 hours 20 mins 45 mins	45 mins 4 hours 1½ hours 15 mins 30 mins	15 mins 1½ hours 30 mins 10 mins 15 mins
zero to -5	*	*	*	*		1 hour 8 hours 2 hours 45 mins	40 mins 5 hours 1¼ hours 20 mins	30 mins 3 hours 1 hour 15 mins	15 mins 1½ hours 30 mins 5 mins
-5 to -10	*	*	*			1 hour 8 hours 1½ hours	40 mins 5 hours 1 hour	30 mins 3 hours 45 mins	15 mins 1½ hours 30 mins
-10 and below	*		*			1 hour 1½ hours	40 mins 1 hour	— —	20 mins 20 mins

NOTE: Kilfrost ABC is normally available in a solution of 50/50, 60/40 or 70/30. It may be difficult to get stronger solutions at short notice unless the temperature conditions at the aerodrome involved are below limits for that solution mix (see Table 2).

TABLE 2  
LOWER TEMPERATURE LIMITS

Mixture strength (Glycol/water)	Kilfroast ABC	Hoechst 1704	Mil. Spec. Fluids 8243
30/70	-	-	-11°C
40/60	-	-	-18°C
50/50	-7½°C	-7½°C	-35°C
60/40	-10°C	-10°C	-
70/30	-13°C	-13°C	-
100%	-28°C	-28°C	-

#### 4 FROST DEPOSITS AND METHODS OF TREATMENT

4.1 A deposit of frost is best removed by the use of a frost remover or, in severe conditions, a de-icing fluid (e.g. Kilfroast ABC or similar proprietary fluids). These fluids normally contain either ethylene glycol and isopropyl alcohol or diethylene glycol (or propylene glycol) and isopropyl alcohol, and may be applied by spray or by hand. The process is not lengthy, as one application is usually sufficient, provided that it is applied within the two hours prior to flight.

NOTES: (1) De-icing fluids may adversely affect glazed panes or the exterior finish of aircraft, particularly when the paint is new. Only the type of fluid recommended by the aircraft manufacturer should therefore be used and any instructions relating to its use should be strictly observed.

(2) De-icing fluids, particularly those with an alcohol base, may cause dilution or complete washing out of oils and greases from control surface bearings, etc., allowing the entry of water which could subsequently freeze, jamming controls. Spray nozzles should not, therefore, be directed at lubrication points or sealed bearings and an inspection of areas where fluid may be trapped is usually necessary. The Maintenance Schedule may specify relubrication in these areas whenever de-icing fluids are used.

4.2 Frost may also be removed from aircraft surfaces using a mobile unit capable of supplying large quantities of hot air through a delivery hose and nozzle. The air is blown on to the wings, fuselage and tail surfaces and either blows away or melts any frost deposits. Operators using this equipment should ensure that any melted frost is deiced up and not allowed to accumulate in hinges, microswitches, etc., where re-freezing could occur.

5 ICE AND SNOW DEPOSITS AND METHODS OF TREATMENT Probably the most difficult deposit to deal with is deep wet snow when ambient temperatures are slightly above freezing point. This deposit should be removed with a brush or squeegee, care being

taken not to damage airdials, vents, stall warning vanes, pitot probes, vortex generators, etc., which may be concealed by the snow. Light dry snow in sub-zero temperatures should be blown off whenever possible; the use of hot air is not recommended, since this would melt the snow, which would then freeze and require further treatment. Moderate or heavy ice and residual snow deposits should be removed with a de-icing fluid, which may be successfully applied to any aircraft by spraying; in severe conditions it may be necessary to spray a final application immediately before flight. The aircraft nose and cockpit canopy should normally be left dry to ensure that the windscreen does not become contaminated with fluid which could cause smearing and reduced vision. Windscreens should be cleared by wiping with an alcohol-soaked cloth or by use of the windscreen anti-icing system.

NOTES: (1) No attempt should be made to remove ice deposits or break an ice bond by force.

(2) It is essential that removal of deposits proceeds symmetrically.

**5.1 Cold Fluid Spray.** A cold fluid spray is the simplest method of applying de-icing fluid, but suffers from several disadvantages which must be considered in relation to the particular circumstances.

**5.1.1** In very severe conditions one sprayed application of cold fluid may not be sufficient to remove all the ice and snow; brushing or rubbing thickly iced areas is usually necessary, followed by a second or even third application of fluid. As the ice and snow melts, the fluid is diluted, becomes less effective and is prone to freezing again quite quickly. This may have serious consequences if the diluted fluid is allowed to run into control surface and landing gear mechanisms. Under these conditions the cold spray method may be both prolonged and expensive.

**5.2 Hot Fluid Spray.** Many airline operators have dispensed with the use of cold spraying techniques except at small airports and in an emergency. They have adopted a hot fluid spraying system which was developed specifically to reduce turnround times and to inhibit the bonding of ice and snow to aircraft surfaces for a period of time. The equipment used consists of a static unit, in which quantities of both water and de-icing fluid are heated, and a mobile unit which houses an insulated tank, a pump, an hydraulically-operated boom-mounted platform and several spray lances.

**5.2.1** In this system hot fluid is pumped from the static unit to the insulated tank on the mobile unit, the proportions of water and de-icing fluid being adjusted to suit prevailing weather conditions. The mobile unit is then driven to the site of operations, the optimum number and disposition of units being found by experience on a particular aircraft type.

**5.2.2** The fluid is normally sprayed on at a temperature of 70°C and a pressure of 700 kN/m<sup>2</sup> (100 lbf/in<sup>2</sup>), holding the nozzle close to the aircraft skin to prevent heat losses. Heat is transferred to the aircraft skin, thus breaking the ice bond, and large areas of ice may be flushed away by turning the nozzle sideways. In this way, time is saved and the dilution of fluid with ice and snow reduced to a minimum. The film of fluid left on the aircraft skin, being only slightly further diluted, is effective in preventing ice re-forming.

NOTE: Overheating, in the de-icing rig, of most de-icing fluids will result in a gelled formation being deposited on the aircraft which will not shear off on take-off and may, therefore, have an adverse aerodynamic effect.

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5.2.3 **Hot Water De-Icing.** Hot water de-icing should not be carried out at temperatures below  $-7^{\circ}\text{C}$ , and the second step must be performed within three minutes of the beginning of step 1, if necessary area by area.

- (a) **Step 1.** Snow and ice is initially removed with a jet of hot water at a maximum temperature of  $95^{\circ}\text{C}$ .
- (b) **Step 2.** A light coating of de-icing fluid is then immediately applied to the aircraft to prevent re-freezing.

### 5.3 High Pressure Sprays

5.3.1 High pressure sprays used for de-icing are capable of causing damage to pitot-static probes and other sensing devices. A carelessly directed spray could also result in the ingress of a considerable quantity of fluid into engine intakes, drains or vents, possibly resulting in cabin smoke or malfunction of an associated aircraft system. Where covers or bungs are provided they should be fitted during de-icing operations. Where this is not possible care must be taken to prevent direct impingement of the spray on any vents or probes.

5.3.2 High pressure sprays can also cause erosion of the aircraft skin and some aircraft manufacturers recommend a maximum impingement pressure which is quoted in the appropriate Maintenance Manual and should not be exceeded.

### 5.4 De-icing of Aircraft with Engines Operating

5.4.1 Aircraft 'taxi-through' de-icing facilities are presently being used which de-ice aircraft with the engines operating. Winter environmental conditions and the manner of application create potentially unsafe conditions if an incorrect de-icer solution is inadvertently sprayed into the engine/APU inlets or contacts the exhausts when the engines or APU are operating. APU and engine bleeds should be closed during such operations to minimise the risk of contamination of the cabin environment.

5.4.2 De-icing fluids have a flashpoint of  $139$  to  $156^{\circ}\text{C}$  in their undiluted state which is within the engine/APU operating range. The numerous de-icing fluids available also include some which have toxic characteristics that could affect personnel or passengers if ingested by the air-conditioning system.

5.4.3 Some aircraft manufacturers issue instructions which contain precautions concerning fluids and techniques for de-icing aircraft with engines operating. A safety hazard could exist if the manufacturer's instructions are not followed.

5.4.4 Safeguards should include procedures which ensure that de-icing fluids are diluted below critical flashpoints and that such fluids are prevented from entering air ducts, air-conditioning systems, and engines/APU inlets or exhaust.

5.4.5 Fire and emergency equipment should also be readily available at all times.

**6 ANTI-ICING MEASURES**

6.1 When used as an anti-icing agent, the FPD fluid should be sprayed onto the aircraft cold and undiluted, either before the onset of icing conditions or after hot de-icing has been carried out. This will leave a film of fluid approximately 0.5 mm (0.020 in) thick on the surfaces sprayed and give protection overnight in all but the most severe weather conditions. The fluid prevents ice and snow from sticking to the aircraft skin and given time will melt any fresh precipitation. Newly fallen snow may be quickly removed by blowing, and heavy ice deposits, such as those produced by freezing rain, may be removed by a light and economical spray of hot fluid. Excess fluid will shear off during the take-off run (but see paragraph 5.2.2 Note).

NOTE: FPD compound should not be applied to windscreens or essential glazed panels as it will severely restrict vision.

6.2 On some aircraft not equipped with an aerofoil de-icing system, the use of a de-icing paste may be specified. This paste is intended to prevent the accumulation of frozen deposits which may result from inadvertent flight into icing conditions. When spread smoothly by hand over the leading edges of the wings and tail unit the paste presents a chemically active surface, on which ice may form but may not bond. Any ice which does form may ultimately be blown off in the airstream.

6.2.1 The paste should be reactivated before each flight in accordance with the manufacturer's instructions.

WARNING: It is important to note that de-icing pastes do not constitute an approved method of de-icing otherwise unprotected aircraft for intended flights into known or forecast icing conditions.

**7 INSPECTION AFTER DE-ICING OPERATIONS** It is important to carry out an inspection of an aircraft after completion of de-icing operations. The aircraft should also be continually monitored between de-icing and departure to ensure no further ice build-up has occurred. The presence of ice in certain areas may not be obvious to personnel handling the de-icing equipment.

NOTE: The effective duration of anti-icing fluids depends on concentration/temperature of application, volume of snow and ice, etc., subsequent ambient temperature and time.

7.1 All external surfaces should be examined for signs of residual snow or ice, particularly in the vicinity of control surface gaps and hinges. This is especially important where control surfaces are sealed by 'curtains' of the Westland-Irvine type. Drainage or pressure sensing holes and radiator honeycombs should be checked to ensure that they are not blocked. Where it has been necessary to physically remove a layer of snow all protrusions and vents should be examined for signs of damage.

7.2 Where possible, control surfaces should be moved by hand to ascertain that they have full and free movement. Where this is not possible the pilot's controls should be gently operated, bearing in mind that power operated controls exert considerable force on the control surface and could cause damage if any part of the circuit is frozen. If any restriction is found, the control cables, pulleys, fairleads, hinges, etc., should be examined and any frozen deposits treated with de-icing fluid until smooth control operation is achieved.

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- 7.3 The landing gear mechanism, doors, bays and wheel brakes should be inspected for snow or ice deposits, and the operation of uplocks and microswitches checked. In very severe conditions it is possible for the tyres to become frozen to the ground; they may be freed by the application of warm air to the ice (not the tyre) and the aircraft should then be moved to a dry area.
  - 7.4 Snow or rain can enter jet engine intakes after flight and freeze in the compressor when the engine has cooled. If compressors cannot be turned by hand for this reason, the engine should be blown through with hot air immediately before starting, until the rotating parts are free.
  - 7.5 The low temperatures associated with icing conditions may also introduce problems apart from those associated with the clearance of precipitation.
    - 7.5.1 Contraction of metal parts and seals can lead to fluid leakage and particular attention should be given to landing gear shock absorber struts and hydraulic jacks.
    - 7.5.2 Tyre and shock absorber strut pressures reduce with temperature and may require adjustment in accordance with the loading requirements.
- 8 TECHNICAL LOGS** An entry should be made in the Technical Log as required by British Civil Airworthiness Requirements, Section A, Chapter A6-8, unless an alternative company procedure has been agreed by the CAA.
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**AL/11-4**

Issue 2

June 1986

**AIRCRAFT****ICE PROTECTION****WINDSCREEN DE-ICING AND ANTI-ICING SYSTEMS**

- 1 **INTRODUCTION** This Leaflet gives details of operating principles and general guidance on the installation and maintenance of windscreen de-icing and anti-icing systems employing fluids and electrical heating elements. It should be read in conjunction with the Maintenance Manuals and operators Maintenance Schedules for the type of aircraft concerned. Reference should also be made to Leaflet AL/7-10, Glass Windscreen Assemblies, for information on the construction, installation and maintenance of windscreens.
  
- 2 **FLUID DE-ICING SYSTEM** The method employed in this system is to spray the windscreen panel with a methyl-alcohol based fluid. The principal components of the system are a fluid storage tank, a pump which may be a hand-operated or electrically-operated type, supply pipe lines and spray tube unit. Figure 1 illustrates the interconnection of components based on a typical aircraft system in which fluid is supplied to the spray tubes by two electrically-operated pumps. The system may be operated using either of the pumps or both, according to the severity of icing.
  
- 3 **ELECTRICAL ANTI-ICING SYSTEM** This system employs a windscreen of special laminated construction heated electrically to prevent, not only the formation of ice and mist, but also to improve the impact resistance of the windscreen at low temperatures (see Leaflet AL/7-10 paragraph 3.1.2).
  - 3.1 The film-type resistance element is heated by alternating current supplied from the aircraft's electrical system. The power required for heating varies according to the size of the panel and the heat required to suit the operating conditions. Details of these requirements are given in the relevant aircraft Maintenance Manual.
  - 3.2 The circuit embodies a controlling device, the function of which is to maintain a constant temperature at the windscreen and also to prevent overheating of the vinyl interlayer which would cause such permanent damage as vinyl 'bubbling' and discolouration (see also Leaflet AL/7-10 paragraphs 5.1.6 and 5.1.7). In a typical anti-icing system shown schematically in Figure 2, the controlling device is connected to two temperature sensing elements laminated into the windscreen. The elements are usually in the form of a fine wire grid, the electrical resistance of which varies directly with the windscreen temperature. One sensing element is used for controlling the temperature at a normal setting and the other is used for overheat protection. A system of warning lights and, in some cases, magnetic indicators, also forms part of the control circuit and provides visual indications of circuit operating conditions, e.g. 'normal', 'off' or 'overheat'.
    - 3.2.1 When the power is applied via the system control switch and power relay, the resistance element heats the glass. When it attains a temperature pre-determined for normal operation the change in resistance of the control element causes the control

# AL/11-4

device or circuit to isolate, or in some cases to reduce, the power supply to the heater element. When the glass has cooled through a certain range of temperature, power is again applied and the cycle is repeated. In the event of a failure of the controller, the glass temperature will rise until the setting of the overheat sensing element is attained. At this setting an overheat control circuit cuts off the heating power supply and illuminates a warning light. The power is restored and the warning light extinguished when the glass has cooled through a specific temperature range. In some systems a lock-out circuit may be incorporated, in which case the warning light will remain illuminated and power will only be re-applied by cycling the system control switch to 'OFF' and back to 'ON'.

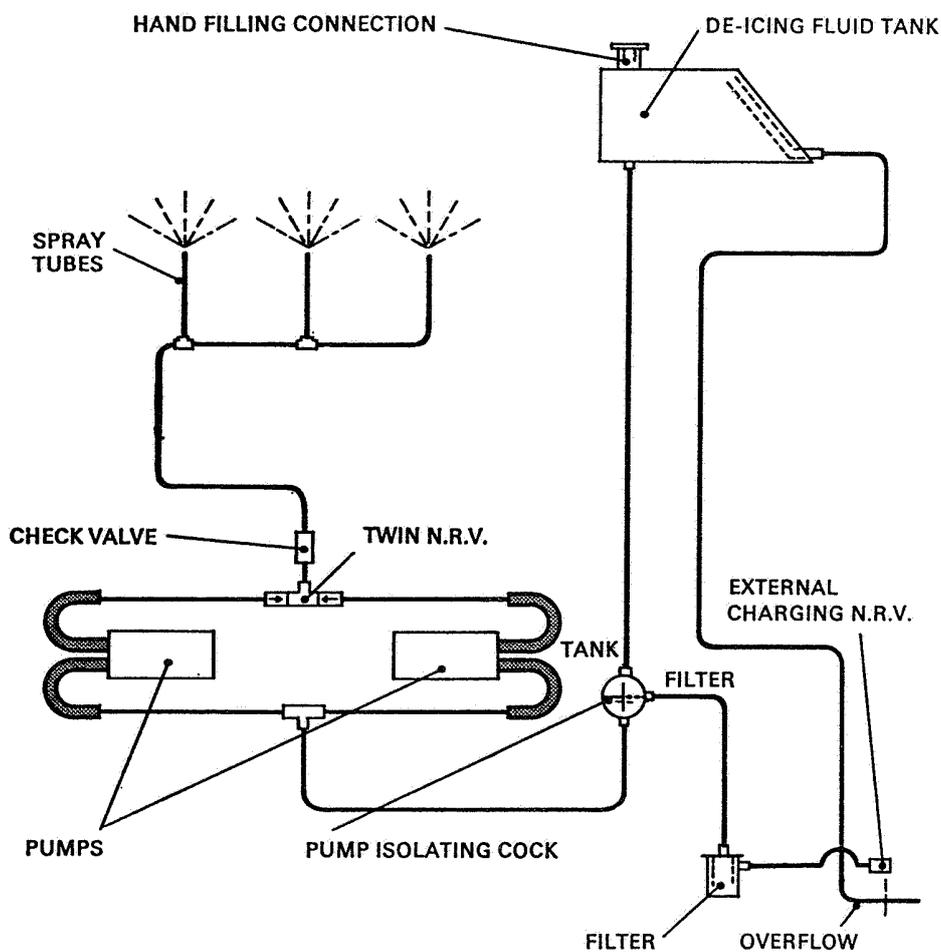


Figure 1 TYPICAL FLUID DE-ICING SYSTEM

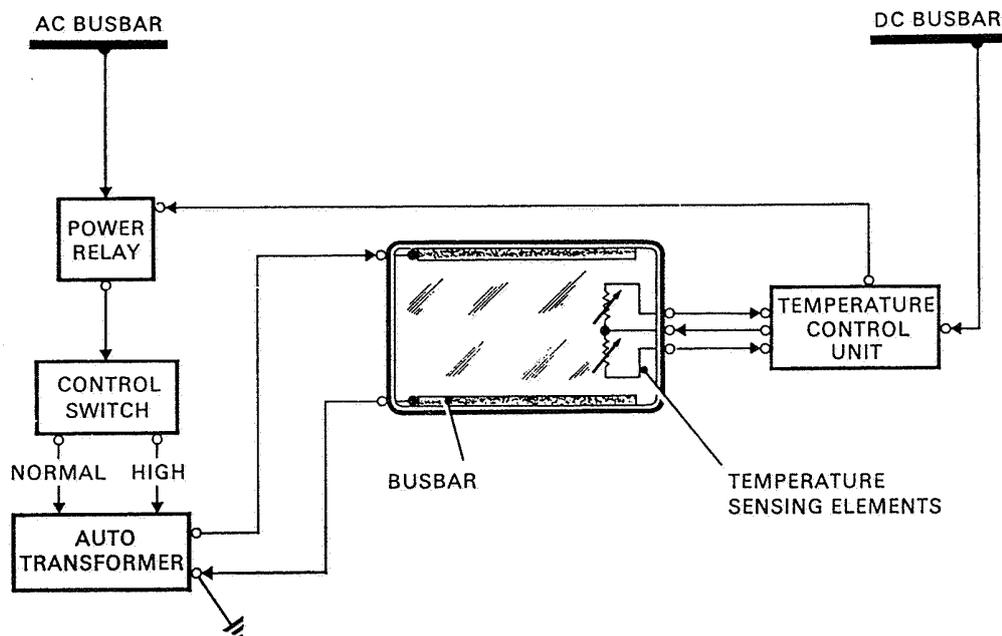


Figure 2 TYPICAL ELECTRICAL ANTI-ICING SYSTEM

- (a) In addition to the normal temperature control circuit it is usual to incorporate a circuit which supplies more heating power under severe icing conditions when heat losses are high. When the high power setting is selected, the supply is switched to higher voltage output tappings of an auto transformer which also forms part of an anti-icing system circuit thus maintaining the normal operating temperature. The temperature is controlled in a manner similar to that of the normal control temperature circuit.
- (b) For ground testing purposes, the heating power supply circuit may also be controlled by landing gear shock-strut microswitches in such a way that the voltage applied to the resistance elements is lower than that normally available in flight.

4 INSTALLATION AND MAINTENANCE Details of the installation methods and maintenance requirements for a particular aircraft system will be found in the Maintenance Manual and approved Maintenance Schedules for the aircraft concerned. The information given in the following paragraphs is intended as a guide and should be read in conjunction with relevant Maintenance Manuals and approved Maintenance Schedules. Reference should also be made to Leaflets AL/3-13, AL/3-14 and AL/3-15 which deal with the installation of pipelines and supply tanks, and Leaflets EEL/1-6 and EEL/3-1 for guidance on the installation of electric cables and testing of circuits.

4.1 Fluid De-icing Systems. The installation and maintenance of components and pipelines of fluid de-icing systems is, in general, a straightforward procedure and only requires checks to ensure security of attachment to appropriate parts of the aircraft structure, signs of fluid leakage, security of connections and wirelocking where necessary. After installation of a component and at the periods detailed in the aircraft approved

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Maintenance Schedule, the tank contents should be checked and replenished with the specified fluid as necessary. The system should also be tested to ensure proper functioning and checks made for fluid leakage at the connections of the various components. Fluid filters, where fitted, should also be inspected for cleanliness.

**4.1.1 Tank Replenishment.** A tank is normally filled by hand through a filler neck in the tank, but in some systems an external charging connection (see Figure 1) is provided for the purpose of pressure filling. An isolating cock at the charging connection location is fitted in the line between tank and pumps and has a third connection which must be coupled to the charging connection before filling. A hand pump should be used for pressure filling to avoid excessive pressure build-up within the tank. On completion of a tank replenishment process, filler caps or blanking plugs must be replaced and correctly secured, isolating cocks returned to their normal operating condition and wirelocked.

NOTE: Care should be taken to avoid spillage of fluid during tank replenishing, and drips should be removed immediately. In a system employing a tank having an overflow pipe a receptacle should be placed at the pipe outlet to catch any fluid.

**4.1.2 Testing of Systems.** With the tank filled with de-icing fluid the pump, or pumps, should be operated and a check made that an even amount of fluid discharges from the spray unit, and is directed on to the panels. Receptacles should be positioned to catch the fluid and any spillage should be removed immediately. The system pipelines and couplings should be checked for fluid leakage. On satisfactory completion of all checks the fluid tank should be replenished.

**4.2 Electrical Anti-icing Systems.** Before installation, the electrical resistance of the conducting film and the temperature sensing elements should be measured to ensure that it is within the limits specified in the relevant aircraft Maintenance Manual. The resistances of conducting films may, in some cases, have to be matched by selective assembly. In certain types of aircraft an indication of conducting film resistance is also given by a code number etched in the corner of the glass near the busbar terminals.

**4.2.1** The power supply and temperature sensing circuit cables should be identified in accordance with the system wiring diagram and connected to their appropriate terminals. The terminals on the windscreen and cable end connections should be checked for contamination such as grease or paint before making connections. This check applies particularly to sensing circuit terminals since contamination could increase the circuit resistance, signalling to the control unit that the windscreen was continuously hot thereby stopping the power supply.

**4.2.2** Auto transformers are provided with several voltage output tapings which permit the voltage to be varied appropriate to heating element resistance, e.g. the resistance increases with age, and so it would be necessary to increase the applied voltage. Cables must therefore be connected to the transformer tapings detailed in the relevant Maintenance Manual, to ensure correct operating temperatures and adequate protection against ice.

**4.2.3** The type of temperature control unit varies between types of aircraft and system; it is therefore necessary to check part numbers to ensure that a unit is correct for the supply voltage and sensing element circuit resistance requirements. In some units potentiometers, or fine adjustment resistances, are provided to vary the temperature controlling point. These are preset and must not be disturbed after installation of the unit.

**4.2.4** At the periods specified in the approved Maintenance Schedule, all components should be checked for security of attachment, security of electrical connections and for evidence of any damage. System functioning checks should also be carried out.

4.2.5 **Testing of Systems.** The method of testing varies between individual systems; reference should therefore be made to relevant aircraft Maintenance Manuals for details of procedure to be adopted, specific test equipment required and also for any precautions to be observed. There are, however, aspects of testing and certain precautions which are of a standard nature, and these are summarised for guidance as follows:—

- (a) In general, test procedures are principally concerned with the checking of the electrical resistance of heating films and temperature sensing elements, checking of the voltages applied at selected system operating conditions, e.g. 'normal', 'low' and 'high' settings of a system control switch and also checking of insulation resistance between circuits.
  - (b) Electrical power should always be applied initially at low intensity and the windscreen allowed to warm up gradually thus minimising the effects of thermal shock stresses.
  - (c) When carrying out resistance and voltage checks of some anti-icing systems it is necessary to isolate the overheat sensing element circuit. In such cases, the period of time during which power is applied to the heating elements must be kept to a minimum to avoid overheating of the windscreens.
  - (d) In systems incorporating electrically heated direct vision and other side windows, the circuits to these windows must be checked at the same time as the windscreen anti-icing system checks.
  - (e) During ground testing attention should be paid to the effect of ambient temperature and strong sunlight on the behaviour of temperature control systems. Ambient temperatures approaching those of the normal operating temperature of windscreens will result in a very brief application of power, followed by no power for a considerable period. In some instances power will not be applied at all. It is possible, therefore, to be misled into believing that a serviceable system is malfunctioning. Where it is necessary to carry out system tests and checks in such conditions, it is recommended that the aircraft be positioned in the shade or in a hangar if practicable, and also that cool wet cloths be applied to the windscreens thereby lowering their temperature prior to switching on the power. Bearing in mind thermal shock stresses, the use of ice should be avoided.
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**AL/11-5**

Issue 2

June 1986

## AIRCRAFT

### ICE PROTECTION

#### FLUID DE-ICING SYSTEMS

- 1 **INTRODUCTION** This Leaflet gives general guidance on the installation and maintenance of fluid systems used in certain types of aircraft, for de-icing wings and tail units. It should be read in conjunction with Maintenance Manuals and approved Maintenance Schedules; such documents providing details of construction, major servicing and test procedures relevant to specific aircraft installations and components.
- 2 **GENERAL** In systems of this type, a de-icing fluid is drawn from a storage tank by an electrically driven pump and fed through micro filters to a number of porous metal distributor panels. The panels are formed to the profiles of the wing and tail unit leading edges into which they are fitted. At each panel the fluid passes into a cavity, and then through a porous plastic sheet to a porous stainless steel outer skin. As the fluid escapes it breaks the bond between ice and the outer skin and the fluid and ice together are directed rearward, by the airflow, over the aerofoil.

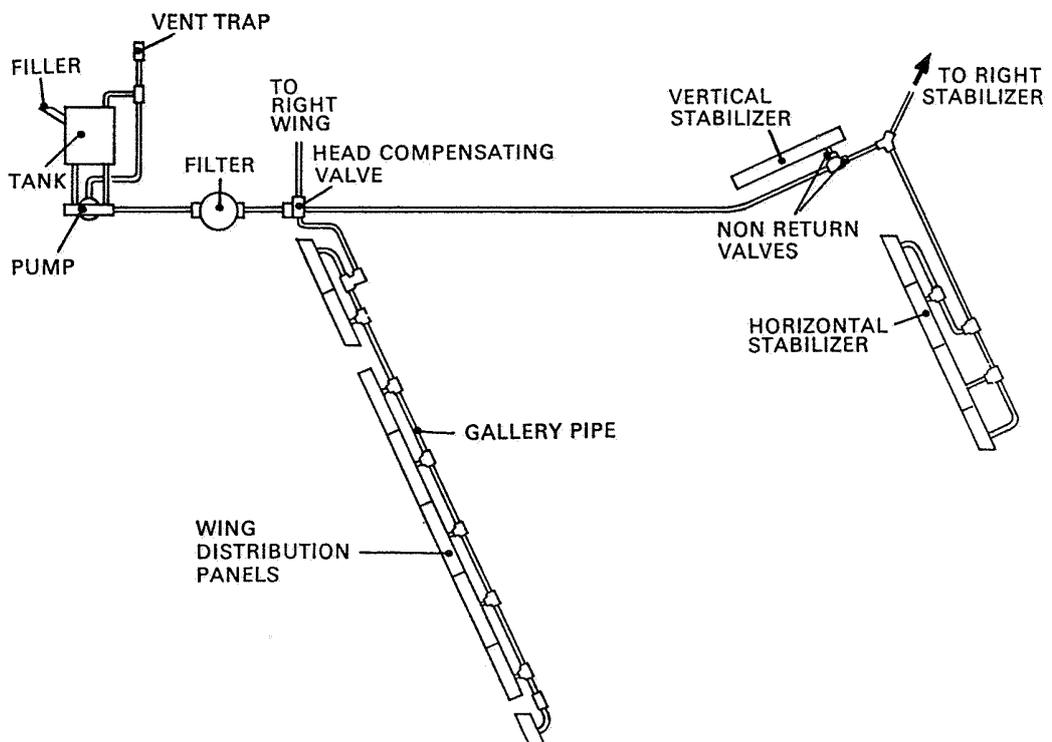


Figure 1 TYPICAL FLUID DE-ICING SYSTEM

## AL/11-5

- 2.1 The interconnection of components of a typical fluid de-icing system is shown in Figure 1. The head compensating valve is fitted in some types of aircraft to correct for variations in system pressure (head effect) due to differences in level between the wings, horizontal and vertical stabilisers. The non-return valves prevent back flow when the system is inoperative. Nylon pipelines are usually used throughout the system; those for the main fluid supply being of 8 mm ( $\frac{5}{16}$  in) inch outside diameter and those for connections to individual distributor panels of 4.7 mm ( $\frac{3}{16}$  in) outside diameter.
- 2.2 A sectional view of a typical distributor panel is shown in Figure 2. The connector contains a metering tube which is accurately calibrated to provide the required rate of fluid flow through the distributor. In some aircraft the metering of fluid to the distributor panels is done via proportioning units containing the corresponding number of metering tubes.

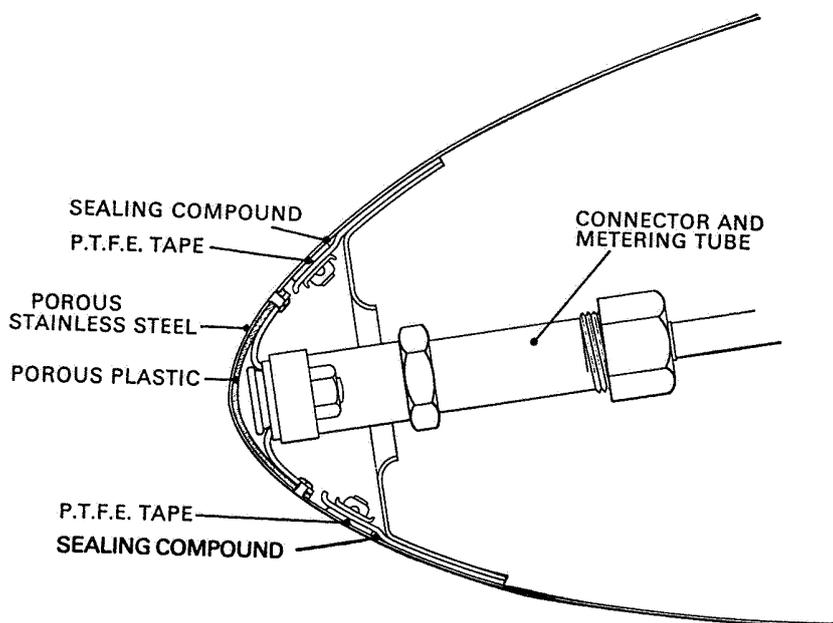


Figure 2. SECTION OF A TYPICAL DISTRIBUTOR PANEL

- 2.2.1 To prevent electrolytic corrosion, plastic sealing strips are interposed between the stainless steel panel and the metal used in the aerofoil structure. In some installations (see Figure 2) an epoxy resin sealing compound is used, and to facilitate the removal of a panel it is sprayed along its edges with a thin coating of polytetrafluorethylene (p.t.f.e.) to act as a release agent. In addition, a strip of p.t.f.e. tape may be laid along the mating surfaces of the aerofoil structure.
- 3 **INSTALLATION AND MAINTENANCE** Details of the installation methods and maintenance requirements for a particular aircraft de-icing system will be found in the Maintenance Manual and approved Maintenance Schedule for the aircraft concerned. The information given in the following paragraphs is intended as a guide and should be read in conjunction with such manuals and schedules. Reference should also be made to

Leaflets AL/3-13, AL/3-14 and AL/3-15 which contain information relevant to the installation of pipelines and supply tanks, and Leaflets EEL/3-1 and EEL/1-6 for guidance on the installation of electric cables and testing of circuits.

**3.1 Distributor Panels.** Before installation of a distributor panel the part number should be checked to ensure that it is the correct type for the aircraft. Where aerofoils are not symmetrical odd part numbers usually indicate a left-hand component and even numbers right-hand. A check should also be made for signs of corrosion, damage and deformation of the panel profile. Panels which are to be sealed by an epoxy resin compound should also be checked to ensure that the coating of p.t.f.e. release agent is undamaged.

**3.1.1** New seals should be fitted to the pipe union of the panel and the pipeline securely coupled and wire-locked. The system pump should be switched on to prime the distributor panel and a check made on the pipe coupling for signs of fluid leakage.

**NOTE:** Care should be taken to prevent de-icing fluid from running along the surfaces of aerofoils and adjacent parts of the structure.

**3.1.2** On satisfactory completion of the leakage check, the de-icing pump should be switched off and the distributor panel secured to the structure in the manner specified for the installation. Attachment screws must be tightened evenly; during tightening, checks should be made to ensure that no distortion of the panel takes place.

**3.1.3** After installation of a panel, a check should be made to ensure that a smooth and continuous profile, free from high spots or depressions, is maintained both chordwise and spanwise. Where specified, special shims may be fitted under a distributor panel to maintain a smooth profile.

**NOTE:** After installing distributor panels on some types of aircraft, a test flight must be carried out to check the stall characteristics.

**3.1.4** When an epoxy resin compound is required for sealing a panel-to-wing joint, it must be applied uniformly to maintain a smooth and continuous profile. Care must be taken to prevent the compound coming into contact with the porous surface of the panel.

**3.1.5** Metering tubes are removeable items and are calibrated according to panel part numbers in order to achieve the correct flow rate at the appropriate locations. It is essential therefore, that when it is necessary to remove and refit a metering tube it should first be identified with its distributor panel. A new rubber sealing grommet must be fitted and the distance from the end of the metering tube checked to ensure that it corresponds to the value given in the relevant aircraft Maintenance Manual.

**3.1.6** Dirt accumulated on the panels in service should be removed with a clean water spray and soft brush. A mild detergent and water solution may also be used.

**NOTE:** The surfaces of distributor panels must not be cleaned with polishing materials or solvents.

**3.1.7** During repainting of an aircraft, distributor panels should be masked with a non-adhesive material attached to the panels at the top and bottom edges only, by masking tape.

**3.1.8** Care must be taken to avoid damaging the panels, particularly when refuelling. The refuelling hose must not be allowed to rest on, or vibrate against, the wing leading edge.

**3.2 Fluid Storage Tank.** Before installation, the tank should be inspected for signs of damage and interior cleanliness, and the tank supporting structure checked to ensure that it is in a suitable condition to receive the tank. With the tank accurately positioned it should be firmly secured by the mounting straps or mounting bolts as appropriate to the type of tank. Blanks should be removed from all pipe unions, new sealing rings fitted and the pipelines connected and wire-locked.

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3.2.1 In a system utilising a tank with an electrical fluid contents indicating system the insulation resistance between the tank and earth should be checked to ensure that it is within the value specified in the relevant aircraft Maintenance Manual. The attachment of the tank transmitter unit and cable connections should be checked for security. Indicating systems should be checked and adjusted in the manner specified in the relevant Maintenance Manual.

3.2.2 After the installation of a tank, and whenever system priming operations and test procedures are carried out, the tank contents should be checked and replenished with the specified fluid as necessary. Replenishment of a tank is normally carried out by hand through a filler connection in the tank itself. Before refitting the filler cap, the sealing washer should be checked for serviceability and replaced as necessary. Strainers, when fitted, should be checked for serviceability and cleanliness.

NOTES: (1) The specification number of the fluid should be stencilled on the structure above the tank filler aperture.

(2) Care should be taken to avoid spillage of fluid during tank replenishing, and drips should be removed on completion.

3.3 **Pumps.** Before installing a pump it should be inspected for signs of damage, and checks made that the part number of the pump is correct for the particular installation. An electrical power supply at the specified voltage should be connected to the pump motor and a functioning check carried out.

NOTE: The inhibiting fluid should be retained in the pump for the functioning check, the duration of which should not exceed the figure specified for the particular type of pump. Dry running of a pump is not permissible.

3.3.1 On completion of the functioning check, the pump should be drained of inhibiting fluid and secured to its mounting. New sealing rings should be fitted to the pump and pipeline connections and the union nuts tightened to the specified torque values and wire-locked. The tank should be filled and the pump connections checked for signs of fluid leakage.

3.3.2 Electrical connections and pump bonding lead must be securely made and the pump operated to check that fluid is delivered to the distributor panels. If fluid is not pumped through the system the pump should be switched off immediately and the cause of the fault investigated and rectified.

3.3.3 If a pump is to be removed from an aircraft for a period exceeding 10 days, it must be inhibited with fluid to Specification DTD 5540B and all pipe connecting unions blanked off with protection caps.

3.4 **Pipelines and Couplings.** Pipelines should be supported by clips spaced not more than 457.2 mm (18 in) apart. Where there is more than one pipe in a run the pipes should be strapped together at approximately every 152.4 mm (6 in).

3.4.1 The ends of nylon pipes are connected to their respective unions by an olive and a sealing ring. Before connecting a pipe the olive must be inspected to ensure that it is firmly clenched to the pipe; the pipe should extend approximately 6.3 mm (0.25 in) beyond the clenched end of the olive. A new sealing ring must be fitted over the end of the pipe and to butt against the olive, and after the pipe is inserted into its coupling, the ring must be carefully packed into the recess.

NOTE: An olive must be fully clenched as a separate operation before the introduction of the sealing ring. Any attempt to clench the olive with the ring in position will destroy the ring and prevent the olive from locking correctly on to the pipe. Sealing rings must be correctly located and not twisted or damaged.

3.4.2 Pipelines should not be crushed or kinked and the minimum bend radii should comply with the dimensions specified in the relevant Maintenance Manual.

- 3.5 **Proportioning Units.** Before installing proportioning units a check should be made that they are of the correct type. Units are identified in two ways; by the part number which includes a variation number relating to the calibration, and by a description of the aircraft type and location for which each unit is calibrated.
- 3.5.1 Pipelines should be checked to ensure that the outlets of the proportioning units are connected to their respective distributor panels in the correct sequence.
- 3.5.2 If a metering unit becomes blocked it should be removed and its tubes cleaned with compressed air. During re-assembly of the unit the sealing washer and locating key must fit correctly in the manifold.
- 3.6 **Filters.** After installation, the system should be operated until fluid flows from the filter outlet connection or, if provided, from a bleed screw hole. The pump should then be switched off and the filter outlet connection or bleed screw as appropriate, refitted.
- 3.6.1 The filter element must be renewed at the period specified in the approved Maintenance Schedule. At the time of element renewal the other component parts of the filter should be thoroughly washed in warm water using a soft brush. On re-assembly of the filter, new sealing washers and rings should be fitted, the unit bled and checks made for signs of leakage.
- 3.7 **Priming and Testing.** After the installation of a component in the de-icing system and at the periods specified in approved Maintenance Schedules, priming and functional testing of the system should be carried out in the manner specified in the relevant aircraft Maintenance Manual. In general, the procedures are straightforward and usually require a check to ensure that the tank is full and that, when the pump is operated, fluid flows out from each of the distributor panels.
- 3.7.1 On completion of the tests, all pipeline connections should be checked for signs of fluid leakage and the tank replenished with fluid (see also paragraph 3.2.2). Any fluid which may have run on to the structure adjacent to distributor panels, should be washed off with water. Fluid should also be washed from the surfaces of the distributor panels by means of a water spray.
- 3.8 **Inhibiting of Systems.** For certain types of aircraft operating under hot dry climatic conditions, it may not be necessary to use the de-icing system. In such cases the system should be drained of de-icing fluid and inhibited with fluid to Specification DTD 5540B in the manner prescribed in the relevant aircraft Maintenance Manual. If prolonged storage of an aircraft is necessary the de-icing system should also be similarly drained and inhibited.
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**AL/11-6**

Issue 1.

December, 1978.

**AIRCRAFT****ICE PROTECTION****ICE DETECTION SYSTEMS**

**1 INTRODUCTION** This Leaflet gives brief details of the operating principles, and guidance on the installation and maintenance, of ice detection systems. This information is not related to any particular aircraft installation and should, therefore, be read in conjunction with the relevant aircraft Maintenance Manuals and Maintenance Schedules. Information on associated subjects is contained in Leaflets AL/11-1—Pneumatic De-icing Systems, AL/11-2—Thermal (Hot Gas) De-icing Systems, AL/11-4—Windscreen De-icing and Anti-icing Systems, AL/11-5—Fluid De-icing Systems, and AL/10-1—Pitot Static Systems. The regulations regarding the use of ice detection equipment is contained in Chapter D4—7 of British Civil Airworthiness Requirements.

1.1 Ice Detection Systems use one of the following methods of detecting and assessing the formation of ice.

- (a) **Ice Accretion Method.** Ice is allowed to accumulate on a probe which projects into the airstream and in doing so operates a warning system.
- (b) **Inferential Method.** Atmospheric conditions conducive to the formation of ice are detected and continuously evaluated to operate a warning system.

NOTE: The inferential method of ice detection is not usually employed in series aircraft, but is used extensively in wind tunnels and on flight trials for aircraft certification.

**2 THEORY OF ICING** Icing on aircraft is caused primarily by the presence of super-cooled water droplets in the atmosphere. If the droplets impinge on the forward facing surfaces of an aircraft, they freeze and cause a build up of ice which may seriously alter the aerodynamic qualities. This applies particularly to small objects, which have a higher catch rate efficiency than large ones, as small amounts of ice will produce relatively bigger changes in shape. The actual amount and shape of the ice build up depends on surface temperature, which results from an energy balance arising from heat input from viscous or kinetic air heating, kinetic heating by water droplets and the latent heat of fusion, and losses from evaporation or sublimation, convection and by warming the impinging droplets.

2.1 Three different situations arise, depending on whether the surface temperature is less than, equal to or greater than 0°C. When the temperature is less than 0°C all the impinging water droplets are frozen, and when it is above 0°C none are frozen. However, for a particular set of atmospheric conditions and altitude it is found that there is quite a wide aircraft speed range over which the energy balance gives a skin temperature of 0°C and this energy balance occurs at one end of the speed range by all the droplets freezing and at the other by none freezing. The potential "catch rate" or "impingement rate" and the actual icing rate are thus not simply related in this region. The "no icing hazard" speed depends, therefore, upon the free water content of the atmosphere as well as the temperature and altitude. For severe conditions it is about the maximum

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speed of subsonic aircraft. The final influencing factor of note is that icing does not occur above about 12 000 m (40,000 ft) since the droplets are all frozen and in the form of ice crystals and will not adhere to the aircraft's surface.

## 3 TYPES OF ICE DETECTOR HEADS

3.1 **Pressure Operated Ice Detector Heads.** These consist of a short stainless steel or chromium plated brass tube, which is closed at its outer end and mounted so that it projects vertically downwards from a portion of the aircraft known to be susceptible to icing. Four small holes are drilled in the leading edge of this tube, and in the trailing edge are two holes of less total area than those of the leading edge (Figure 1). A heater element is fitted to allow the detector head to be cleared of ice. In some units of this type a further restriction to the air flow is provided by means of a baffle mounted through the centre of the tube.

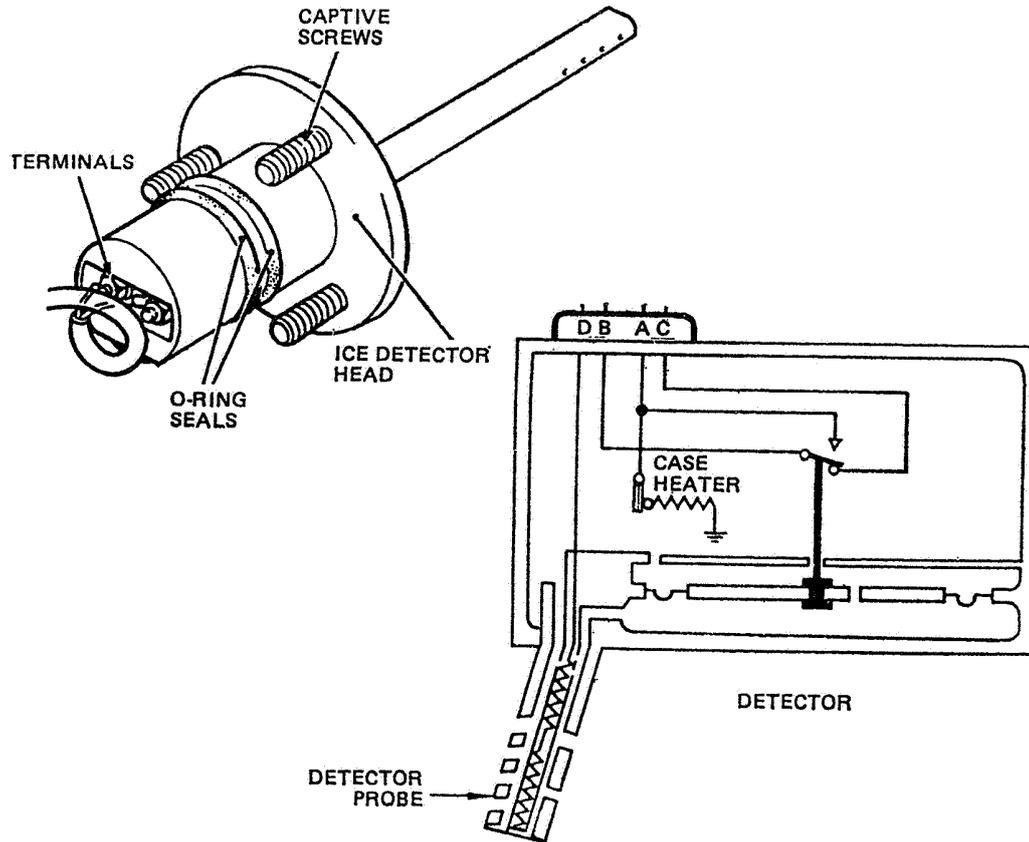


Figure 1 PRESSURE OPERATED ICE DETECTOR HEAD

3.1.1 When, in normal flight, pressure is built up inside the tube by the airstream, this pressure is then communicated, by tubing, to the capsule of an electro-pneumatic relay tending to expand it and separate a pair of electrical contacts. When icing conditions are met, ice will form on the leading edge and close off the holes. As the holes in the trailing edge will not be covered by ice the airstream will now tend to exhaust the system, collapsing the relay capsule and so closing the relay contacts. Generally these contacts operate in conjunction with a thermal device, to illuminate a warning indicator in the flight compartment and to switch on the heater in the detector head; the latter clears the head of ice and is then switched off allowing continued detection of icing conditions. This cycling will continue until such time that the icing conditions no longer exist.

3.2 **Hot Rod Ice Detector Head.** This consists of an aluminium alloy oblong base (called the plinth) on which is mounted a steel tube detector mast of aerofoil section, angled back to approximately  $30^\circ$  from the vertical, mounted on the side of the fuselage, so that it can be seen from the flight compartment windows. The mast houses a heating element, and in the plinth there is a built-in floodlight (Figure 2).

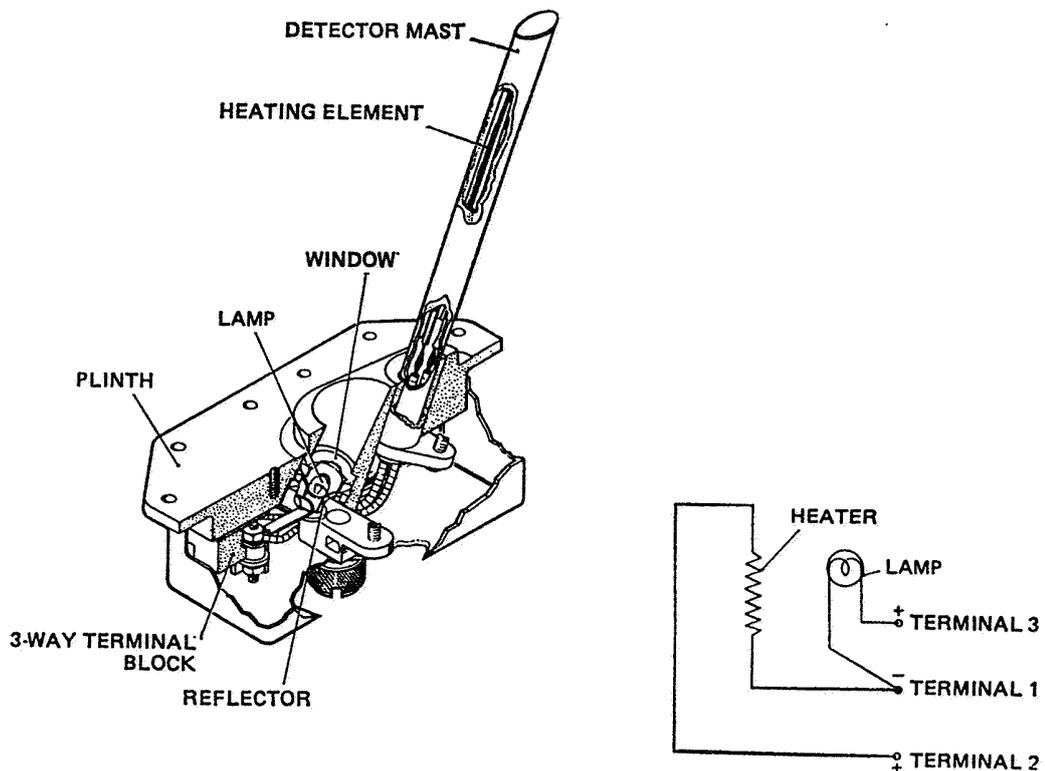


Figure 2 HOT ROD ICE DETECTOR HEAD

# AL/11-6

3.2.1 The heating element is normally off and when icing conditions are met ice accretes on the leading edge of the detector mast. This can then be observed by the flight crew. During night operations the built-in floodlight may be switched on to illuminate the mast. By manual selection of a switch to the heating element the formed ice is dispersed for further observance.

3.3 **Serrated Rotor Ice Detector Head.** This consists of a serrated rotor, incorporating an integral drive shaft coupled to a small a.c. motor via a reduction gearbox, being rotated adjacent to a fixed knife-edge cutter (Figure 3). The motor casing is connected via a spring-tensioned toggle bar to a micro-switch assembly. The motor and gearbox assembly is mounted on a static spigot attached to the motor housing, and together with the micro-switch assembly, is enclosed by a cylindrical housing. The detector is mounted through the fuselage side so that the inner housing is subjected to the ambient conditions with the outer being sealed from the aircraft cabin pressure.

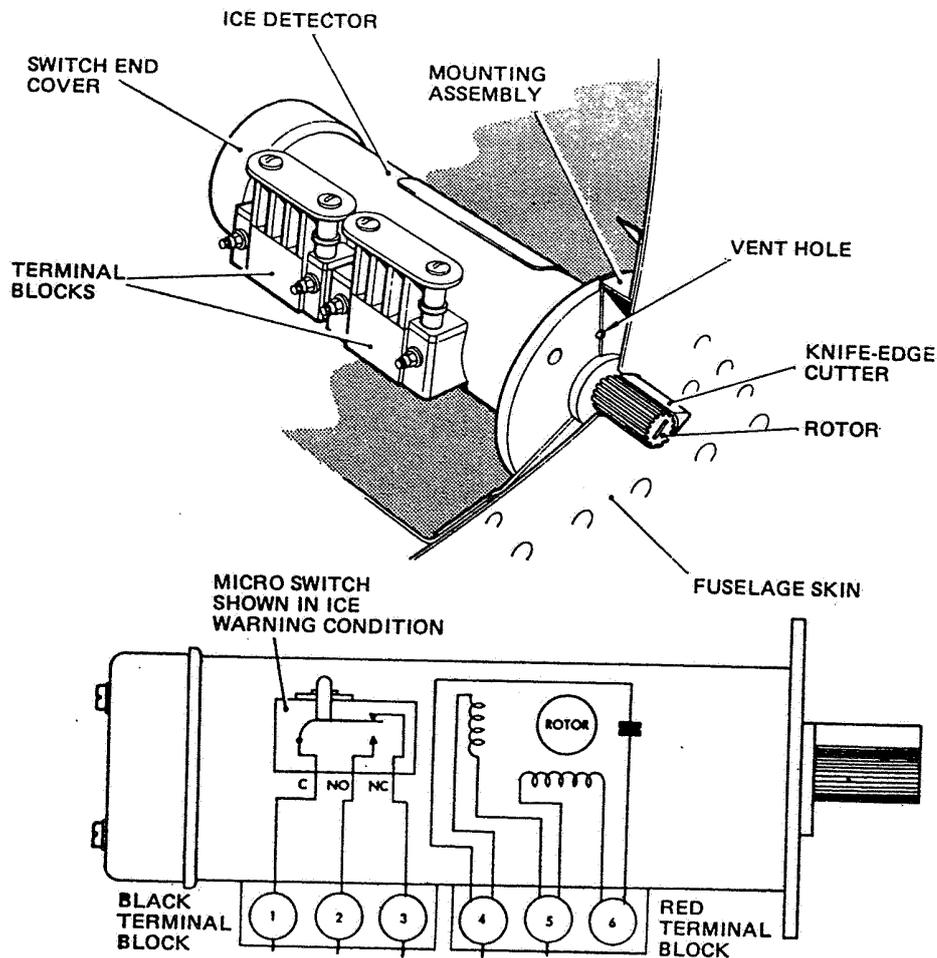


Figure 3 SERRATED ROTOR ICE DETECTOR HEAD

3.3.1 The serrated rotor on the detector head is continuously driven by the electrical motor so that its periphery rotates within 0.050 mm (0.002 in) of the leading edge of the knife-edge cutter. The torque therefore required to drive the rotor under non-icing conditions will be slight, since bearing friction only has to be overcome. Under icing conditions, however, ice will accrete on the rotor until the gap between the rotor and knife edge is filled, whereupon a cutting action by the knife edge will produce a substantial increase in the required torque causing the toggle bar to move against its spring mounting and so operate the micro switch, to initiate a warning signal. Once icing conditions cease, the knife-edge cutter will no longer shave ice, torque loading will reduce and allow the motor to return to its normal position and the micro switch will open-circuit the ice warning indicator.

3.4 **Vibrating Rod Ice Detector Head.** This ice detector senses the presence of icing conditions and provides an indication in the flight compartment that such conditions exist. The system consists of a solid-state ice detector and advisory warning light. The ice detector is attached to the fuselage with its probe protruding through the skin (Figure 4). The ice detector probe (exposed to the airstream) is an ice sensing element that ultrasonically vibrates in an axial mode of its own resonant frequency of approximately 40 KHz.

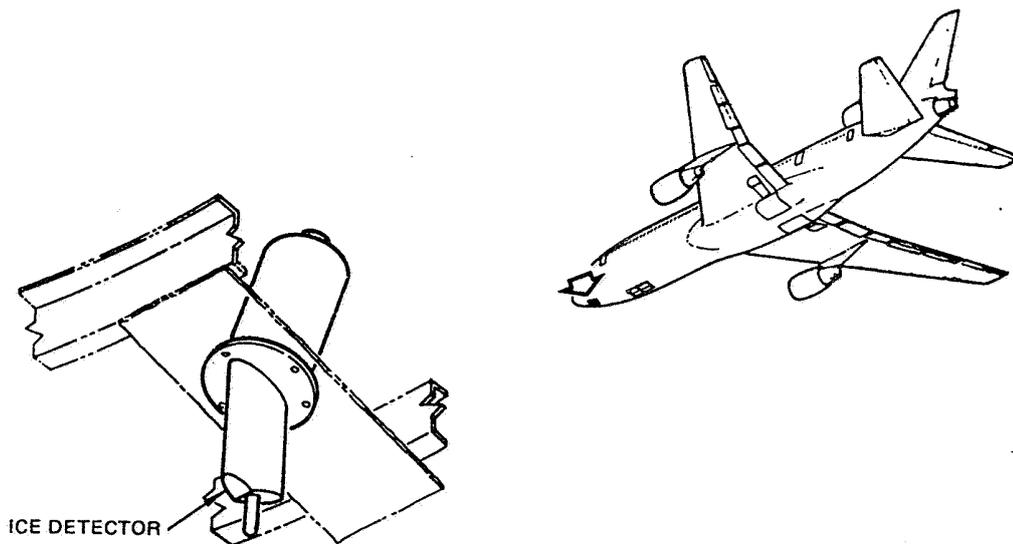


Figure 4 VIBRATING ROD ICE DETECTOR HEAD

3.4.1 When ice forms on the sensing element, the probe frequency decreases. The ice detector circuit detects the change in probe frequency by comparing it with a reference oscillator. At a pre-determined frequency change (proportional to ice build-up), the ice detector circuit is activated. Once activated, the ice warning light in the flight compartment is illuminated and a timer circuit is triggered. The operation of the

## AL/11-6

time circuit switches a probe heater on for a set period of time to remove the ice from the probe. After the timer has timed out, it switches off the ice warning indicator and returns the system to a detector mode, providing that icing conditions no longer exist. If, however, a further ice warning signal is received during the timer period, the timer will be re-triggered, the warning light will remain on and the heater will again be selected on. This cycle will be repeated for as long as the icing conditions prevail.

**3.5 Ice Formation Spot Light.** Many aircraft have two ice formation spot lights mounted one each side of the fuselage, in such a position as to light up the leading edges of the mainplanes, when required, to allow visual examination for ice formation (Figure 5).

NOTE: In some aircraft, this may be the only method of ice detection.

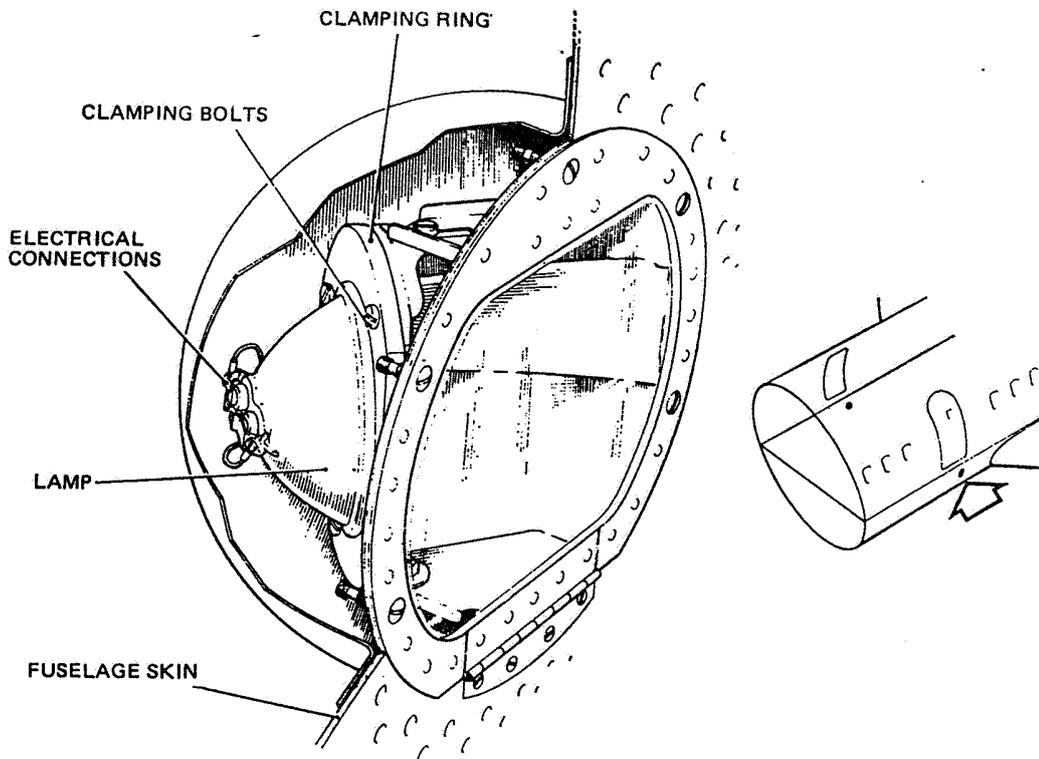


Figure 5 ICE FORMATION SPOT LIGHT

**4 INSTALLATION AND MAINTENANCE** The efficiency of any detection system depends on the suitable positioning of the detectors and on the proper maintenance of all components within the system. For details of particular installations reference should be made to the relevant manuals for the aircraft concerned; information given in the

following paragraphs serves as a general guide to typical maintenance practices. Reference should also be made to Leaflets EEL/3-1 and EEL/1-6 for guidance on the installation of electric cables and testing of circuits, respectively. As some ice detection systems require the use of static pressure for the operation of their associated equipment (which may be an independent static vent or the pitot-static system of the aircraft), reference should also be made to Leaflet AL/10-1—Flight Instruments—Pitot-Static Systems.

#### **4.1 Installation**

- 4.1.1 Before fitting a new detector head the part number should be checked, the head inspected for cleanliness or damage, and a new sealing gasket should be fitted. Where possible an electrical check should be carried out to ensure that continuity and insulation resistance are within the limits quoted in the relevant Maintenance Manual. Testing should be carried out at normal room temperature (20°C), since an elevated temperature would result in different readings being obtained.
- 4.1.2 The end fittings of each detector head, and other components in the system, are protected by caps during storage. These caps should only be removed for testing purposes or immediately before installation. New sealing washers must be fitted whenever a pressure or static pipe line is broken and all parts must be perfectly clean and dry. Coupling nuts should be tightened to the appropriate values, using two spanners to prevent twisting of the pipes or capsule.
- 4.1.3 Electrical connections to the units may be made by terminal posts, or by plugs and sockets; whichever type is used care must be taken to ensure that the contacts are clean. The correct torque loading tool should be used, if called for by the Maintenance Manual.
- 4.1.4 **Bonding.** The methods of testing and inspection will vary with different types of aircraft and the equipment fitted; reference, therefore, must be made to the appropriate Maintenance Manuals for detailed information. Each test requires specified equipment and care should be taken that it is correctly used. Further information on bonding will be found in Leaflet EEL/1-6.
- 4.1.5 **Torque Testing of Serrated Rotor.** The functional testing of the serrated rotor ice detector head is carried out with the use of a torque tester of the type specified by the relevant aircraft Maintenance Manual. Care should be taken so that sufficient torque only is applied to cause the warning system to operate but not enough to stall the motor as this may cause overheating with a subsequent electrical failure (see Figure 6).
- 4.1.6 **Leak Testing of Pressure and Static Lines.** Ice detector systems that are pressure operated and which require a source of static pressure must be tested for leaks after the installation of any component parts, at any time system malfunctioning is suspected, and at periods specified in the aircraft Maintenance Schedule. The method of testing consists basically of applying pressure and suction to detector heads and static vents, respectively, by means of a special leak tester and coupling adapters, and noting that there is no leakage, or that the rate of leakage is within the permissible tolerances prescribed for the system. Leak tests also provide a means of checking that a system is functioning correctly. Specific applications of the basic method of leak testing and the type of equipment recommended depend on the type of aircraft and its ice detector system, and as these are detailed in relevant manufacturer's and aircraft Maintenance Manuals, reference must always be made to these documents.

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There are, however, certain aspects of the procedures and precautions to be observed which are of a standard nature, and these are summarised for guidance as follows:—

- (a) Pressure and suction must always be applied and released slowly to avoid damage to capsules.
- (b) If two static vents are interconnected, one vent should be blanked off before testing is commenced.
- (c) When fitting leak tester adapters to detector heads, care must be taken not to apply loads which tend to disturb their setting.
- (d) When carrying out a leak test on a system that uses the aircraft static pressure system an apparent leak will be indicated by the dropping back of the altimeter pointer until the system stabilises.
- (e) On completion of tests which have necessitated the blanking-off of various sections of a system, a check must be made that all blanking plugs and adapters have been removed.

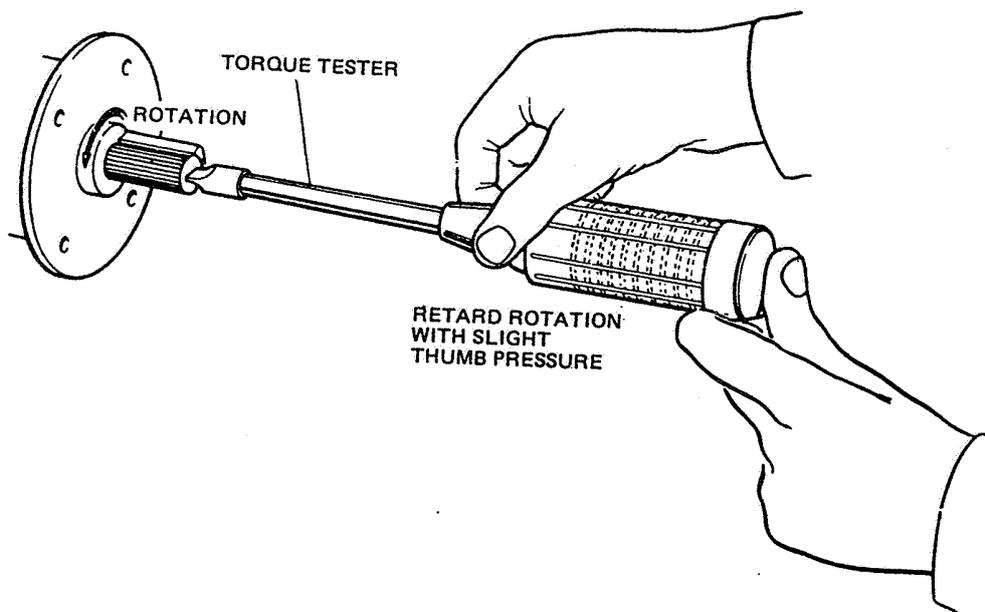


Figure 6 TORQUE TESTING OF SERRATED ROTOR ICE DETECTOR HEAD

4.1.7 When the installation has been completed, operation of the system should be checked in accordance with the relevant aircraft Maintenance Manual, including leak testing as appropriate.

## 4.2 Inspection

**4.2.1 Acceptance Checks.** All components should be examined externally for damage which may have occurred in transit, and sealing caps should be removed to ensure that threads and coupling connections are clean and internal parts undamaged. All caps and protective devices must be refitted for storage unless the components are to be installed immediately. Some components can be bench checked by means of special test sets or fixtures; others should be tested for continuity and insulation resistance, where appropriate. Procedures for the electrical checks vary between installations and reference should be made to the relevant aircraft Maintenance Manual for details of the test requirement for a particular component.

**4.2.2 Function Test.** In view of the difficulty of producing icing conditions, functional tests are mainly related to all other parts of the installation, other than the detector head, except for the head heater unit, with which extreme care should be taken because of the high temperatures that can be obtained. Particular note should be given to the isolation of associated de-icing and anti-icing systems so that possible damage may be avoided.

### 4.2.3 Periodic Checks

- (a) At the intervals prescribed in the approved Maintenance Schedule all components should be examined, in situ, for security of attachment, damage, corrosion or deterioration. Any damage found on detector heads should be compared with the limits laid down in the relevant manuals and components replaced with new ones as necessary. Parts with acceptable physical damage should be given an electrical check to ensure that functioning characteristics and, where applicable, the insulation resistance remains satisfactory. All cable and piping should also be examined for chafing and security of attachment.
- (b) When required by the Maintenance Schedule or when serviceability is suspect, components should be removed, so that they may be properly cleaned and inspected. New sealing gaskets should always be fitted on installation.

NOTE: The time interval between these checks varies considerably and is based on experience gained with each particular aircraft installation. On some aircraft, detector heads are only removed when unserviceable.

## 5 MAINTENANCE OF ICE DETECTOR SYSTEMS

The following paragraphs detail the maintenance generally necessary on ice detector systems and their major components, and should be read in conjunction with the Maintenance Manuals for the type of aircraft and equipment concerned.

**5.1 Detector Heads.** These should be inspected for security of mounting and signs of distortion. Checks should also be made that electrical connections at terminal blocks are secure and the insulation of cables does not show signs of cracking or chafing. The pressure entry and exit holes, and if applicable the static holes, should be inspected to ensure that they are unobstructed.

NOTE: The size of pressure inlet, exhaust, static and drain holes is aerodynamically critical and they must never be cleared of obstruction with tools likely to cause enlargement or burring. In the absence of a special clearing technique, which may be obtained from the manufacturer's or aircraft Maintenance Manual, the use of a stiff non-metallic brush is recommended, taking care not to displace debris into the system and cause obstructions.

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- 5.1.1 **Electrical Checks.** Heating elements should be checked for functioning by ensuring that detector heads commence to warm up when switched on until they are just too hot to hold with the bare hand. The current should then be switched off and the insulation resistance measured, while the head is hot, using the specified tester. The head should then be allowed to cool and the insulation resistance measured again. The resistance values obtained should not be less than those quoted in the relevant Maintenance Manual.
- 5.1.2 **Leakage Tests.** The method of checking for leaks differs with the various types, and in each case the procedures given in the relevant manual should be followed (see paragraph 4.1.6).
- 5.1.3 **Protective Covers.** If the aircraft is to be left standing for prolonged periods, e.g. during overnight parking or hangar maintenance checks, detector heads should be covered with a moulded protective sheath or cover to prevent the entry of foreign matter and contamination by water or other liquids. Any protective sheath or cover should be able to 'breathe', and extreme care should also be taken to ensure that the system heater is not operated. The sheath or cover should be of a prominent colour and have a streamer attached to it to attract attention should a take-off be attempted before removal of the sheath.
- 5.1.4 **Static Vents.** Static vent plates should be inspected to ensure that exposed surfaces are free from scratches, indentations, etc., and that holes are unobstructed and their edges free from burrs and other damage. Mud and dirt should be removed from exposed surfaces with a 'lint-free' cloth to ensure that particles of material are not rubbed off into vent holes. Protection of static vents during long standing periods of the aircraft is effected by blanking the vent holes with special vent plugs. If plugs made from rubber are used they should be able to 'breathe' otherwise pressure differentials can build up, causing the system to operate when power is applied. They should also be periodically inspected for signs of cracking or fracture. This is important since, if part of a fractured rubber plug remains in the vent when the plug assembly is thought to be removed, incorrect operation of the detector will result. The plugs should be of a prominent colour and have a streamer attached, to attract attention should a take-off be attempted before removal of the plugs.
- 5.1.5 **Pipelines.** Pipelines should be checked to ensure freedom from corrosion, kinking and other damage, and that the pipes are securely clamped and their connections tight and locked. Flexible hoses should be carefully inspected for security and evidence of kinking, twisting, deterioration (particularly at the joints between hose and connectors) and other defects. At the periods specified in the aircraft Maintenance Schedule the pressure and static systems should be drained at each of any provided draining points, and pipes disconnected from the equipment and blown through with clean, dry, low-pressure air. To avoid contamination of the adjacent equipment and structure, a suitable container should be placed at the draining points for the collection of water.
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