# EL/5-2

*Issue* 3.

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## AIRCRAFT

## ENGINES

### PISTON ENGINE IGNITION CABLES AND HARNESSES

1 INTRODUCTION

1.1 The procedure outlined in this Leaflet gives general guidance on the installation and maintenance of fully screened high-tension ignition cables and cable harnesses. The information should be read in conjunction with the Maintenance Manual for the type of engine concerned.

1.2 To maintain efficient functioning, the cables and harnesses should be inspected, serviced and tested at the periods which are given in the Approved Maintenance Schedule. It is essential that the test equipment recommended by the manufacturer is used.

1.3 The following Leaflets contain information associated with the subject covered by this Leaflet and reference should be made to these as appropriate.

**EL/3-9** Piston Engines—Magnetos

**EL/5-1** Sparking Plugs

2 GENERAL

2.1 The flow of high tension current along the ignition cables from the magnetos to the sparking plugs results in unwanted electrical radiation which could, if not checked, result in interference with the aircraft radio equipment. Avoidance of interference is achieved by 'screening' the ignition cables by covering them with a metallic braiding which is connected to ground potential. It is also necessary to provide protection against mechanical damage, deterioration and contact with liquids; this is normally achieved either by enclosing the cables in a prefabricated 'ignition harness' (see Figure 1) or by providing an outer covering of neoprene or plastic tubing (see Figure 2).

2.1.1 All types of harness are basically the same in principle, but because of the proprietary nature of the manufacture, both the materials used and the arrangement of details may vary. The three main parts of a typical harness are as follows:—

(a) The body of the harness comprises a rigid metal duct which may be in several parts and may be joined by means of threaded joints. Materials commonly used for these ducts are brass, aluminium alloy, or corrosion resisting steel. The harness assembly is often attached to the engine by means of brackets soldered or brazed to the rigid duct.

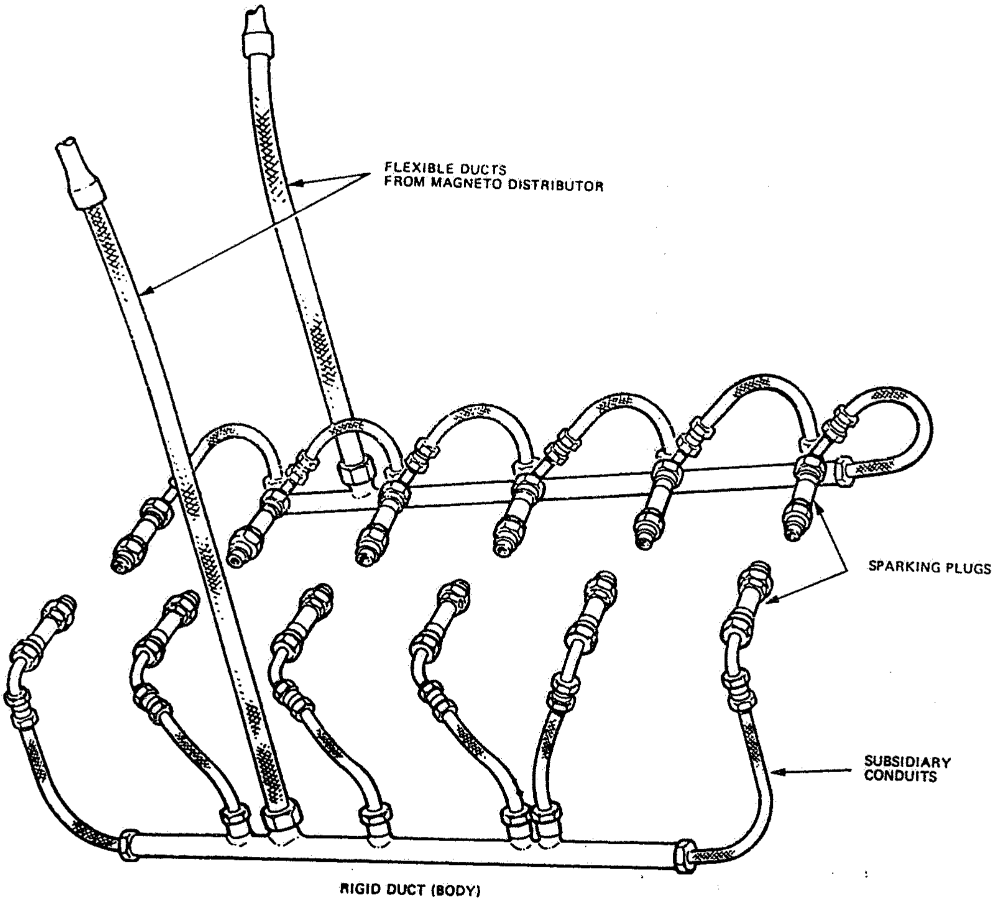


*Figure* 1 IGNITION HARNESS FOR A TYPICAL SIX CYLINDER, IN-LINE ENGINE

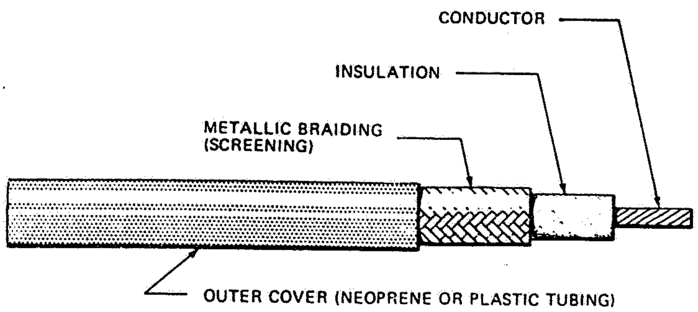


*Figure* 2 IGNITION CABLE WITH PROTECTIVE COVERING

(b) From the rigid duct, large diameter flexible ducts house the cables between the duct and the magneto distributors. These flexible ducts are usually made from a close mesh metallic braiding often of tinned copper or tinned phosphor bronze wire.

(c) The individual ignition cables, which are routed through individual apertures in the rigid duct, are covered with a similar braiding to that described in (b). The cable ends are fitted with metallic connectors for attachment to the sparking plugs and magneto distributors.

## 3 IGNITION HARNESSES

3.1 **Dismantling.** When a harness is removed from an engine and is awaiting dismantling, it should be properly stored so that it is not damaged either physically or by contact with oils or other liquids. The harness should be secured by its attachment brackets to a suitable stand so as to avoid distortion of the subsidiary conduits and ducts, which can easily result from the unsupported weight of the assembly. The sequence of dismantling should be as recommended in the manufacturer's publication, and will vary according to the type of harness.

### 3.2 Inspection of the Dismantled Harness

3.2.1 Every magneto distributor-block or harness connector assembly should be examined for freedom from cracks or signs of tracking. Where fitted, the carbon brush should be free from chips and excessive wear and should move freely in the guide under spring pressure.

3.2.2 The body of the harness should be free from cracks and dents, especially around the apertures and attachment brackets, which should also be in good condition. The threads of the couplings should be undamaged, and the nuts should be correctly fitted.

3.2.3 All flexible ducts and subsidiary conduits should be free from internal damage and wear caused by abrasion.

3.2.4 All ignition cable connections and plug terminal sleeves should be in good condition. These parts must be renewed if there are any signs of burning or tracking.

3.2.5 Any neoprene seals should be free from deformation and cracks.

3.2.6 Rubber sleeves and bushes which have deteriorated should be rejected and new ones should be fitted.

3.2.7 All sharp corners or irregularities liable to damage the covering of the cables should be removed, and all vents should be clear so that air may circulate freely.

3.2.8 The ducts of waterproof type harnesses may require pressure testing. This is usually carried out by blanking off all the outlet connections except the one to which an air pressure supply is connected. The pressure is then raised to the specified figure. Precise details of this test will be found in the manufacturer's Maintenance Manual.

### 3.3 Assembly

3.3.1 Before assembly, ducts and subsidiary conduits should be checked for obstructions, and all parts including cables and detail fittings should be clean.

3.3.2 The mating surface of all metal joints, including those formed by union-nuts and flanged-end fittings, should be free from enamel, lacquer or other protective treatments which will increase the electrical resistance across the joint.

3.3.3 All parts should be in good condition and should be inspected particularly after storage or transit. Screw threads and other jointing surfaces should be smooth and free from burrs.

3.4 **Cables**

3.4.1 The ignition cables should be assembled into the ducting in the proper sequence. The manner and sequence of assembly are usually so arranged that any one cable may be replaced without disturbing the other cables.

3.4.2 The cables should be fitted into the harness body through the main openings, and each cable pulled through its appropriate subsidiary opening with a small steel hook. When pulling, care should be taken to avoid damage to the body of the harness and the cables. In some cases a special silicone compound may be used as a lubricant to reduce fretting between cables.

3.4.3 Subsidiary conduits should be fitted together with all rubber or neoprene seals and grommets, and the cable connectors should be attached to the end of the ignition cables (see paragraph 3.5).

3.4.4 The cables should be re-adjusted so that the required lengths protrude from the body openings. The cables should be so arranged that correct orientation of the cables, sparking plug ends to distributor ends, has been ensured. The seals and, where applicable, the large diameter flexible ducts, should then be fitted to the body. After the flexible ducts have been tightened to the body of the harness, a check should be made to ensure that the cables protrude the correct distance.

3.5 **Cable Connectors**

3.5.1 When preparing the ends of the ignition cable for the terminal end fittings, only sufficient insulation should be cut from the cable to allow the specified amount of conductor to extend through. Extreme care should be taken not to cut any of the individual strands of the conductor when removing the insulation. Examples of ignition cable assembly details are illustrated in Figures 3 and 4.

3.5.2 The terminal sleeve should be maintained in a clean condition and free from scratches, otherwise a leakage to earth may occur and cause damage to the connectors and faulty operation of the sparking plug.

3.5.3 The terminal end connections should be securely attached; no looseness or end movement is permissible. The cable conductor should not be exposed under the terminal sleeve as this may cause an insulation loss under adverse conditions.

3.6 **Final Checks**

3.6.1 The attachment of all flexible ducts and subsidiary conduits to the harness body should be secure. The flexibility of the ducts and conduits should not be affected by the attachment of cable connectors, fittings or protective coverings.

3.6.2 The conductor should be in firm contact with the terminal connection points.

3.6.3 Spring-loaded terminal ends should have free movement throughout the full range of travel.

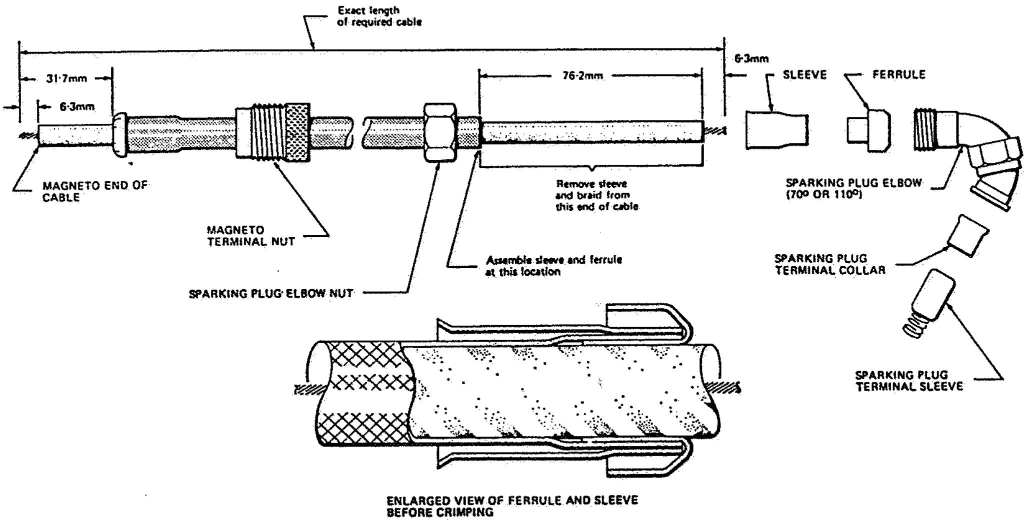


*Figure* 3 ASSEMBLY DETAILS OF IGNITION CABLES

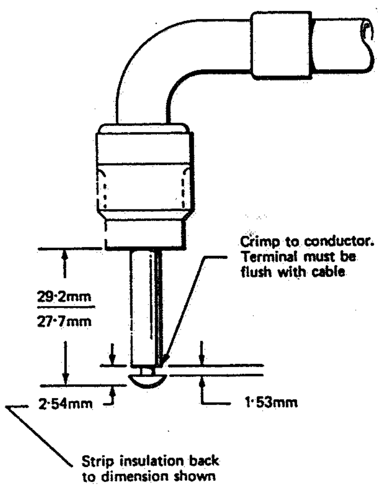


*Figure* 4 DETAILS OF TERMINAL CRIMP AT MAGNETO END OF IGNITION CABLE

3.6.4 All parts should be securely attached and correctly locked. A nut which has not been fitted correctly may cause an intermittent contact which could result in electrical interference.

3.6.5 Each cable end and subsidiary conduit, as applicable to the harness type, should be clearly identified.

3.6.6 The tests described in paragraph 4 should be applied after the harness is assembled.

3.7 **Fitting a Replacement Ignition Cable**

3.7.1 The cable connector, conduit and seals should be removed.

3.7.2 The cable should be disconnected at the magneto distributor-block and plug connector and a check made to ascertain from which direction the cable will pull out more easily.

3.7.3 The new cable should be secured and soldered to the end of the old cable to be pulled through the harness, and any ragged ends should be cleaned from the joint.

3.7.4 The defective cable should be pulled out, thus pulling the new cable into the harnesss.

3.7.5 After fitting a new cable, the tests outlined in paragraph 4 should be applied when all connections have been re-made.

## 4 TESTS

4.1 When the harness is completely assembled the tests detailed by the manufacturer should be carried out. The tests required may vary in detail with different harnesses but generally consist of continuity and insulation tests. It is important that good electrical contact is always made with the leads of test equipment.

4.2 **Continuity Test.** This test should be made with a low-voltage lamp and battery (e.g. 3·5 volts 0·4 amperes). The brilliance of the lamp must be checked before making the test so that the result may be compared.

4.2.1 One lead of the test equipment should be placed in good contact with a magneto distributor-block segment, the other connected to the appropriate sparking-plug terminal end and a slight tension applied to the lead under test. On pressing the test-button, a weak or flickering light of less brilliance than standard, or no light at all, would indicate a faulty connection, a broken wire or an incorrectly positioned lead.

NOTE: When a resistor is incorporated in a plug connector, the test equipment specified in the Maintenance Manual should be used instead of a lamp and battery.

4.2.2 If the continuity test indicates a defect, it should be located by first examining the connections and then the cable. Faulty ignition cables should be renewed as described in paragraph 3.7.

4.3 **Joint Resistance Tests.** In some instances the resistance of the joints in the harness screen should be measured with a suitable low reading ohmmeter or by a reading on a suitable millivolt meter across the joint when a known current is passed through it. The instrument used should be provided with prongs for making contact close to each side of the joint. The resistance of each joint should not exceed 0·0001 ohm.

4.4 **Insulation Tests.** The test equipment required for insulation tests will vary with the type of harness. In some cases the manufacturer may recommend an insulation resistance tester, but in other cases a spark gap test apparatus may be specified.

4.4.1 With the recommended insulation resistance tester a minimum acceptable reading in megohms will be specified. In general, it is desirable to obtain an "infinity" reading, but a lower reading may be expected from a harness which has been exposed to humid atmospheric conditions.

4.4.2 A spark gap tester is often specified by the manufacturer for testing ignition harnesses fitted to the larger types of engine. Briefly, the tester consists of a battery supplied induction coil designed to give the required voltage. A switch is interposed between the battery and the coil interrupter, and connected across the secondary terminal of the coil is a standard spark gap the points of which are set to discharge at the test voltage specified. Satisfactory insulation of the harness under test will be indicated by consistent sparking at the spark gap.

4.4.3 The sequence of operations for insulation tests recommended by the manufacturer should be carefully followed. For example, a test should be made between each cable in sequence and the remaining cables connected to the metal harness. A test should also be made between each cable and the other related cables connected together.

NOTE: When testing low-voltage ignition systems which have booster transformers fitted to the plug leads, care should be taken to adapt this test in accordance with the manufacturer's instructions.

## 5 ASSEMBLY TO ENGINE

5.1 The efficiency of the installation is dependent on the harness being fitted in such a manner that every point of contact with the engine makes a good and permanent electrical connection. All joints should be adequately tightened and locked to withstand the vibration encountered in service, thereby maintaining all parts of the harness at substantially the same potential.

5.2 During assembly to the engine, precautions should be taken to avoid damaging the ducts, subsidiary conduits and points of attachment.

5.3 All points of attachment should assemble freely to the supports without strain. Certain types of harness are manufactured as complete units and the respective sections must not be interchanged with those of other harnesses, since stress in the conduits and at points of attachment may occur when aligning the harness for final fitting.

5.4 When fitting the ignition cable connector to the plug screen, care should be taken to ensure that the lining of the screen is not damaged during the insertion of the terminal, and that the terminal seats correctly in the sparking plug. The effort applied to tighten the lead-end nut should not be excessive and the manufacturer often specifies the torque loading required. The plug leads should be positioned to clear exhaust systems and also correctly secured to prevent chafing and cutting. Guidance on the installation and testing of sparking plugs is given in Leaflet **EL/5-1.**

## C[illegible]RSE LIST

## A[illegible]OVED MAINTENANCE CONVERSION COURSES (PROPOSE[illegible]

| COURSE CODE | TITLE | DURATION | | | INSTRUCTORS | |
|---|---|---|---|---|---|---|
| | | Classroom | Simulator | Field Trip | Mechanical & Electrical (mod 1, 2 & 3) | Avionics (mod 2, 4, 5 & 6) |
| HH001 | B747-200 & -300 & Freighter B1 Conversion Course (for Airframe / Powerplant authorization holder) | 28 hrs (4 days) | 2 hrs | 6 hrs | KC Lai, FC Tsang, CK Yu, MH Kwong, CK Leung KL Chan, SF Poon, SH Lee | HC Chan, KH Yip, YY Ng, MW Chu, YT Tung, WC Chan |
| HH002 | B747-400 & Freighter Difference B1 Conversion Course (for Airframe / Powerplant authorization holder) | 28 hrs (4 days) | 2 hrs | 6 hrs | KC Lai, SF Poon, FC Tsang, MH Kwong, CK Leung KL Chan, SH Lee | HC Chan, KH Yip, YY Ng, MW Chu, YT Tung, WC Chan |
| HH003 | B777-200 & -300 B1 Conversion Course (for Airframe / Powerplant authorization holder) | 28 hrs (4 days) | 2 hrs | 6 hrs | CK Leung KL Chan, SF Poon | KH Yip, YT Tung, WC Chan, YY Ng, MW Chu |
| HH004 | A320 & A321 B1 Conversion Course (for Airframe / Powerplant authorization holder) | 28 hrs (4 days) | 2 hrs | 6 hrs | FC Tsang, CK Yu, CK Leung | KH Yip, YY Ng, MW Chu, YT Tung |
| HH005 | A340-200 & -300 B1 Conversion Course (for Airframe / Powerplant authorization holder) | 28 hrs (4 days) | 2 hrs | 6 hrs | CK Leung KL Chan, SF Poon, SH Lee | YY Ng, MW Chu, YT Tung, HC Chan, KH Yip, WC Chan |
| HH006 | A330-300 Difference B1 Conversion Course (for Airframe / Powerplant authorization holder) | 28 hrs (4 days) | 2 hrs | 6 hrs | CK Leung KL Chan, SF Poon, SH Lee | YY Ng, MW Chu, YT Tung, HC Chan, KH Yip, WC Chan |
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## COU[illegible]SE LIST

## APP[illegible]VED SPECIALIZED TYPE TRAINING COURSES (PROPOSE[illegible]

| | TITLE | DURATION | | | INSTRUCTORS | |
|---|---|---|---|---|---|---|
| | | Classroom | Simulator | Field Trip | Mechanical & Electrical (mod 1, 2 & 3) | Avionics (mod 2, 4, 5 & 6) |
| HE001 | Rolls Royce RB211-524B/C/D Maintenance Course | | 2 hrs | 6 hrs | KC Lai, CK Leung KL Chan, SH Lee | |
| HE002 | Rolls Royce RB211-524G/H/T Maintenance Course | | 2 hrs | 6 hrs | KC Lai, CK Leung KL Chan, SH Lee | |
| HE003 | Rolls Royce TRENT700 Maintenance Course | | 2 hrs | 6 hrs | CK Leung, KL Chan, SF Poon, SH Lee | |
| HE004 | Rolls Royce TRENT800 Maintenance Course | | 2 hrs | 6 hrs | CK Leung, KL Chan, SF Poon, SH Lee | |
| HE005 | General Electric CF6-50 Maintenance Course | | N/A | N/A | KL Chan, MH Kwong, | |
| HE006 | CFM International CFM56-5C Maintenance Course | | 2 hrs | 6 hrs | CK Leung, KL Chan, SF Poon, SH LEE | |
| HE007 | International Aero Engine V2500-A1/A5 Maintenance Course | | N/A | 6 hrs | FC Tsang, CK Yu, CK Leung | |
| HS001 | Matsushita Avionics Systems 2000E In-flight Entertainment System Course | 14 hrs | N/A | N/A | | YY Ng, MW Chu |
| HS002 | Sony Trans Com P@SSPORT In-flight Entertainment System Course | 14 hrs | N/A | N/A | | HC Chan, MW Chu |
| HS003 | GTE GENSTAR Airphone System Course | 7 hrs | N/A | N/A | | MW Chu |
| HS004 | Boeing/Airbus ETOPS Procedures Course | 7 hrs | N/A | N/A | SF Poon, CK Leung KL Chan, SH Lee, | YT Tung, YY Ng |
| HS005 | Boeing/Airbus RVMS/CAT III Landing Procedures Course | 3.5 hrs | N/A | N/A | | HC Chan, YY Ng, MW Chu, YT Tung |

# INSTRUCTOR / COURSES CAPABILITY

MAINT / RAMP & TRANS. GEN FAM COURSES

**B747-200 & -300 & Freighter RB211-524B/C/D**

| CHAPTERS \ INSTRUCTOR | (KC Lai)* | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | MW Chu | (YT Tung)* | WC Chan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mechanical & Electrical (Mod 1, 2 & 3) | | | | | | | | Avionics (Mod 2, 4, 5 & 6) | | | | | |
| ATA 00 Introduction & Document | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 21 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 22 | | | | | | | | | ✓ | | ✓ | ✓ | ✓ | |
| ATA 23 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | | ✓ | ✓ | |
| ATA 24 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 25 (part i) Cabin & cargo | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ |
| ATA 25 (part ii) Entertainment | | | | | | | | | ✓ | | ✓ | ✓ | ✓ | |
| ATA 26 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ |
| ATA 27 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 28 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 29 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 30 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ |
| ATA 31 | | | | | | | | | ✓ | | ✓ | ✓ | ✓ | |
| ATA 32 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ |
| ATA 33 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 34 (part i) Instrument navigation | | | | | | | | | ✓ | | ✓ | ✓ | ✓ | |
| ATA 34 (part ii) Radio navigation | | | | | | | | | ✓ | | | ✓ | ✓ | |
| ATA 35 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | |
| ATA 36 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ |
| ATA 38 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ |
| ATA 45 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| ATA 49 (part i) APU system | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ |
| ATA 49 (part ii) APU indication | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 51,53,54,55,56,57 Structure | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | | |
| ATA 52 Door Operation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ |
| ATA 72 Inlet & turbine | ✓ | | | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| ATA 76, 77 Indication & control | ✓ | | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 73,74,75,78,79,80 Systems | ✓ | | | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| ATA 71 Engine run & monitoring | ✓ | | | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| | Col 1 | Col 2 | Col 3 | Col 4 | Col 5 | Col 6 | Col 7 | Col 8 | Col 9 | Col 10 | Col 11 | Col 12 | Col 13 | Col 14 |

**B747-400 & Freighter RB211-524G/H/T**

| CHAPTERS \ INSTRUCTOR | (KC Lai)* | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | SH Lee | HC Chan | (KH Yip)* | YY Ng | MW Chu | YT Tung | WC Chan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mechanical & Electrical (Mod 1, 2 & 3) | | | | | | | | Avionics (Mod 2, 4, 5 & 6) | | | | | |
| ATA 00 Introduction & Document | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 21 | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 22 | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 23 | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 24 | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 25 (part i) Cabin & cargo | ✓ | ✓ | | | | | ✓ | | | ✓ | | | | ✓ |
| ATA 25 (part ii) Entertainment | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 26 | ✓ | ✓ | | | | | ✓ | | | ✓ | | | | ✓ |
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| ATA 32 | ✓ | ✓ | | | | | ✓ | | | ✓ | | | | ✓ |
| ATA 33 | ✓ | ✓ | | | | | ✓ | | | ✓ | | | | ✓ |
| ATA 34 (part i) Instrument navigation | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 34 (part ii) Radio navigation | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 35 | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 36 | ✓ | ✓ | | | | | ✓ | | | ✓ | | | | ✓ |
| ATA 38 | ✓ | ✓ | | | | | ✓ | | | ✓ | | | | ✓ |
| ATA 45 | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 49 (part i) APU system | ✓ | ✓ | | | | ✓ | ✓ | | | ✓ | | | | ✓ |
| ATA 49 (part ii) APU indication | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 51,53,54,55,56,57 Structure | ✓ | ✓ | | | | | ✓ | | | | | | | |
| ATA 52 Door Operation | ✓ | ✓ | | | | | ✓ | | | ✓ | | | | ✓ |
| ATA 72 Inlet & turbine | ✓ | | | | ✓ | ✓ | | ✓ | | ✓ | | | | ✓ |
| ATA 76, 77 Indication & control | ✓ | | | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 73,74,75,78,79,80 Systems | ✓ | | | | ✓ | ✓ | | ✓ | | ✓ | | | | ✓ |
| ATA 71 Engine run & monitoring | ✓ | | | | ✓ | ✓ | | ✓ | | ✓ | | | | ✓ |
| | Col 15 | Col 16 | Col 17 | Col 18 | Col 19 | Col 20 | Col 21 | Col 22 | Col 23 | Col 24 | Col 25 | Col 26 | Col 27 | Col 28 |

**B777-200 & -300 TRENT800**

| CHAPTERS \ INSTRUCTOR | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | (KL Chan)* | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | MW Chu | YT Tung | (WC Chan)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mechanical & Electrical (Mod 1, 2 & 3) | | | | | | | | Avionics (Mod 2, 4, 5 & 6) | | | | | |
| ATA 00 Introduction & Document | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 21 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 22 | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 23 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 24 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 25 (part i) Cabin & cargo | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 25 (part ii) Entertainment | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 26 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 27 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
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| ATA 32 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 33 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 34 (part i) Instrument navigation | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 34 (part ii) Radio navigation | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 35 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 36 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 38 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 45 | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 49 (part i) APU system | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 49 (part ii) APU indication | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 51,53,54,55,56,57 Structure | | | | ✓ | ✓ | ✓ | ✓ | | | | | | | |
| ATA 52 Door Operation | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 72 Inlet & turbine | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 76, 77 Indication & control | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 73,74,75,78,79,80 Systems | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 71 Engine run & monitoring | | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Col 29 | Col 30 | Col 31 | Col 32 | Col 33 | Col 34 | Col 35 | Col 36 | Col 37 | Col 38 | Col 39 | Col 40 | Col 41 | Col 42 |

**A320 & A321 V2500-A1/A5**

| CHAPTERS \ INSTRUCTOR | KC Lai | (FC Tsang)* | CK Yu | MH Kwong | CK Leung | KL Cahan | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | (MW Chu)* | YT Tung | WC Chan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mechanical & Electrical (Mod 1, 2 & 3) | | | | | | | | Avionics (Mod 2, 4, 5 & 6) | | | | | |
| ATA 00 Introduction & Document | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 21 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 22 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 23 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 24 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 25 (part i) Cabin & cargo | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 25 (part ii) Entertainment | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 26 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 27 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 28 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 29 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 30 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 31 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 32 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 33 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 34 (part i) Instrument navigation | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 34 (part ii) Radio navigation | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 35 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 36 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 38 | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 45 | | N/A | N/A | | N/A | | | | N/A | N/A | N/A | N/A | N/A | N/A |
| ATA 49 (part i) APU system | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 49 (part ii) APU indication | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 51,53,54,55,56,57 Structure | | ✓ | ✓ | | ✓ | | | | | | | | | |
| ATA 52 Door Operation | | ✓ | ✓ | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 72 Inlet & turbine | | ✓ | | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 76, 77 Indication & control | | ✓ | | | ✓ | | | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 73,74,75,78,79,80 Systems | | ✓ | | | ✓ | | | | | ✓ | ✓ | | | |
| ATA 71 Engine run & monitoring | | ✓ | | | ✓ | | | | | ✓ | ✓ | | | |
| | Col 43 | Col 44 | Col 45 | Col 46 | Col 47 | Col 48 | Col 49 | Col 50 | Col 51 | Col 52 | Col 53 | Col 54 | Col 55 | Col 56 |

**A340-200 & -300 CFM56-5C**

| CHAPTERS \ INSTRUCTOR | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | (SF Poon)* | SH Lee | HC Chan | KH Yip | (YY Ng)* | MW Chu | YT Tung | WC Chan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mechanical & Electrical (Mod 1, 2 & 3) | | | | | | | | Avionics (Mod 2, 4, 5 & 6) | | | | | |
| ATA 00 Introduction & Document | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 21 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 22 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 23 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| ATA 24 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 25 (part i) Cabin & cargo | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 25 (part ii) Entertainment | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| ATA 26 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 27 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 28 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 29 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 30 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 31 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 32 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 33 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 34 (part i) Instrument navigation | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 34 (part ii) Radio navigation | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 35 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 36 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 38 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 45 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| ATA 49 (part i) APU system | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 49 (part ii) APU indication | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 51,53,54,55,56,57 Structure | | | | | ✓ | ✓ | ✓ | ✓ | | | | | | |
| ATA 52 Door Operation | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| ATA 72 Inlet & turbine | | | | | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 76, 77 Indication & control | | | | | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 73,74,75,78,79,80 Systems | | | | | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | |
| ATA 71 Engine run & monitoring | | | | | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | |
| | Col 57 | Col 58 | Col 59 | Col 60 | Col 61 | Col 62 | Col 63 | Col 64 | Col 65 | Col 66 | Col 67 | Col 68 | Col 69 | Col 70 |

**A3[illegible] TRENT700**

| CHAPTERS \ INSTRUCTOR | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | (SH Lee)* | HC Chan | KH Yip | (YY Ng)* | MW Chu | YT Tung | WC Chan | ATA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mechanical & Electrical (Mod 1, 2 & 3) | | | | | | | | Avionics (Mod 2, 4, 5 & 6) | | | | | | |
| ATA 00 Introduction & Document | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 00 |
| ATA 21 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 21 |
| ATA 22 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 22 |
| ATA 23 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | 23 |
| ATA 24 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 24 |
| ATA 25 (part i) Cabin & cargo | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 25 |
| ATA 25 (part ii) Entertainment | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | 25 |
| ATA 26 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 26 |
| ATA 27 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 27 |
| ATA 28 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 28 |
| ATA 29 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 29 |
| ATA 30 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 30 |
| ATA 31 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 31 |
| ATA 32 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 32 |
| ATA 33 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 33 |
| ATA 34 (part i) Instrument navigation | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 34 |
| ATA 34 (part ii) Radio navigation | | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 34 |
| ATA 35 | | | | | | | | | | ✓ | ✓ | ✓ | ✓ | | 35 |
| ATA 36 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 36 |
| ATA 38 | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 38 |
| ATA 45 | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 45 |
| ATA 49 (part i) APU system | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 49 |
| ATA 49 (part ii) APU indication | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 49 |
| ATA 51,53,54,55,56,57 Structure | | | | | ✓ | ✓ | ✓ | ✓ | | | | | | | 51 etc |
| ATA 52 Door Operation | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 52 |
| ATA 72 Inlet & turbine | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 72 |
| ATA 76, 77 Indication & control | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 76,77 |
| ATA 73,74,75,78,79,80 Systems | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 73 etc |
| ATA 71 Engine run & monitoring | | | | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 71 |
| | Col 71 | Col 72 | Col 73 | Col 74 | Col 75 | Col 76 | Col 77 | Col 78 | Col 79 | Col 80 | Col 81 | Col 82 | Col 83 | Col 84 | |

**Head of Section** = CK Leung

B747 Mechanical & Electrical Leading Instructor = KC Lai
B747-400 Mechanical & Electrical Leading Instructo = KC Lai
B777 Mechanical & Electrical Leading Instructor = KL Chan
A320 Mechanical & Electrical Leading Instructor = FC Tsang
A340 Mechanical & Electrical Leading Instructor = SF Poon
A330 Mechanical & Electrical Leading Instructor = SH Lee

**Head of Section** = HC Chan

B747 Avionics Leading Instructor = YT Tung
B747-400 Avionics Leading Instructor = KH Yip
B777 Avionics Leading Instructor = WC Chan
A320 Avionics Leading Instructor = MW Chu
A340 Avionics Leading Instructor = YY Ng
A330 Avionics Leading Instructor = YY Ng

Mod 1 = Airframe sys - mech & elect (ATA 21,25 part i,26,27,28,29,30,32,35,36,38,49,52), Structure (ATA 51,53,54,55,56,57)
Mod 2 = Electrical power & lighting sys (ATA 24,33)
Mod 3 = Engine sys (ATA 71,72,73,74,75,76,77,78,79,80)
Mod 4 = Instrument & radio extension (ATA 22,23,25 part ii,31,34,45)
Mod 5 = Instrument sys (ATA 22,27,31,34 part i,45), APU & Engine indication / control (ATA 49 part ii,76,77)
Mod 6 = Radio sys (ATA 23,25 part ii,34 part ii)

# COURSE CONTENT

# B747-200 & -300 & -400 & FREIGHTER / RB211-524B/C/D/G/H/T

| | PROPOSED TYPE COURSES | | | | | | | | PROPOSED CONVERSION CRS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| COURSE TITLE | B747-200/300/400/F GENERAL FAMILIARIZATION | | B747-200/300/400/F RAMP & TRANSIT MAINTENANCE | | B747-200/300/F LINE & BASE MAINTENANCE (MECH & ELECT) | | B747-200/300/F LINE & BASE MAINTENANCE (AVIONICS) | | B747-200/300/F MAINT CONVERSION (for A&C HOLDER) | | |
| COURSE CODE | HC001 | | HA001 | | HB001 | | HB002 | | HH001 | | |
| PROSPECTIVE CANDIDATES | BME (CAT C) | | LMM (CAT A) | | LMT (CAT B1) | | LMT (CAT B2) | | AMEL | | |
| CHAPTERS | ATA 104 Level | Classroom Hours | ATA 104 Level | Classroom Hours | ATA 104 Level | Classroom Hours | ATA 104 Level | Classroom Hours | ATA 104 Level | Classroom Hours | ATA |
| ATA 00 Introduction & Document | I | 0.5 | I | 1 | II | 3.5 | II | 3.5 | | | 00 |
| ATA 21 | I | 1 | II | 4 | III | 21 | | | | | 21 |
| ATA 22 | I | 1.5 | I | 2 | II | 7 | III | 28 | II | 7 | 22 |
| ATA 23 | I | 1 | I | 2 | II | 5 | III | 17.5 | II | 7 | 23 |
| ATA 24 | I | 1 | II | 3 | III | 14 | III | 14 | | | 24 |
| ATA 25 (part i) Cabin & cargo | I | 0.5 | II | 2 | III | 10.5 | | | | | 25 |
| ATA 25 (part ii) Entertainment | I | 0.5 | II | 2 | II | 2 | III | 7 | II | 2.5 | 25 |
| ATA 26 | I | 0.5 | II | 2 | III | 7 | | | | | 26 |
| ATA 27 | I | 1 | II | 4 | III | 35 | III | 7 | | | 27 |
| ATA 28 | I | 1 | II | 4 | III | 14 | | | | | 28 |
| ATA 29 | I | 0.5 | II | 2 | III | 10.5 | | | | | 29 |
| ATA 30 | I | 0.5 | II | 2 | III | 3.5 | | | | | 30 |
| ATA 31 | I | 1 | I | 4 | II | 3.5 | III | 10.5 | | | 31 |
| ATA 32 | I | 0.5 | II | 3 | III | 24.5 | | | | | 32 |
| ATA 33 | I | 0.5 | II | 2 | III | 3.5 | III | 3.5 | III | 3.5 | 33 |
| ATA 34 (part i) Instrument navigation | I | 0.5 | I | 2 | II | 3.5 | III | 12.5 | II | 3.5 | 34 |
| ATA 34 (part ii) Radio navigation | I | 1 | I | 2 | II | 3.5 | III | 21 | II | 3.5 | 34 |
| ATA 35 | I | 0.5 | II | 2 | III | 3.5 | | | | | 35 |
| ATA 36 | I | 0.5 | II | 2 | III | 7 | | | | | 36 |
| ATA 38 | I | 0.5 | II | 2 | III | 3.5 | | | | | 38 |
| ATA 45 | I | 1 | I | 2 | N/A | N/A | N/A | N/A | N/A | N/A | 45 |
| ATA 49 (part i) APU system | I | 0.5 | II | 2 | III | 10.5 | II | 1 | | | 49 |
| ATA 49 (part ii) APU indication | I | 0.5 | II | 2 | III | 3.5 | III | 3.5 | | | 49 |
| ATA 51,53,54,55,56,57 Structure | I | 0.5 | I | 2 | II | 7 | | | | | 51 etc |
| ATA 52 Door Operation | I | 0.5 | II | 2 | III | 10.5 | | | | | 52 |
| ATA 72 Inlet & turbine | I | 0.5 | II | 2 | III | 7 | II | 1 | | | 72 |
| ATA 76, 77 Indication & control | I | 0.5 | II | 1 | III | 7 | III | 7 | | | 76,77 |
| ATA 73,74,75,78,79,80 Systems | I | 1 | II | 4 | III | 35 | II | 1 | | | 73 etc |
| ATA 71 Engine run & monitoring | I | 0.5 | II | 2 | III | 7 | | | | | 71 |
| FINAL & PHASE EXAMINATIONS & REVIEWS | | 1 | | 2 | | 7 | | 2 | | 1 | Exam |
| Classroom (hrs) | | 21 | | 70 | | 280 | | 140 | | 28 | Clsrm |
| Duration (days) | | 3 | | 10 | | 40 | | 20 | | 4 | Duration |
| Simulator (hrs) | | N/A | | N/A | III | 2 | III | 2 | II | 2 | Sim |
| Field trip (hrs) | | N/A | II | 6 | III | 6 | III | 6 | II | 6 | FT |

# COURSE CONTENT
## A320 & A321 / V2500-A1/A5

| | PROPOSED TYPE COURSES | | | | | | | | PROPOSED CONVERSION CRS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| COURSE TITLE | A320 & A321 GENERAL FAMILIARIZATION | | A320 & A321 RAMP & TRANSIT MAINTENANCE | | A320 & A321 LINE & BASE MAINTENANCE (MECH & ELECT) | | A320 & A321 LINE & BASE MAINTENANCE (AVIONICS) | | A320 & A321 MAINT CONVERSION (for A&C HOLDER) | | |
| COURSE CODE | HC003 | | HA003 | | HB009 | | HB010 | | HH004 | | |
| PROSPECTIVE CANDIDATES | BME (CAT C) | | LMM (CAT A) | | LMT (CAT B1) | | LMT (CAT B2) | | AMEL | | |
| CHAPTERS | ATA 104 Level | Classroom Hours | ATA 104 Level | Classroom Hours | ATA 104 Level | Classroom Hours | ATA 104 Level | Classroom Hours | ATA 104 Level | Classroom Hours | ATA |
| ATA 00 Introduction & Document | I | 0.25 | I | 0.5 | II | 3 | II | 3 | II | 3 | 00 |
| ATA 21 | I | 0.5 | II | 2 | III | 12 | | | | | 21 |
| ATA 22 | I | 0.75 | I | 1 | II | 6 | III | 11 | II | 6 | 22 |
| ATA 23 | I | 0.75 | I | 1 | II | 6 | III | 8 | II | 6 | 23 |
| ATA 24 | I | 0.5 | II | 1.5 | III | 12 | III | 12 | | | 24 |
| ATA 25 (part i) Cabin & cargo | I | 0.25 | II | 1 | III | 3 | | | | | 25 |
| ATA 25 (part ii) Entertainment | I | 0.25 | II | 1 | II | 3 | III | 4 | II | 3 | 25 |
| ATA 26 | I | 0.25 | II | 1 | III | 6 | | | | | 26 |
| ATA 27 | I | 0.5 | II | 2 | III | 12 | III | 12 | | | 27 |
| ATA 28 | I | 0.5 | II | 2 | III | 6 | | | | | 28 |
| ATA 29 | I | 0.25 | II | 1 | III | 6 | | | | | 29 |
| ATA 30 | I | 0.25 | II | 1 | III | 3 | | | | | 30 |
| ATA 31 | I | 2.25 | I | 3 | II | 10 | III | 11 | | | 31 |
| ATA 32 | I | 0.5 | II | 1.5 | III | 12 | | | | | 32 |
| ATA 33 | I | 0.25 | II | 1 | III | 3 | III | 3 | III | 3 | 33 |
| ATA 34 (part i) Instrument navigation | I | 0.75 | I | 1 | II | 2 | III | 4 | II | 2 | 34 |
| ATA 34 (part ii) Radio navigation | I | 0.75 | I | 1 | II | 4 | III | 8 | II | 4 | 34 |
| ATA 35 | I | 0.25 | II | 1 | III | 3 | | | | | 35 |
| ATA 36 | I | 0.25 | II | 1 | III | 6 | | | | | 36 |
| ATA 38 | I | 0.25 | II | 1 | III | 3 | | | | | 38 |
| ATA 45 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 45 |
| ATA 49 (part i) APU system | I | 0.25 | II | 1 | III | 9 | II | 1 | | | 49 |
| ATA 49 (part ii) APU indication | I | 0.25 | II | 1 | III | 2 | III | 2 | | | 49 |
| ATA 51,53,54,55,56,57 Structure | I | 0.75 | I | 1 | II | 3 | | | | | 51 etc |
| ATA 52 Door Operation | I | 0.25 | II | 1 | III | 6 | | | | | 52 |
| ATA 72 Inlet & turbine | I | 0.25 | II | 1 | III | 3 | II | 1 | | | 72 |
| ATA 76, 77 Indication & control | I | 0.25 | II | 0.5 | III | 6 | III | 6 | | | 76,77 |
| ATA 73,74,75,78,79,80 Systems | I | 0.5 | II | 2 | III | 12 | II | 1 | | | 73 etc |
| ATA 71 Engine run & monitoring | I | 0.25 | II | 1 | III | 3 | | | | | 71 |
| FINAL & PHASE EXAMINATIONS & REVIEWS | | 1 | | 1 | | 10 | | 4 | | 1 | Exam |
| Classroom (hrs) | | 14 | | 35 | | 175 | | 91 | | 28 | Clsrm |
| Duration (days) | | 2 | | 5 | | 25 | | 13 | | 4 | Duration |
| Simulator (hrs) | | N/A | | N/A | III | N/A | III | N/A | II | N/A | Sim |
| Field trip (hrs) | | N/A | II | 6 | III | 6 | III | 6 | II | 6 | FT |

# INSTRUCTOR / COURSES CAPABILITY

| MAINT / RAMP & TRANSIT / GEN FAM COURSES — ATA104 LEVELS / CHAPTERS \ INSTRUCTORS | B747-200 & -300 & Freighter RB211-524B/C/D | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | MW Chu | YT Tung | WC Chan |
| ATA 00 | III | III | III | III | III | III | III | | III | III | III | III | III | III |
| ATA 21 | III | III | III | III | III | III | III | | III | III | III | III | III | III |
| ATA 22 | | | | | | | | | III | | III | III | III | |
| ATA 23 | III | III | III | III | III | III | III | | III | | | III | III | |
| ATA 24 | III | III | III | III | III | III | III | | III | III | III | III | III | III |
| ATA 25 Cabin & cargo | III | III | III | III | III | III | III | | | III | III | | III | III |
| ATA 25 Entertainment | | | | | | | | | III | | III | III | III | |
| ATA 26 | III | III | III | III | III | III | III | | | III | III | | III | III |
| ATA 27 | III | III | III | III | III | III | III | | III | III | III | III | III | III |
| ATA 28 | III | III | III | III | III | III | III | | III | III | III | III | III | III |
| ATA 29 | III | III | III | III | III | III | III | | III | III | III | III | III | III |
| ATA 30 | III | III | III | III | III | III | III | | | III | III | | III | III |
| ATA 31 | | | | | | | | | III | | III | III | III | |
| ATA 32 | III | III | III | III | III | III | III | | | III | III | | III | III |
| ATA 33 | III | III | III | III | III | III | III | | III | III | III | III | III | III |
| ATA 34 Instrument navigation | | | | | | | | | III | | III | III | III | |
| ATA 34 Radio navigation | | | | | | | | | III | | | III | III | |
| ATA 35 | III | III | III | III | III | III | III | | III | | III | III | III | |
| ATA 36 | III | III | III | III | III | III | III | | | III | III | | III | III |
| ATA 38 | III | III | III | III | III | III | III | | | III | III | | III | III |
| ATA 45 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| ATA 49 APU system | III | III | III | III | III | III | III | | | III | III | | III | III |
| ATA 49 APU indication | III | III | III | III | III | III | III | | III | III | III | III | III | III |
| ATA 51,53,54,55,56,57 | II | II | II | II | II | II | II | | | | | | | |
| ATA 52 | III | III | III | III | III | III | III | | | III | III | | III | III |
| ATA 72 Inlet & turbine | III | | | III | III | III | | III | | III | III | | III | III |
| ATA 76, 77 Indication & control | III | | | III | III | III | | III | III | III | III | III | III | III |
| ATA 73,74,75,78,79,80 Systems | III | | | III | III | III | | III | | III | III | | III | III |
| ATA 71 Engine run & monitoring | III | | | III | III | III | | III | | III | III | | III | III |
| | Col 1 | Col 2 | Col 3 | Col 4 | Col 5 | Col 6 | Col 7 | Col 8 | Col 9 | Col 10 | Col 11 | Col 12 | Col 13 | Col 14 |

| MAINT / RAMP & TRANSIT / GEN FAM COURSES — ATA104 LEVELS / CHAPTERS \ INSTRUCTORS | B747-400 & Freighter RB211-524G/H/T | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | MW Chu | YT Tung | WC Chan |
| ATA 00 | III | III | | | | | III | | III | III | III | III | III | III |
| ATA 21 | III | III | | | | | III | | III | III | III | II | II | III |
| ATA 22 | | | | | | | | | III | III | III | III | III | III |
| ATA 23 | III | III | | | | | III | | III | III | III | III | III | III |
| ATA 24 | III | III | | | | | III | | III | III | III | II | II | III |
| ATA 25 Cabin & cargo | III | III | | | | | III | | | III | | | | III |
| ATA 25 Entertainment | II | II | | | | | II | | III | III | III | III | III | III |
| ATA 26 | III | III | | | | | III | | | III | | | | III |
| ATA 27 | III | III | | | | | III | | III | III | III | II | II | III |
| ATA 28 | III | III | | | | | III | | | III | | | | III |
| ATA 29 | III | III | | | | | III | | III | III | III | II | II | III |
| ATA 30 | III | III | | | | | III | | | III | | | | III |
| ATA 31 | | | | | | | | | III | III | III | III | III | III |
| ATA 32 | III | III | | | | | III | | | III | | | | III |
| ATA 33 | III | III | | | | | III | | | III | | | | III |
| ATA 34 Instrument navigation | | | | | | | | | III | III | III | III | III | III |
| ATA 34 Radio navigation | | | | | | | | | III | III | III | III | III | III |
| ATA 35 | III | III | | | | | III | | III | III | III | III | III | III |
| ATA 36 | III | III | | | | | III | | | III | | | | III |
| ATA 38 | III | III | | | | | III | | | III | | | | III |
| ATA 45 | III | III | | | | | III | | III | III | III | III | III | III |
| ATA 49 APU system | III | III | | | | | III | | | III | | | | III |
| ATA 49 APU indication | III | III | | | | | III | | III | III | III | III | III | III |
| ATA 51,53,54,55,56,57 | II | II | | | | | II | | | | | | | |
| ATA 52 | III | III | | | | | III | | | III | | | | III |
| ATA 72 Inlet & turbine | III | | | | III | III | | III | | III | | | | III |
| ATA 76, 77 Indication & control | III | | | | III | III | | III | III | III | III | III | III | III |
| ATA 73,74,75,78,79,80 Systems | III | | | | III | III | | III | | III | | | | III |
| ATA 71 Engine run & monitoring | III | | | | III | III | | III | | III | | | | III |
| | Col 15 | Col 16 | Col 17 | Col 18 | Col 19 | Col 20 | Col 21 | Col 22 | Col 23 | Col 24 | Col 25 | Col 26 | Col 27 | Col 28 |

| MAINT / RAMP & TRANSIT / GEN FAM COURSES — ATA104 LEVELS / CHAPTERS \ INSTRUCTORS | B777-200 & -300 TRENT800 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | MW Chu | YT Tung | WC Chan |
| ATA 00 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 21 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 22 | | | | | | | | | | III | III | III | III | III |
| ATA 23 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 24 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 25 Cabin & cargo | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 25 Entertainment | | | | II | II | II | II | | | III | III | III | III | III |
| ATA 26 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 27 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 28 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 29 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 30 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 31 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 32 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 33 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 34 Instrument navigation | | | | | | | | | | III | III | III | III | III |
| ATA 34 Radio navigation | | | | | | | | | | III | III | III | III | III |
| ATA 35 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 36 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 38 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 45 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 49 APU system | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 49 APU indication | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 51,53,54,55,56,57 | | | | II | II | II | II | | | | | | | |
| ATA 52 | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 72 Inlet & turbine | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 76, 77 Indication & control | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 73,74,75,78,79,80 Systems | | | | III | III | III | III | | | III | III | III | III | III |
| ATA 71 Engine run & monitoring | | | | III | III | III | III | | | III | III | III | III | III |
| | Col 29 | Col 30 | Col 31 | Col 32 | Col 33 | Col 34 | Col 35 | Col 36 | Col 37 | Col 38 | Col 39 | Col 40 | Col 41 | Col 42 |

| MAINT / RAMP & TRANSIT / GEN FAM COURSES — ATA104 LEVELS / CHAPTERS \ INSTRUCTORS | A320 & A321 V2500 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | MW Chu | YT Tung | WC Chan |
| ATA 00 | | III | III | | III | | | | | III | III | III | III | |
| ATA 21 | | III | III | | III | | | | | III | III | | | |
| ATA 22 | | III | III | | III | | | | | III | III | III | III | |
| ATA 23 | | III | III | | III | | | | | III | III | III | III | |
| ATA 24 | | III | III | | III | | | | | III | III | II | II | |
| ATA 25 Cabin & cargo | | III | III | | III | | | | | III | III | | | |
| ATA 25 Entertainment | | II | II | | II | | | | | III | III | III | III | |
| ATA 26 | | III | III | | III | | | | | III | III | | | |
| ATA 27 | | III | III | | III | | | | | III | III | II | II | |
| ATA 28 | | III | III | | III | | | | | III | III | | | |
| ATA 29 | | III | III | | III | | | | | III | III | II | II | |
| ATA 30 | | III | III | | III | | | | | III | III | | | |
| ATA 31 | | III | III | | III | | | | | III | III | III | III | |
| ATA 32 | | III | III | | III | | | | | III | III | | | |
| ATA 33 | | III | III | | III | | | | | III | III | | | |
| ATA 34 Instrument navigation | | | | | | | | | | III | III | III | III | |
| ATA 34 Radio navigation | | | | | | | | | | III | III | III | III | |
| ATA 35 | | III | III | | III | | | | | III | III | | | |
| ATA 36 | | III | III | | III | | | | | III | III | | | |
| ATA 38 | | III | III | | III | | | | | III | III | | | |
| ATA 45 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| ATA 49 APU system | | III | III | | III | | | | | III | III | | | |
| ATA 49 APU indication | | III | III | | III | | | | | III | III | | | |
| ATA 51,53,54,55,56,57 | | II | II | | II | | | | | | | | | |
| ATA 52 | | III | III | | III | | | | | III | III | | | |
| ATA 72 Inlet & turbine | | III | | | III | | | | | III | III | | | |
| ATA 76, 77 Indication & control | | III | | | III | | | | | III | III | II | II | |
| ATA 73,74,75,78,79,80 Systems | | III | | | III | | | | | III | III | | | |
| ATA 71 Engine run & monitoring | | III | | | III | | | | | III | III | | | |
| | Col 43 | Col 44 | Col 45 | Col 46 | Col 47 | Col 48 | Col 49 | Col 50 | Col 51 | Col 52 | Col 53 | Col 54 | Col 55 | Col 56 |

| MAINT / RAMP & TRANSIT / GEN FAM COURSES — ATA104 LEVELS / CHAPTERS \ INSTRUCTORS | A340-200 & -300 CFM56-5C | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | MW Chu | YT Tung | WC Chan |
| ATA 00 | | | | | III | III | III | III | III | III | III | III | III | III |
| ATA 21 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 22 | | | | | III | III | III | III | II | III | III | III | III | II |
| ATA 23 | | | | | III | III | III | III | III | | III | III | III | III |
| ATA 24 | | | | | III | III | III | III | III | III | III | III | III | III |
| ATA 25 Cabin & cargo | | | | | III | III | III | III | | III | III | III | III | |
| ATA 25 Entertainment | | | | | II | II | II | II | III | | III | III | III | III |
| ATA 26 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 27 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 28 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 29 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 30 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 31 | | | | | III | III | III | III | III | III | III | III | III | III |
| ATA 32 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 33 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 34 Instrument navigation | | | | | | | | | II | III | III | III | III | II |
| ATA 34 Radio navigation | | | | | | | | | III | III | III | III | III | III |
| ATA 35 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 36 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 38 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 45 | | | | | III | III | III | III | III | III | III | III | III | III |
| ATA 49 APU system | | | | | III | III | III | III | | III | III | III | III | |
| ATA 49 APU indication | | | | | III | III | III | III | | III | III | III | III | |
| ATA 51,53,54,55,56,57 | | | | | II | II | II | II | | | | | | |
| ATA 52 | | | | | III | III | III | III | | III | III | III | III | |
| ATA 72 Inlet & turbine | | | | | III | III | | | | III | III | III | III | |
| ATA 76, 77 Indication & control | | | | | III | III | | | | III | III | III | III | |
| ATA 73,74,75,78,79,80 Systems | | | | | III | III | | | | III | III | III | III | |
| ATA 71 Engine run & monitoring | | | | | III | III | | | | III | III | III | III | |
| | Col 57 | Col 58 | Col 59 | Col 60 | Col 61 | Col 62 | Col 63 | Col 64 | Col 65 | Col 66 | Col 67 | Col 68 | Col 69 | Col 70 |

| MAINT / RAMP & TRANSIT / GEN FAM COURSES — ATA104 LEVELS / CHAPTERS \ INSTRUCTORS | A330 TRENT700 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | KC Lai | FC Tsang | CK Yu | MH Kwong | CK Leung | KL Chan | SF Poon | SH Lee | HC Chan | KH Yip | YY Ng | MW Chu | YT Tung | WC Chan | ATA |
| ATA 00 | | | | | III | III | III | III | III | III | III | III | III | III | 00 |
| ATA 21 | | | | | III | III | III | III | | III | III | III | III | | 21 |
| ATA 22 | | | | | III | III | III | III | II | III | III | III | III | II | 22 |
| ATA 23 | | | | | III | III | III | III | III | | III | III | III | III | 23 |
| ATA 24 | | | | | III | III | III | III | III | III | III | III | III | III | 24 |
| ATA 25 Cabin & cargo | | | | | III | III | III | III | | III | III | III | III | | 25 |
| ATA 25 Entertainment | | | | | II | II | II | II | III | | III | III | III | III | 25 |
| ATA 26 | | | | | III | III | III | III | | III | III | III | III | | 26 |
| ATA 27 | | | | | III | III | III | III | | III | III | III | III | | 27 |
| ATA 28 | | | | | III | III | III | III | | III | III | III | III | | 28 |
| ATA 29 | | | | | III | III | III | III | | III | III | III | III | | 29 |
| ATA 30 | | | | | III | III | III | III | | III | III | III | III | | 30 |
| ATA 31 | | | | | III | III | III | III | III | III | III | III | III | III | 31 |
| ATA 32 | | | | | III | III | III | III | | III | III | III | III | | 32 |
| ATA 33 | | | | | III | III | III | III | | III | III | III | III | | 33 |
| ATA 34 Instrument navigation | | | | | | | | | II | III | III | III | III | II | 34 |
| ATA 34 Radio navigation | | | | | | | | | III | III | III | III | III | III | 34 |
| ATA 35 | | | | | III | III | III | III | | III | III | III | III | | 35 |
| ATA 36 | | | | | III | III | III | III | | III | III | III | III | | 36 |
| ATA 38 | | | | | III | III | III | III | | III | III | III | III | | 38 |
| ATA 45 | | | | | III | III | III | III | III | III | III | III | III | III | 45 |
| ATA 49 APU system | | | | | III | III | III | III | | III | III | III | III | | 49 |
| ATA 49 APU indication | | | | | III | III | III | III | | III | III | III | III | | 49 |
| ATA 51,53,54,55,56,57 | | | | | II | II | II | II | | | | | | | 51 etc |
| ATA 52 | | | | | III | III | | III | | III | III | III | III | | 52 |
| ATA 72 Inlet & turbine | | | | | III | III | | III | | III | III | III | III | | 72 |
| ATA 76, 77 Indication & control | | | | | III | III | | III | | III | III | III | III | | 76,77 |
| ATA 73,74,75,78,79,80 Systems | | | | | III | III | | III | | III | III | III | III | | 73 etc |
| ATA 71 Engine run & monitoring | | | | | III | III | | III | | III | III | III | III | | 71 |
| | Col 71 | Col 72 | Col 73 | Col 74 | Col 75 | Col 76 | Col 77 | Col 78 | Col 79 | Col 80 | Col 81 | Col 82 | Col 83 | Col 84 | |

# A340-200 & -300 / CFM56-5C LINE & BASE MAINTENANCE COURSE (MECH & ELECT)

| ITEM | DURATION (Hours) | PERFORMANCE BLOCK | ATA 104 (Level) |
|---|---|---|---|
| **SIMULATOR** | **2** | Engine Starting & Shut-down | III |
| | | Engine Indications | III |
| | | Adnormal Conditions | III |
| **FIELD TRIP** | **7** | Aircraft Systems Identification | III |
| | | Equipment & Components Location | III |
| | | Cockpit Layout Familiarization | III |
| | | ECAM Indications | III |
| | | Control Panel Use | III |
| | | MCDU Utilization | III |
| | | Aircraft Servicing | III |

REVISED DATE

ISSUED DATE 20 Sep, 1999

# COURSE SYLLABUS
## A320 & A321 / V2500-A1/A5 GENERAL FAMILIARIZATION COURSE

| | |
|---|---|
| COURSE TITLE | A320 & A321 / V2500-A1/A5 General Familiarization Course |
| COURSE CODE | HC003 |
| COURSE DURATION | 21 hours - Classroom training |
| COURSE OBJECTIVES | 1. To provide general knowledge & understanding on A320 & A321 Airframe/Electrical/Powerplant/Avioncs systems.<br>2. To satisfy the training requirements for the granting of A320 & A321 (V2500-A1/A5) category C type rating, and the issuance of maintenance authorization to the engineering personnel on A320 & A321 Airframe/Electrical/Powerplant/Avionics systems. |
| OCCUPATION SPECIALTY | Base Maintenance Engineer (BME) or staff with equivalent knowledge standard who have adequate practical experience. |
| LEVEL OF INSTRUCTIONS | This course is mechanical, electrical & avionics oriented, and provides brief overview on functional description, and training information points to ATA 104 level I. |
| COURSE ARCHITECTURE | Classroom lecture by instructor includes system functional description & training information points (maintenance practice, tool / equipment, safety), and current technical information. |
| COURSE EXAMINATION & REVIEW | A final examination & review are conducted at the end of the course. |

REVISED DATE
ISSUED DATE 20 Sep, 1999

# COURSE SYLLABUS

## A340-200 & -300 / CFM56-5C LINE & BASE MAINTENANCE COURSE (MECH & ELECT)

| | |
|---|---|
| COURSE TITLE | A340-200 & -300 / CFM56-5C Line & Base Maintenance Course (Mechanical & Electrical) |
| COURSE CODE | H001 |
| COURSE DURATION | 210 hours - Classroom training<br>2 hours - Simulator training<br>6 hours - Field trip training |
| COURSE OBJECTIVES | 1. To provide adequate knowledge for performing maintenance operations, trouble-shooting and inspection on A340 Airframe/Electrical/Powerplant/Avionics systems.<br>2. To satisfy the training requirements for the granting of A340-200/-300 (CFM56-5C) category B1 type rating, and the issuance of maintenance authorization to the engineering personnel on A340 Airframe/Electrical/Powerplant/Avionics systems. |
| OCCUPATION SPECIALTY | Line / Base Maintenance Technician (LMT / BMT) or staff with equivalent knowledge standard who have adequate practical experience. |
| LEVEL OF INSTRUCTIONS | This course is mechanical, electrical & avionics oriented, and provides detailed information on functional description, operation, purpose & interface, identification & location, and training information points to ATA 104 level III. |
| COURSE ARCHITECTURE | Methods of course delivery comprise of classroom lecture, VACBI ( VIDEO AIDED COMPUTER BASED INSTRUCTION), simulator & field trip trainings.<br><br>Classroom lecture by instructor includes system functional description & operation, and current technical information, while VACBI courseware provides information on purpose & interface, identification & location, and training information points (maintenace practice, tooling / equipment, safety, servicing, component replacement, testing, on-board maintenance system / BITE, trouble-shooting, MCDU utilization, and power supply / electrical circuit).<br><br>Classroom training also includes the projection of filmed operations associated with line / base servicing and safety. |

REVISED DATE
ISSUED DATE 20 Sep, 1999

# COURSE SYLLABUS

## A340-200 & -300 / CFM56-5C LINE & BASE MAINTENANCE COURSE (AVIONICS)

| | |
|---|---|
| COURSE TITLE | A340-200 & -300 / CFML-5C Line & Base Maintenance Course (Avionics) |
| COURSE CODE | H002 |
| COURSE DURATION | 105 hours - Classroom training<br>2 hours - Simulator training<br>6 hours - Field trip training |
| COURSE OBJECTIVES | 1. To provide adequate knowledge for performing maintenance operations, trouble-shooting and inspection on A340 Radio/Instrument/Electrical Power systems.<br><br>2. To satisfy the training requirements for the granting of A340-200/-300 (CFM56-5C) category B1 type rating, and the issuance of maintenance authorization to the engineering personnel on A340 Radio/Instrument/Electrical Power systems. |
| OCCUPATION SPECIALTY | Line / Base Maintenance Technician (LMT / BMT) or staff with equivalent knowledge standard who have adequate practical experience. |
| LEVEL OF INSTRUCTIONS | This course is electrical & avionics oriented and provides detailed information on functional description, operation, purpose & interface, identification & location, and training information points to ATA 104 level III. |
| COURSE ARCHITECTURE | Methods of course delivery comprise of classroom lecture, VACBI ( VIDEO AIDED COMPUTER BASED INSTRUCTION), simulator & field trip trainings.<br><br>Classroom lecture by instructor includes system functional description & operation, and current technical information, while VACBI courseware provides information on purpose & interface, identification & location, and training information points (maintenace practice, tooling / equipment, safety, servicing, component replacement, testing, on-board maintenance system / BITE, trouble-shooting, MCDU utilization, and power supply / electrical circuit).<br><br>Classroom training also includes the projection of filmed operations associated with line / base servicing and safety. |

REVISED DATE

ISSUED DATE 20 Sep, 1999

# COURSE SYLLABUS

## A340-200 & -300 / CFM56-5C RAMP & TRANSIT MAINTENANCE COURSE

| | |
|---|---|
| COURSE TITLE | A340-200 & -300 /CFM56-5C Ramp & Transit Maintenance Course |
| COURSE CODE | H003 |
| COURSE DURATION | 35 hours - Classroom training<br>6 hours - Field Trip |
| COURSE OBJECTIVES | 1. To provide adequate knowledge for performing ramp maintenance operations, trouble-shooting and inspection on A340 Airframe/Electrical/Powerplant/Avioncs systems.<br>2. To satisfy the training requirements for the granting of A340-200/-300 (CFM56-5C) category A type rating, and the issuance of maintenance authorization to the engineering personnel on A340 Airframe/Electrical/Powerplant/Avionics systems. |
| OCCUPATION SPECIALTY | Line Maintenance Mechanic (LMM), or staff with equivalent knowledge standard who have adequate practical experience. |
| LEVEL OF INSTRUCTIONS | This course is mechanical, electrical & avionics oriented, and provides overview on functional description, operation, purpose & interface, identification & location, and training information points to ATA 104 level II. |
| COURSE ARCHITECTURE | Methods of course delivery comprise of classroom lecture & field trip training.<br><br>Classroom lecture by instructor includes system functional description & operation, purpose & interface, identification & location, and training information points (maintenace practice, tooling / equipment, safety, servicing, component replacement, testing, on-board maintenance system / BITE, trouble-shooting, MCDU utilization, and power supply / electrical circuit), and current technical information.<br><br>Field trip training is arranged to provide attendees with the opportunity to locate & identify aircraft systems, equipment & components, familiarize with cockpit layout & control panels, gain hands-on experience on MCDU utilization, and in-service operation scenarios & system ECAM indications. |

REVISED DATE
ISSUED DATE 28 June,1999

# COURSE SYLLABUS

# A340-200 & -300 /CFM56-5C GENERAL FAMILIARIZATION COURSE

| | |
|---|---|
| COURSE TITLE | A340-200 & -300 / CFM56-5C General Familiarization Course |
| COURSE CODE | H004 |
| COURSE DURATION | 21 hours - Classroom training |
| COURSE OBJECTIVES | 1. To provide general knowledge & understanding on A340 Airframe/Electrical/Powerplant/Avioncs systems.<br>2. To satisfy the training requirements for the granting of A340-200/-300 (CFM56-5C) category C type rating, and the issuance of maintenance authorization to the engineering personnel on A340 Airframe/Electrical/Powerplant/Avionics systems. |
| OCCUPATION SPECIALTY | Base Maintenance Engineer (BME) or staff with equivalent knowledge standard who have adequate practical experience. |
| LEVEL OF INSTRUCTIONS | This course is mechanical, electrical & avionics oriented, and provides brief overview on functional description, and training information points to ATA 104 level I. |
| COURSE ARCHITECTURE | Classroom lecture by instructor includes system functional description & training information points (maintenance practice, tool / equipment, safety), and current technical information. |
| COURSE EXAMINATION & REVIEW | A final examination & review are conducted at the end of the course. |

REVISED DATE

ISSUED DATE 28 June, 1999

PL/1-1

*Issue* 2.

16*th May*, 1975.

# AIRCRAFT

## PROPELLERS

## CONSTRUCTION, OPERATION AND MAINTENANCE

1 INTRODUCTION This Leaflet gives general guidance on the construction, operation and maintenance of both fixed-pitch and variable-pitch propellers, such as may be fitted to many types of piston and gas turbine engines.

1.1 There are a number of propeller manufacturers, and many possible propeller/engine and engine/airframe combinations. For these reasons, there is a wide variety of propellers and propeller control systems. This Leaflet is not intended to cover all possible combinations, and should be read in conjunction with the appropriate aircraft and propeller manuals, from which information relating to a particular installation may be obtained.

NOTE: The relevant information previously published in Leaflet PL/2—1, Issue 1, 1st December 1962, is included in this Leaflet.

2 GENERAL A propeller is a means of converting engine power into propulsive force. A rotating propeller imparts rearward motion to a mass of air, and the reaction to this is a forward force on the propeller blades.

2.1 Each propeller blade is of aerofoil cross-section. As the blade moves through the air, forces are produced, which are known as thrust and torque, and which may be regarded as roughly equivalent to the forces of lift and drag produced by an aircraft wing. Thrust is the propulsive force, and torque the resistance to rotation, or propeller load. The magnitude of the thrust and torque forces produced will depend on the size, shape and number of blades, the blade angle, the speed of rotation, the air density and the forward speed.

2.2 Since each blade is of aerofoil cross-section, thrust will be produced most efficiently at a particular angle of attack, that is the angle between the chord line at a particular blade section and the relative airflow. This angle varies both with operating conditions and with the design camber of the blade sections, but, for a given blade and given in-flight conditions, it will be found to be relatively constant along the length of the blade. The rotational speed of a particular cross-section of a blade will increase with its distance from the axis of rotation, and, since the forward speed of all parts of the blade is the same, the relative airflow will vary along the blade, and it is, therefore, necessary to provide a decreasing blade angle from root to tip. The various terms relating to propeller operation are illustrated in Figure 1. This is a simplified diagram omitting inflow angles for clarity, but in practical designs these angles cannot be ignored.

2.2.1 The geometric pitch of a propeller is the distance which it should move forward in one revolution without slip; it is equal to $2\pi r \tan \theta$, where r is the radius (or station) of the particular cross-section, and $\theta$ is the blade angle at that point. Fixed pitch propellers are usually classified by their diameter and pitch, the pitch being related to the blade angle at $\frac{3}{4}$ radius, or other nominated station.

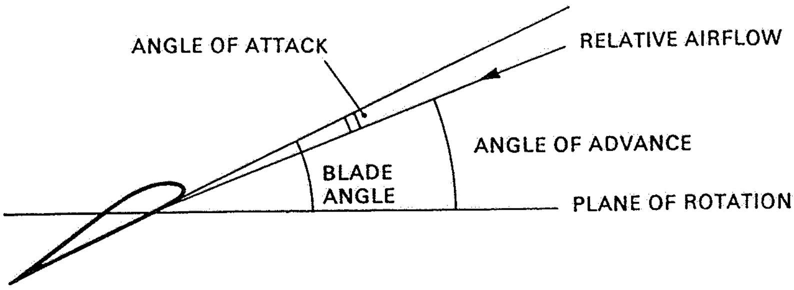


*Figure* 1 PROPELLER TERMS

2.3 Centrifugal, bending, and twisting forces act on a propeller during flight, and can be very severe at high rotational speeds. Propellers must be both strong enough to resist these forces, and rigid enough to prevent flutter. The main forces experienced are as follows:—

(a) Centrifugal forces which induce radial stress in the blades and hub, and, when acting on material which is not on the blade axis, also induce a twisting moment. Centrifugal force can be resolved into two components in the plane of rotation; one is a radial force parallel to the blade axis, and the other a force at 90° to the blade axis; the former produces radial stress, and the latter tends to turn the blade to a finer pitch. The turning effect is referred to as centrifugal twisting moment, and is illustrated in Figure 2; the wider the blade, the greater will be the twisting moment.

(b) Thrust forces which tend to bend the blades forward in the direction of flight.

(c) Torque forces which tend to bend the blades against the direction of rotation.

(d) Air loads which normally tend to oppose the centrifugal twisting moment and coarsen blade pitch.

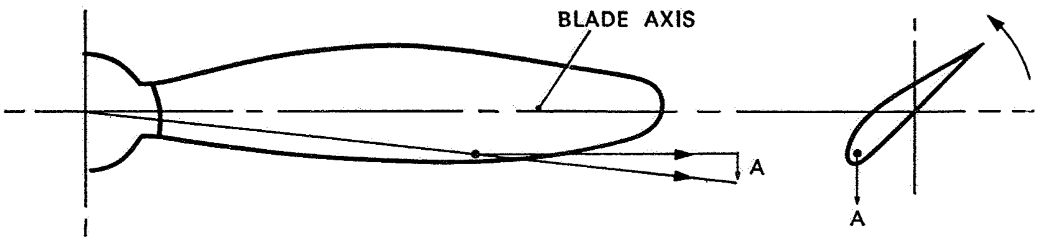


*Figure* 2 CENTRIFUGAL TWISTING MOMENT

2.4 The diameter of a propeller, and the number and shape of its blades, depend on the power it is required to absorb, on the take-off thrust it is necessary to produce, and on the noise-level limits which have to be met. High tip speeds absorb greater power than low tip speeds, but if the tip speed approaches the speed of sound, efficiency will fall, and this consideration limits practical diameter/rotational speed combinations. High tip speed is also the main source of propeller noise. Large diameters normally result in better performance than small diameters, and blade area is chosen to ensure that blade lift coefficients are kept in the range where the blade sections are efficient. Wide chord blades and/or large diameters lead to heavy propellers; increase in number of blades increases cost but reduces noise. The design of any propeller is, therefore, a compromise between conflicting requirements, and the features which are given prominence will vary from one application to another. Small two-bladed propellers, of suitable profile, are satisfactory for low-powered piston engines, but for high-powered piston or turbine engines, three, four, or five bladed, or contra-rotating, propellers are used, and are driven through a reduction gear to enable high engine power to be used at efficient propeller speeds.

2.5 **Propeller Balance.** A propeller is a rotating mass, and if not correctly balanced can produce unacceptable vibration. An unbalanced condition may be caused by uneven weight distribution, or by uneven air loads or centrifugal forces on the blades when the propeller is rotating. Even weight distribution is known as static balance; this is checked by mounting the propeller on a shaft between knife edges; or by use of a single-plane precision balancing machine. An unbalanced condition can be corrected by adding weight to the lighter blade(s) and/or removing weight from the heavier blade(s). Material may easily be removed from wooden propellers, but metal propellers are usually balanced by attaching weights to the blade hub or by adding lead wool to the hollow blade roots. If there are significant differences in form or twist between the blades on a propeller, vibration can result because the thrust and/or torque produced by the blades is uneven. Procedures for evaluating such differences, and for achieving aerodynamic balance, are often available for large propellers. In their absence, careful checking of the blade profiles, and adjustment of any deviations, may often eliminate vibration. It is possible for a propeller to be in perfect static and aerodynamic balance, but still suffer from dynamic unbalance when rotating. The cause of such unbalance is non-symmetrical disposition of mass within the propeller, or non-symmetrical mounting of the propeller. Such unbalance can be corrected by adding balance weights, but this may be a lengthy procedure, involving repeated runs with the propeller installed on the aircraft. Propellers are balanced after manufacture, and whenever repairs, or overhaul, have been carried out, or vibration has been reported.

**3** TYPES OF PROPELLERS The various types of propellers are described briefly in this paragraph. The construction and operation of the main types of propellers in common use, are described in detail in paragraphs 4 and 5.

3.1 **Fixed-pitch Propellers.** Because of its lightness, cheapness and simplicity, a fixed-pitch propeller is often fitted to a single-engined aircraft. The pitch selected for any particular engine/airframe combination will always be a compromise, since the angle of attack will vary with changes in engine speed and aircraft attitude. Too coarse a pitch would prevent maximum engine power from being used during take-off and climb, and too fine a pitch would prevent economical cruising, and would lead to overspeeding of the engine in a dive.

3.2 **Variable-pitch Propellers.** With this type of propeller the blade angle may be varied in flight, so that engine power may be fully utilized. Variable-pitch propellers were originally produced with two blade-angle settings; a fine pitch to enable full engine speed to be used during take-off and climb, and a coarse pitch to enable an economical engine speed to be used for cruising. The introduction of an engine-driven centrifugal governor enabled the blade angle to be altered automatically (within a pre-determined range), in order to maintain any engine speed selected by the pilot, regardless of aircraft speed or attitude.

3.3 **Feathering Propellers.** If an engine failure occurs, the windmilling propeller may cause considerable drag, and adversely affect controllability of the aircraft. In order to reduce this drag, the blades of most constant speed propellers fitted to multi-engined aircraft are capable of being turned past the normal maximum coarse-pitch setting into line with the airflow. This is known as the 'feathered' position. Feathering the propeller not only reduces drag, but also minimizes engine rotation, thus preventing any additional damage to the engine.

3.4 **Reversible-pitch Propellers.** On some aircraft, the propeller blades may be turned past the normal fine-pitch setting, to a pitch which will produce thrust in the opposite direction (reverse thrust). On selection of reverse pitch by the pilot, the blades may be turned to a fixed reverse-pitch angle, but on some installations the pilot has control of blade angle, and can select any angle within a given range on each propeller individually. Reversible-pitch propellers provide braking during the landing run, and facilitate aircraft ground manoeuvring.

4 FIXED-PITCH PROPELLERS Fixed-pitch propellers normally have two blades, and are manufactured from either wood or aluminium alloy; they are generally only fitted to single-engined light aircraft.

4.1 **Wooden Propellers.** Wooden propellers are made up from a number of planks glued together. The wood used is usually either birch or mahogany, and is specially selected and seasoned for the purpose. After glueing and a further short seasoning period to equalise moisture content in the planks, the block is cut to shape and finished. An abrasion resistant coating of either canvas or cellulose is applied to the blades, and a metal sheath is normally screwed on to the leading edges and blade tips to protect the wood from being damaged by stones. The propeller is then given several coats of varnish or cellulose paint to protect it from atmospheric conditions.

4.1.1 If the engine shaft has an integral flange, the propeller is clamped between this flange and a separate steel faceplate. If the shaft is splined, the propeller is mounted on a steel hub, which is internally splined to fit the shaft, and has an integral rear flange and detachable front flange between which the propeller is mounted. In either case, a large clamping area is required so as to minimize damage to the wood fibres when the attachment bolts are tightened.

4.1.2 Hubs fitted to parallel splined shafts are mounted between a front and rear cone, the purpose of which is to ensure that the propeller is concentric with the shaft. The shaft is threaded to receive a large nut, which is tightened against the front face of the front cone. Hubs fitted to tapered shafts are similarly attached, but may not be mounted on cones.

4.2 **Metal Propellers.** Metal propellers are usually aluminium alloy forgings, and are anodised and painted for protection. They are usually bolted directly on to a shaft with an integral flange, but if they are fitted to a splined shaft they are mounted on a hub which is similar to that used for wooden propellers, but without a front flange.

5 VARIABLE-PITCH PROPELLERS Variable-pitch propellers consist of a number of separate blades mounted in a central hub, and a mechanism to change the blade angle according to aircraft requirements. The blades and hub are often aluminium alloy forgings, but the hub on a large propeller may be constructed from steel forgings because of the high centrifugal forces which it has to contain. The blades are mounted in the hub in ball or tapered roller bearings, and the pitch-change mechanism is attached to the hub and connected to each blade through rods, yokes or bevel gears. Operation and control of the pitch-change mechanism varies considerably, and three main types are discussed in this paragraph.

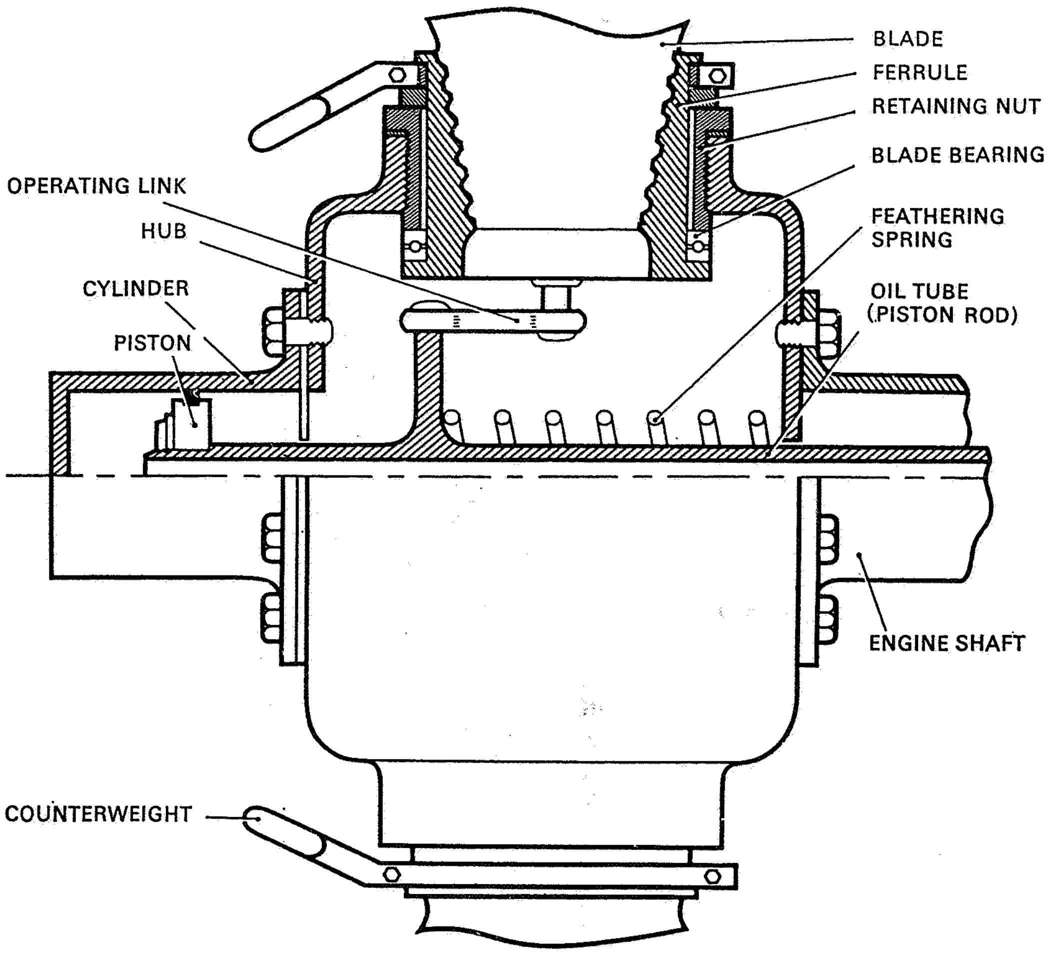


*Figure* 3 SINGLE-ACTING PROPELLER

5.1 **Single-acting Propeller.** A single-acting propeller is illustrated in Figure 3; it is a constant-speed, feathering type, and is typical of the propellers fitted to light and medium sized twin-engined aircraft. A cylinder is bolted to the front of the hub, and contains a piston and piston rod which move axially to alter blade angle. On some propellers, oil under pressure, fed through the hollow piston rod to the front of the piston, moves the piston to the rear to turn the blades to a finer pitch; on other propellers the reverse applies. When oil pressure is relieved, the counterweights and feathering spring move the piston forward to turn the blades to a coarser pitch. Counterweights produce a centrifugal twisting moment as described in paragraph 2.3 (a), but, because they are located at 90° to the chord line, they tend to move the blades to a coarser pitch. Counterweights must be located far enough from the blade axis, and must be heavy enough to overcome the natural twisting moment of the blade, but since weight and space are limiting factors, they are generally only used with blades of narrow chord.

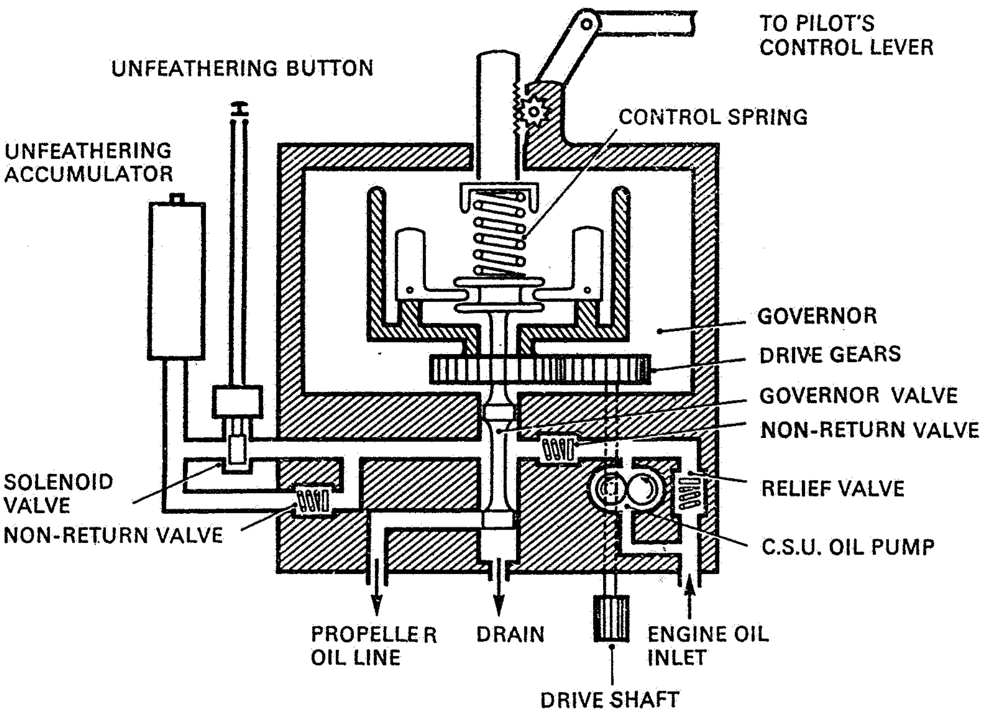


*Figure* 4 CONSTANT SPEED UNIT

5.1.1 **Propeller Control.** Blade angle is controlled by a constant-speed unit (Figure 4), which comprises a centrifugal governor, a governor valve, and an oil pump to boost engine oil pressure sufficiently for operation of the propeller control mechanism. The governor is driven from the engine shaft, and movement of the governor weights under centrifugal force is opposed by a control spring, the loading of which is set by means of the pilot's control lever. The position of the governor valve is determined, therefore, by engine speed and the force exerted by the spring; when these forces balance the oil line to the propeller is blanked off, and oil is trapped in the cylinder of the pitch change mechanism (see Figure 3).

(a) When the pilot's control lever is set to the maximum rev/min position, and the throttle is at a low power setting, the governor valve will be fully down, and oil from the pump will be directed through the hollow piston rod to turn the propeller blades to fully fine pitch. As the throttle is opened and rev/min are increased, centrifugal force on the governor weights will raise the valve, until a position is reached where maximum rev/min are obtained and the oil line to the propeller is blanked off. Any further increase in power will tend to increase rev/min and result in the governor valve being lifted; oil will drain from the propeller and produce a coarser blade pitch to maintain the specified maximum rev/min.

(b) During flight, rearward movement of the pilot's control lever will reduce control spring loading, and allow the governor weights to lift the valve; this will result in a coarser blade angle, and the increased load on the engine will reduce engine speed until the spring force is balanced by centrifugal force on the governor weights. Forward movement of the pilot's control lever will increase spring loading, and result in a finer propeller pitch and higher engine speed.

(c) If propeller load decreases in flight, or power is increased, the engine will begin to speed up, the governor weights will raise the valve, and propeller pitch will coarsen to maintain the set engine speed; conversely an increase in propeller load, or a decrease in engine power, will result in a finer propeller pitch, to maintain the set engine speed.

5.1.2 Feathering is accomplished by moving the pilot's control lever to the appropriate position, which is normally obtained by moving the lever through a gate in the quadrant. This action raises the governor valve fully, allowing oil to drain from the propeller, and the blades to turn to the fully coarse (feathered) position under the action of the counterweights and feathering spring.

5.1.3 In order to unfeather the propeller, a separate source of oil under pressure is required; on light aircraft this is usually provided by an accumulator which is charged during normal operation. To unfeather, the pilot's control lever is moved into the constant speed range, thus lowering the governor valve, and the unfeathering button is pressed, releasing oil from the accumulator and allowing it to flow to the propeller. This action commences unfeathering, and once the propeller starts to windmill the normal oil supply completes the operation.

5.1.4 When the engine is stopped on the ground, oil pressure in the cylinder is gradually relieved by leakage through the constant speed unit (CSU), and this would enable the propeller blades to turn to the feathered position under action of the feathering springs. This condition would result in unacceptable loads on the engine during starting, and a centrifugal latch is fitted to prevent forward movement of the propeller piston when the engine is stopped. Figure 5 shows the operation of a centrifugal latch; it is disengaged by centrifugal force at all speeds above ground idling, thus enabling the propeller to function normally during flight, but below this speed centrifugal force is overcome by return springs, and the piston can only move forward a short distance, equivalent to approximately 5° of blade angle. When the engine is started, oil pressure builds up to move the blades to fully fine pitch, and centrifugal force disengages the latch.

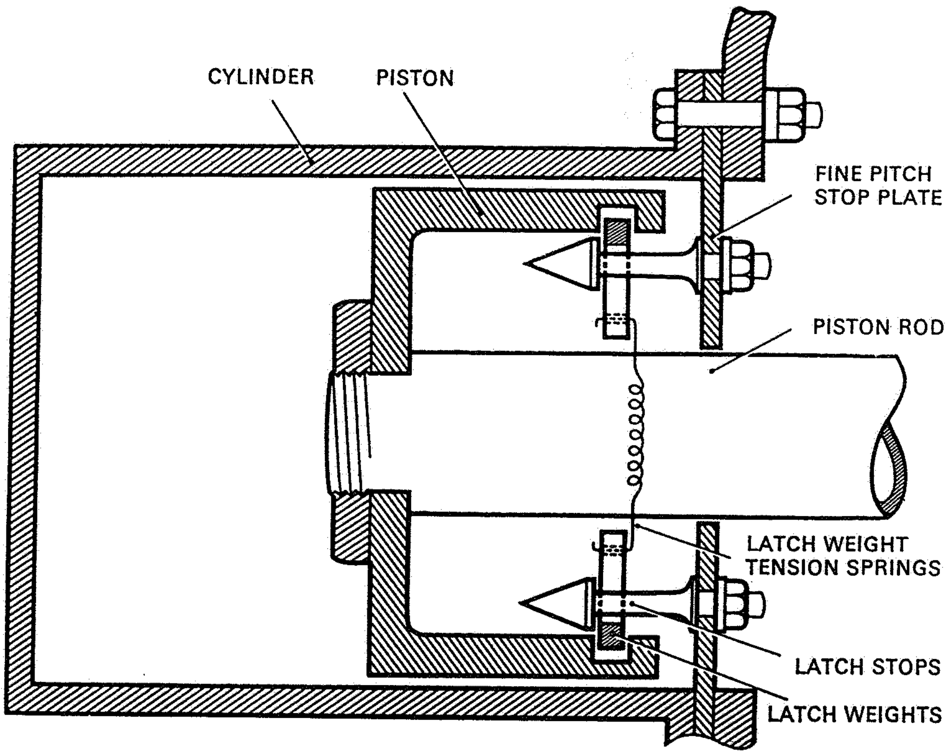


*Figure* 5 CENTRIFUGAL LATCH

5.1.5 Because of the predominance of single-acting propellers on light aircraft, only a simple propeller has been described. However, there is a wide variety of propeller/engine installations, and some of the safety features attributed to double-acting propellers will also be found on particular single-acting propellers.

5.2 **Double-acting Propeller.** This type of propeller is normally fitted to larger engines and, because of engine requirements, is more complicated than the propellers fitted to smaller engines. Construction is similar to that of the single-acting propeller, the hub supporting the blades, and the cylinder housing the operating piston. In this case, however, the cylinder is closed at both ends, and the piston is moved in both directions by oil pressure. In one type of mechanism (Figure 6), links from the annular piston pass through seals in the rear end of the cylinder, and are connected to a pin at the base of each blade. In another type of mechanism, the piston is connected by means of pins and rollers to a cam track and bevel gear, the bevel gear meshing with a bevel gear segment at the base of each blade; axial movement of the piston causes rotation of the bevel gear, and alteration of blade angle. Operating oil is conveyed to the propeller mechanism through concentric tubes in the bore of the engine reduction gear shaft.

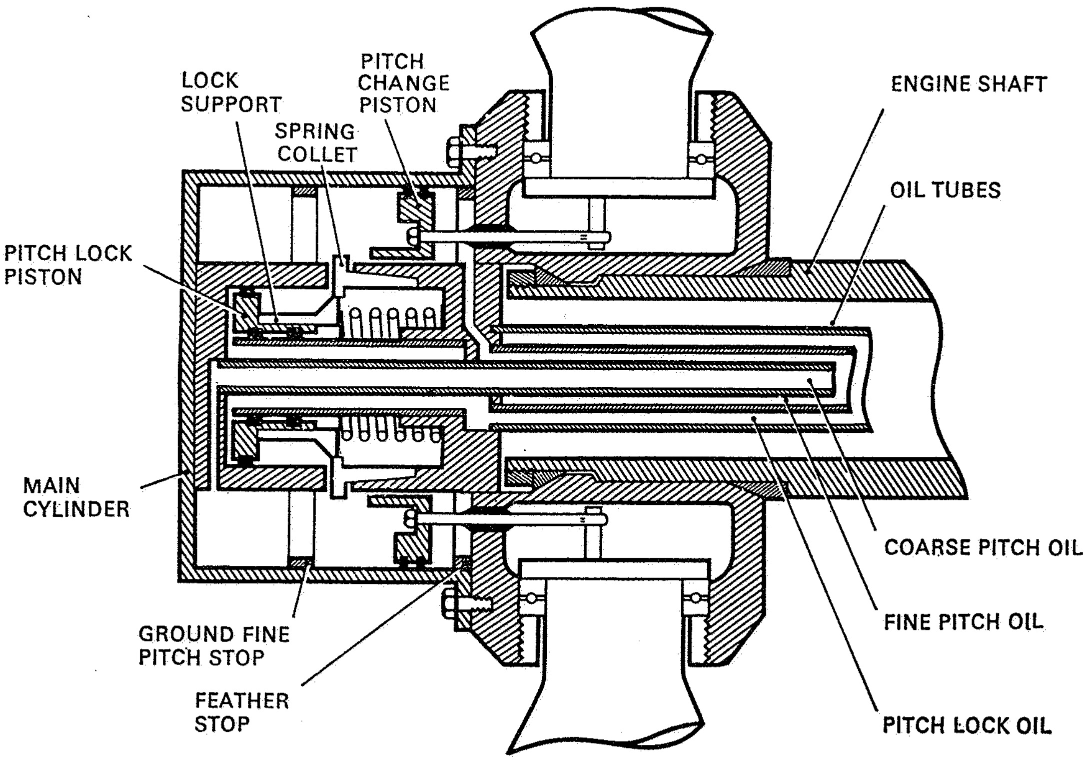


*Figure* 6 DOUBLE-ACTING PROPELLER

5.2.1 **Normal Operation.** In a turbo-propeller installation the power control lever is often connected to both the fuel control unit and the propeller control unit (PCU), so that fuel flow and engine speed are selected at the same time. The PCU is basically a CSU as illustrated in Figure 4, but the PCU includes a number of additional features. Constant speed operation is controlled in a similar manner to that on the single-acting propeller; the governor weights opposing control spring force to raise or lower the governor valve, and to supply oil to the appropriate side of the pitch change piston, whenever engine speed varies from the speed selected. Figure 7 illustrates the PCU.

(a) In the 'on speed' condition, centrifugal force on the flyweights balances the force of the control spring, and the governor valve traps oil in both sides of the pitch change cylinder.

(b) In the 'underspeed' condition, control spring force is greater than the centrifugal force on the flyweights, and the governor valve is lowered, supplying oil to the rear of the pitch change cylinder, and providing a drain for oil from the front of the cylinder. Blade angle decreases, and the engine speeds up until centrifugal force on the flyweights balances the force of the control spring, and the governor valve is returned to the 'on speed' condition.

(c) In the 'overspeed' condition, control spring force is less than the centrifugal force on the flyweights, and the governor valve is raised, directing oil to the front of the pitch change cylinder, and providing a drain for oil in the rear of the cylinder. Blade angle increases, and the engine speed decreases because of the added load, until the flyweights and control spring are once more in balance.

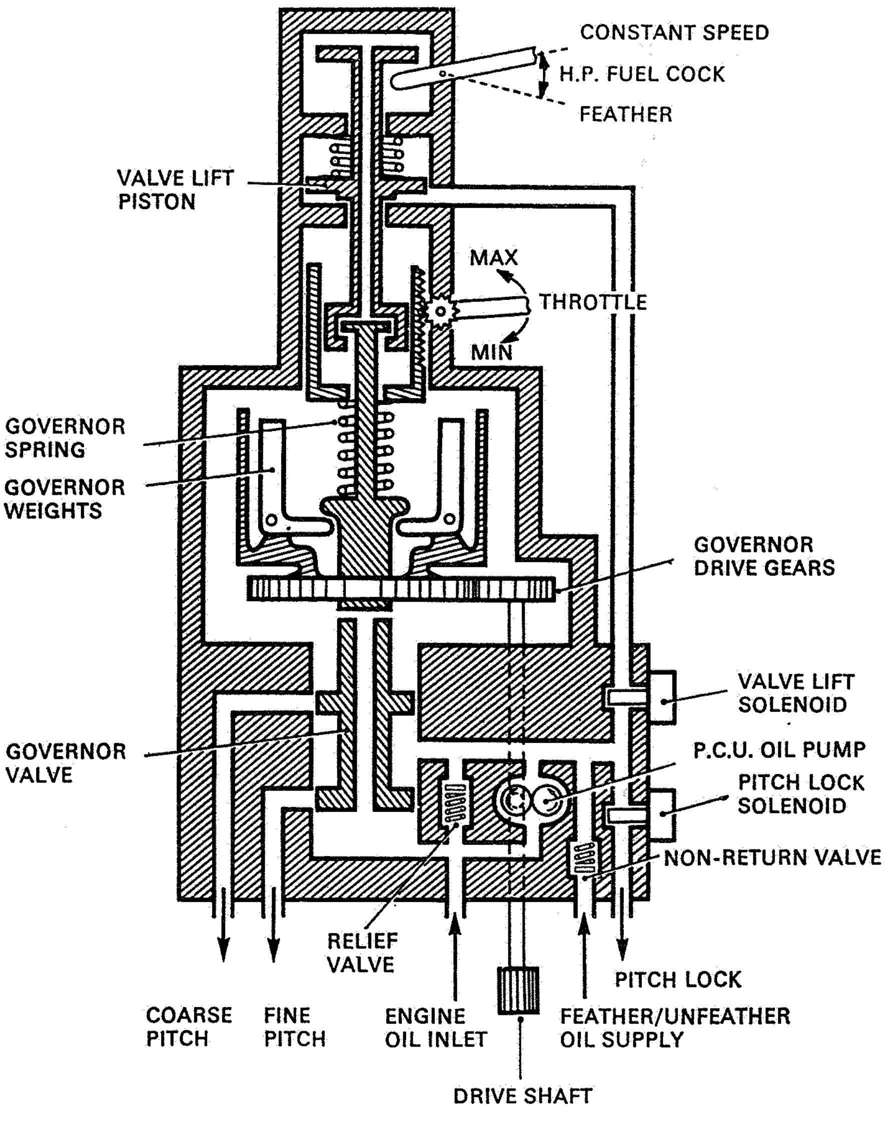


*Figure 7* PROPELLER CONTROL UNIT

5.2.2 **Fine Pitch Stops.** During starting and ground running, a very fine propeller pitch may be required, to minimize propeller load, and to prevent engine overheating; however, during flight, this very fine pitch would lead to engine overspeeding, and excessive drag if the PCU were to fail. To cater for both these requirements, the pitch change piston on the type of propeller illustrated in Figure 6, is provided with two fine pitch stops, the flight fine pitch stop being withdrawn for starting and ground operations. The flight fine pitch stop is in the form of a spring collet, the prongs of which are designed to spring inwards. When the collet is operating as a stop, the pitch-lock piston is held in the forward position by a spring, forcing the spring collet open, and preventing the pitch change piston from moving forward further than the flight fine pitch position. When ground fine pitch is required, a solenoid in the PCU is energized (normally by operation of both a stop withdrawal lever and a throttle-operated switch) and oil pressure is ducted through the third oil line to the front of the pitch lock piston; as the piston moves rearwards, support for the collet is withdrawn and the prongs spring inwards, allowing the pitch change piston to move fully forward to the ground fine pitch position. The pitch lock solenoid is disarmed when the throttles are moved forward for take-off, and, when the propeller has coarsened into the constant speed range, the pitch lock piston moves forward under spring pressure and opens the spring collet to form the flight fine pitch stop.

NOTE: The term 'pitch lock' is used, in the above paragraph, to describe a means of holding the fine pitch stop in a prescribed position. Some manufacturers use the term to describe a device which locks the blades at whatever angle they happen to be, should failure of the pitch change mechanism occur.

(a) The entire power-unit and the aircraft must be safeguarded in the event of the failure of the pitch-lock unit to operate, and a safety system is incorporated in the PCU. If, during flight, the propeller blades move to a pitch finer than flight fine pitch, a switch fitted to one blade closes, and completes the circuit through an isolating switch to a solenoid in the PCU. This solenoid directs oil pressure to a valve-lift piston, which lifts the governor valve and directs oil to the front of the pitch change piston. This action coarsens the propeller blade angle, and breaks the circuit to the valve-lift solenoid. If the pitch-change piston does not latch over the spring collet as it moves rearwards, the sequence will be repeated as the blades fine-off past flight fine pitch again. An isolation switch prevents operation of this safety system when ground-fine pitch is purposely selected.

5.2.3 **Feathering.** Facilities for the manual feathering of the propeller are provided on all large piston and turbo-propeller engines. With some turbo-propeller installations, however, the drag from a windmilling propeller in fine pitch could be very dangerous, particularly with a twin-engined aircraft, and for these aircraft automatic feathering is also provided.

(a) Manual feathering of the propeller on a piston engine, is normally carried out by movement of the propeller control lever to the 'feather' position, and operation of the feathering pump. These actions raise the governor valve, and supply oil under pressure to the appropriate side of the pitch-change piston. On a turbo-propeller installation, manual feathering is carried out by an interconnection between the PCU and the high pressure fuel cock. When the fuel cock is moved to the 'feather' position, linkage to the PCU lifts the governor valve independently of the governor control, and oil is directed to the front of the pitch change piston to turn the blades fully coarse. Since the oil pump in the PCU is driven by the engine, the oil supply may be insufficient to feather the propeller completely, and operation of the electrically-driven feathering pump may be necessary.

(b) Automatic feathering is initiated by means of a torque switch. Whenever the power levers are positioned above the idling range, and the engine torque falls below a specified amount, the torque switch closes and completes a circuit to the feathering pump and the valve-lift solenoid in the PCU. The solenoid directs oil to the valve-lift piston, which raises the governor valve, and opens the oil ports from the feathering pump to the front of the pitch change piston, thus feathering the propeller.

5.2.4 **Unfeathering.** On turbo-propeller engines, when the high pressure fuel cock is open and the power levers closed, the governor valve is in a suitable position to direct oil from the feathering pump to the rear of the pitch change piston. Selection of the feathering pump switch (which is often incorporated in the fire control handle), supplies oil to the PCU and thence to the propeller, and activates the engine ignition system. When the propeller blades have turned from the feathered position, the airstream commences to windmill the propeller and rotate the engine, and normal oil pressure builds up to complete the unfeathering operation.

5.2.5 **Reversing.** In a reversing propeller, the propeller mechanism includes a removable ground fine pitch stop, which enables the propeller to fine-off to a negative pitch when certain actions have been taken and certain conditions are fulfilled. Various safeguards are incorporated to prevent selection during flight. The means of achieving negative pitch vary considerably, but operation of a typical hydraulically operated propeller is described in the following paragraphs.

(a) Electrical control is exercised by throttle-mounted switches, weight contact switches on the landing gear, and a master switch or lever to arm the circuit. With the throttle levers closed beyond normal idling to a datum position, 'reverse' selected, and the weight of the aircraft on its wheels, electrical power is supplied to a pitch-stop withdrawal solenoid, and oil pressure is directed to withdraw the fine-pitch stop and move the pitch-change piston forward to the reverse stop, where it is held by hydraulic pressure. Operation of the 'reverse' lever also changes the sense of operation of the throttle levers, which are pulled further back to increase power in reverse pitch.

(b) Indication of stop withdrawal, and movement of the blades to negative pitch, is provided by hub-mounted switches, which illuminate appropriate warning lamps on the flight deck.

(c) Re-selection of positive blade angle is achieved by moving the throttle into the normal idling range, and by moving the master lever out of the reverse position. Oil is ducted to the front of the pitch change piston, and the blades move to a positive angle; the stop returns to normal operation once the blades have moved past the ground fine pitch angle.

5.3 **'Beta' Control.** On some gas turbine engines, a form of control known as 'beta', or blade angle control, is used for ground operations, and may be applied to either single-acting or double-acting propellers. With this system, the throttles (usually known as power levers) operate in a gated quadrant. During flight these levers cannot be closed below the 'flight idle' gate, and the CSU operates normally to maintain any pre-selected propeller speed. In the ground idling and reversing range, the power levers control propeller pitch to vary power at both positive and negative blade angles, at constant propeller speed, and the governor mechanism is overridden. An overspeed sensor, and mechanical pitch stop, prevent operation in the ground (fine pitch) range during flight. In the beta range, the pitch stop is withdrawn, and movement of a power lever rotates a setting cam in the associated CSU, which raises or lowers the governor valve according to whether a coarser or finer pitch is required. A mechanical feed-back mechanism, operated by linkage from the propeller blades, resets the governor valve via a follow-up cam, and pitch change ceases when the angle scheduled by the power lever is achieved.

5.4 **Electrically Operated Propellers.** As with other types of variable-pitch propellers, a hub is mounted on the engine reduction gear shaft, the individual blades are fitted into the hub, and the pitch change mechanism is fitted to the front of the hub. In this type, however, the pitch change mechanism consists of a reversible electric motor, driving a bevel gear through a gear train with a very high reduction ratio. The bevel gear meshes with a bevel gear segment attached to the root of each blade, and, when rotated, turns the blades to alter propeller pitch. Electric power to the motor is provided through a brush and slip-ring arrangement at the rear of the hub. A motor brake is provided to prevent overrun, and normally consists of two friction discs, one fixed to the rotating motor shaft, and the other keyed to the stationary motor casing. The brake is applied (discs held together) by spring pressure, and released by means of a solenoid whenever a pitch change is initiated.

5.4.1 Some electrically operated propellers are controlled by an engine-driven CSU, and switches are also provided which enable propeller pitch to be controlled manually. The CSU is similar to those fitted to hydraulically operated propellers, but the governor valve supplies oil to the appropriate side of a piston contained in the CSU, which is connected to the central contact of a switch unit. Movement of this piston in either direction completes a circuit to the pitch change motor, and alters blade angle as required.

5.4.2 On some multi-engined aircraft an electrical control system is used. A single propeller pitch lever controls the speed of a master electric motor, which is used as a reference for engine speed, and which drives the stator of a contactor unit for each engine. Each engine drives an alternator, which supplies three-phase alternating current to the stator windings of the appropriate contactor, the frequency being proportional to engine speed. During operation, a magnetic field is built up round the stator with a phase rotation opposite to that of the stator. If the stator speed and alternator speed are the same, the magnetic field will, therefore, be stationary; any variation in alternator speed will result in rotation of the magnetic field, the direction of rotation depending on whether the alternator is rotating faster or slower than the stator. Rotation of the magnetic field influences a concentric rotor, which rotates with it, and closes a pair of contacts to complete the circuit to the appropriate windings in the propeller pitch change motor. Switches are normally provided to enable pitch changes and feathering to be carried out manually.

## 6 INSTALLATION AND MAINTENANCE

6.1 **Wooden Fixed-pitch Propellers.** Because of the nature of the material from which they are made, wooden propellers are relatively easily damaged by stones and other hard objects, and they may also be affected by climatic conditions. These propellers should frequently be inspected for breaks in the surface finish, scores, nicks, cracks, delamination, and security of the leading edge sheath. Minor defects in the surface finish may be repaired by touching-up with varnish or paint as appropriate, but any damage to the wood, other than very minor damage (see paragraph 6.1.2), must be assessed in accordance with the approved repair schemes, and the propeller repaired or returned to the manufacturer as appropriate.

6.1.1 **Periodic Maintenance.** The intervals at which the propeller must be removed for inspection are specified in the approved Maintenance Schedule. With the propeller removed from the aircraft, the blades and boss should be inspected for the sort of damage described in paragraph 6.1, paying particular attention to those areas which are not visible when the propeller is installed. In addition, the following inspections should be carried out:—

(a) Bolt holes should be examined for ovality, rough edges, and cracks radiating into the boss.

(b) Boss faces should be examined for damage where they have been in contact with the hub flanges, particularly at the circumference of the flanges.

(c) The centre bore should be examined for cracks and delamination of the plies.

(d) The mounting hub should be examined for corrosion, cracks, correct fit on the crankshaft, and for condition of the attachment bolts and nuts.

(e) Where mounting cones are fitted, these should be checked for corrosion, and for picking-up of the surface. Correct fit between the hub and cones may be checked using engineers' blue, an 80% contact normally being required.

6.1.2 **Repairs.** The limits of repairable damage are normally laid down in the appropriate aircraft manual, and are related to a maximum depth and area, expressed as a percentage of the thickness or chord of the blade at that point.

(a) Minor indentations and small longitudinal cracks may usually be repaired by plugging with a mixture of glue and sawdust, then sanding smooth.

(b) Deep cuts or damage must be removed, and an insertion repair carried out. Identical timber must be used, and particular attention must be paid to matching the grain direction.

(c) If slight tip or trailing edge damage is repaired by sanding to a new profile, both blades must be similarly shaped.

(d) If repairs to the metal sheath are permitted, extreme care is necessary to prevent bruising of the wood when shaping the new metal. The original screw and rivet holes must be used, and the manufacturer's recommended procedures carefully followed.

(e) In all cases where repairs have been carried out, the propeller must be balanced (paragraph 2.5), and re-protected in the original manner.

6.1.3 **Installation.** Before installing a propeller, the propeller shaft and threads should be checked for damage. The fit of the hub on the shaft should be checked using engineers' blue, and any high spots should be removed with a fine oil stone. Boss and hub flange faces should be checked for cleanliness, to ensure that maximum friction will be obtained.

(a) When assembling the hub to the shaft, it is usually recommended that an anti-seize compound should be applied to the threads, and engine oil to the shaft. Where cones are fitted, these should be clean and dry.

(b) The angular position of the propeller on the hub is not important, unless the engine is likely to be started by hand swinging. In this case it should be mounted in a convenient position in relation to aircraft height and engine compression. The attachment bolts should be tightened evenly, and in proper sequence, to the specified torque.

(c) After installation, the track of the propeller must be checked. This is normally measured on a trestle or platform vertically below the boss; when the propeller is rotated the blades should track within $\frac{1}{8}$ inch of each other, but a greater tolerance may be permitted on repaired propellers, provided that no vibration is evident during engine runs.

(d) After engine runs to check the reference rev/min, the propeller attachment bolts and the hub retaining nut should be checked for tightness, and re-locked. It is recommended that the bolts should also be checked after each of the first few flights.

NOTE: Shrinkage washers are sometimes fitted to the attachment bolts of wooden propellers, to take up any shrinkage which may occur after installation. These washers must be fitted strictly in accordance with the manufacturer's instructions.

6.2 **Metal Fixed-pitch Propellers.** Aluminium alloy propeller blades are less prone to surface damage than wooden propeller blades, but sharp indentations and scores will cause stress concentrations which may lead to failure, particularly if a number of damaged areas form a line across a blade. Such propellers should be inspected frequently for corrosion, dents, nicks, cuts, and other surface damage.

NOTE: Blade failures have been known to occur, through corrosion which has started underneath blade decals attached with a water-soluble adhesive. Particular attention should be paid to any instructions or directives which have been issued regarding inspection, removal or replacement of these items.

6.2.1 **Periodic Maintenance.** Metal propellers are not normally overhauled at definite periods, and are only removed for repair or reconditioning when the condition of the blades makes this necessary. When the propeller is removed, the mounting bolts should be examined for cracks, using a suitable non-destructive testing method, and the propeller mounting flange bolt holes should be examined for ovality and cracks. In addition, the faces of the propeller boss should be checked for fretting, corrosion, and cracks emanating from the bolt holes. Further information on the maintenance of propeller blades will be found in CAA Airworthiness Notice No. 55.

6.2.2 **Repairs.** Propellers which are bent or twisted, which have surface cracks in a chordwise direction, or which have sustained damage in the form of cuts, nicks, or gouges, beyond the limits of depth or area specified by the manufacturer, must be returned to an approved overhaul organisation for repair. Minor repairs may be carried out by removing metal from the damaged area, so that the final depression is within the specified repair limits for the particular blade area. Metal should be removed with a smooth file and emery cloth, and the repair should progressively be checked by the penetrant dye process, until all damage has been removed and a smooth shallow depression remains.

(a) After repairs have been satisfactorily carried out, the propeller should be carefully balanced. If repairs have been made to one blade only, it may be necessary to remove material from the other, heavier blade, at the position corresponding to that of the repair on the damaged blade. Care must be taken not to reduce blade chord or thickness below the minimum dimensions specified for the particular propeller. If only a very small amount of metal was removed during repair, balance may often be restored by applying additional paint to the lighter blade.

(b) After balancing, the propeller should be partly or completely reprotected, depending on the extent of the surface damage, using the primer and paint or varnish specified by the manufacturer.

6.2.3 **Installation.** Fixed-pitch metal propellers are normally installed on a flanged propeller shaft, and a spacer is often used to give clearance between the propeller and the engine cowling. Dowels are used to lccate the propeller on the spacer or propeller shaft flange, and these should be a tight press fit in the holes. The dowels, spacer and flange should be inspected before assembly to ensure that they are undamaged, and the propeller and spacer should be assembled together before installation on the engine.

(a) If the engine is likely to be hand-swung, the propeller should be fitted to the engine in a convenient position. The attachment bolts should be tightened evenly, and in proper sequence, to the specified torque.

(b) It is not usually necessary to check the track of a metal propeller after initial installation, but it may be necessary if vibration is evident during operation.

(c) The engine should be ground run after installing the propeller, to check for vibration and determine the engine speed obtained at full throttle. This reference rev/min should be corrected for ambient conditions, and recorded in the engine log book.

(d) The propeller attachment bolts should be checked for tightness after the engine run.

6.3 **Variable-pitch Propellers.** In some instances, variable-pitch propellers may be fitted with steel blades, and particular care must be exercised during inspection, because of the adverse effects of surface damage on the fatigue life of these blades. Inspection and repair must be carried out strictly in accordance with the manufacturer's instructions. Maintenance of variable-pitch propellers with aluminium alloy blades is described below.

6.3.1 **Periodic Inspection.** The following inspections should be carried out at the periods specified in the approved Maintenance Schedule, or as recommended in CAA Airworthiness Notice No. 75.

(a) All visible parts of the propeller, its components, controls, pipe connections and wiring, should frequently be inspected for damage and security.

(b) The blades should be inspected for damage in the form of abrasions, cuts, nicks, or corrosion. Minor erosion or dents may usually be left until the propeller is removed, but cuts or gouges which may lead to cracks should be blended out immediately, and the area should be repainted.

(c) The spinner, hub and blade roots of hydraulically-operated propellers should be examined for traces of oil leaking from the pitch change mechanism. If the propeller is a 'dry hub' type, oil leaking into the hub may, through centrifugal force, flow through the blade bearings, remove the grease, and result in premature failure of the bearings. Some traces of oil may be found after initial installation, but, if the leakage persists, the propeller must be stripped to the extent necessary to cure the leak, and to clean and re-grease the bearings. This particular problem does not apply to propellers with 'wet' hubs, but any leakage should, nevertheless, be investigated.

(d) The CSU/PCU, and connecting pipes should be inspected for oil leaks. Leakage at the mounting face of the CSU/PCU may be remedied by tightening the nuts or replacing the gasket, but leakage from other parts of the unit will normally require a replacement of the complete unit.

(e) Whenever the propeller is removed, the slip rings and contact brushes should be examined for damage and wear. Brush wear over the operating period should be assessed, and the brushes should be replaced if the rate of wear indicates that they will not remain serviceable until the next overhaul.

6.3.2 **Damaged Blades.** Blades which are bent, twisted or cracked, or have severe surface damage, must be considered unserviceable, and the propeller must be returned to the manufacturer or an approved overhaul organisation. Minor surface damage may be blended out in the same way as for fixed-pitch metal propellers, and within the limitations imposed by the manufacturer.

(a) If vibration is experienced, the blades should be inspected for signs of cracks, dents, or bending. The track of each blade should be checked, and the blade angles should be measured at the specified station. It is usually possible to adjust the blade angle of an individual blade by fitting shims to, or by adjusting the length of, the operating rod from the pitch-change mechanism to the blade. If all these checks are satisfactory, it is unlikely that the propeller is the cause of the vibration.

6.3.3 **Installation of Propeller.** The method of installation will depend on the type of propeller, and all instructions detailed in the appropriate Maintenance Manual should be carefully followed; these will include any special checks to be carried out, and details concerning lubrication, torque loading and locking of retaining parts. The following procedures are applicable to most propellers.

(a) Remove all protective covers and plugs, and clean parts which have been treated with a protective coating. Lubricate specified parts with the recommended grease or oil before installation.

(b) Fit the electrical brush gear housing to the engine reduction gear casing, and check that it is square with the engine shaft, using a dial test indicator clamped to the shaft.

(c) Fit the sling to the propeller, lightly smear the front and rear cone seatings with engineers' blue, and temporarily fit the propeller to check the contact area of the cones. Tighten the hub retaining nut by hand, rotate the propeller at least one revolution, then remove the propeller and check the extent of blueing of the cones. If the contact area is less than 80%, high spots may be removed by light stoning, or, where permitted, by lapping on a suitable mandrel. Clean the cones and cone seatings.

(d) With hydraulically-operated propellers, fit and lock the oil tubes in the engine shaft.

(e) Refit the propeller, lightly lubricating the splines, cone bore and threads with the specified lubricants. Cone faces should not normally be lubricated, as this may result in looseness of the propeller when the oil film is lost. Lubricating the propeller bore, rather than the shaft, will prevent any lubricant from being displaced on to the cone face when the propeller is installed.

(f) Turn the blades to the feathered angle, and fit the pitch-change mechanism.

(g) Install the brush gear, and check for correct contact between the brushes and the slip rings.

(h) Fit the spinner, and turn the blades through their full pitch range, to check for fouling.

6.3.4 **Installation of CSU/PCU.** Installation of the CSU/PCU is normally straightforward. A new gasket should be fitted to the mounting flange, and the unit should be installed carefully, ensuring that the driven gear meshes with the driving gear or quill shaft, and that any dowels are correctly located. Mechanical linkage on a piston engine should be adjusted, so that the CSU control is on the maximum rev/min stop when there is a slight clearance between the pilot's control lever and the forward end of the gate in which it operates. The controls to the PCU of a turbine engine are interconnected with the high pressure fuel cock, and with one or more of the electrical contacts associated with the operation of the various propeller functions; they may also be electrically or mechanically connected to the controls on the flight deck. Mechanical linkage is normally adjusted by locking the pulleys and levers in set positions, using rigging pins or similar equipment as necessary, and adjusting the connecting rods or cables to suit. Details of the procedures for setting up the propeller controls on any particular aircraft must be obtained from the appropriate Maintenance Manual.

6.3.5 **Testing After Installation.** After installing a propeller, the engine must be ground run to check propeller operation. Aircraft propeller installations vary considerably, and no set testing procedure would be satisfactory for all aircraft. It is imperative, therefore, that any particular installation should be tested in accordance with the approved Maintenance Manual, which will normally include the following general requirements.

(a) The engine should normally be fully cowled, and the aircraft should be facing into wind before starting an engine run. It is sometimes recommended that the pitch change cylinder should be primed with oil before starting, by operation of the feathering pump.

(b) The safety precautions appropriate to engine ground running should be taken, the controls should be set as required, and the engine should be started.

(c) As soon as the engine is operating satisfactorily, and before using high power, the propeller should be exercised in the manner specified in the Maintenance Manual, to establish that the pitch change mechanism is operating.

(d) The checks specified in the Maintenance Manual to confirm satisfactory operation of the propeller system, including constant speed operation, feathering, operation of the propeller pitch change throughout its range, synchronisation with other propellers on the aircraft, and operation of associated warning and indicating systems, should be carried out.

(e) Engine running time should be kept to a minimum consistent with satisfactory completion of the checks, and a careful watch should be kept on engine temperatures to avoid overheating. With turbine engines, changes to operating conditions should be carried out slowly, to avoid rapid engine temperature changes, and to conserve engine life.

(f) When all checks have been successfully carried out, the engine should be stopped, and a thorough inspection of all propeller system components should be carried out, checking for security, chafing of pipes and cables, and signs of oil leaks.

NOTE: If vibration was experienced during the engine run, the hub retaining nut should be retightened after the engine shaft has cooled down.

6.4 **Additional Inspections.** In addition to the normal inspections carried out on a routine basis, certain occurrences will require special checks to be carried out, and these checks are briefly described in the following paragraphs.

6.4.1 **De-icing Equipment.** Damage to de-icing equipment fitted to the propeller should be dealt with as described in Leaflets **PL/1—3** or **PL/1—4**, as appropriate.

6.4.2 **Lightning Damage.** If a metal propeller is struck by lightning, burn damage to the blades is likely to occur. In removing this damage the normal repair limits apply, but after cleaning out all physical damage, a further specified thickness of metal must be removed, and the depression blended to a smooth contour. The damaged area should then be chemically etched, and inspected with a magnifying glass to ensure that there are no signs of material abnormalities. Any electrical circuits in the propeller should be checked for continuity and insulation resistance.

6.4.3 **Overspeeding.** Propellers may occasionally exceed their normal maximum rotational speed, and be subjected to centrifugal forces in excess of those for which they were designed. With variable-pitch propellers, overspeeding will normally only occur following failure of the control system, but with fixed-pitch propellers the maximum engine speed may easily be exceeded during manoeuvres if the engine speed indicator is not carefully monitored. The extent of the checks which must be carried out following overspeeding, will depend on the margin by which the normal maximum rev/min have been exceeded, and on any particular instructions contained in the approved Maintenance Manual. The figures quoted here are typical values.

(a) No special checks are normally required following overspeeding up to 115% of normal maximum rev/min, but it may be recommended that the track of the propeller is checked.

(b) If the propeller has been overspeeding between 115% and 130% of normal maximum rev/min, for a period in excess of any specified time limit, it should be removed for inspection. All blades should be carefully inspected for material failure, using a penetrant dye process. Blade bearings should be crack tested, and the rolling elements and raceways should be inspected for brinelling (i.e. indentation). The hub and counter-weights should be inspected for cracks and distortion, and particular attention should be paid to the blade mounting threads and spigots.

(c) If the overspeeding has been in excess of 130% of normal maximum rev/min, the propeller should be returned to the manufacturer for investigation.

6.4.4 **Special Instructions.** Manufacturers of propellers may issue, from time to time, instructions dealing with the detection and rectification of faults which are known to exist on particular types of propellers. These instructions are often issued in the form of Service Bulletins, and engineers should be acquainted with such advice, and should take action accordingly.

## 7 STORAGE

7.1 **Installed Propellers.** Propellers installed on an engine which may be out of use for a period of up to three months should be kept clean, and should be inspected regularly for corrosion. The internal parts of a variable-pitch propeller will be protected by exercising the propeller during weekly engine runs where these are possible, but, if the engine cannot be run, the propeller should be feathered and unfeathered using the feathering pump. If the engine is likely to be out of use for more than three months, the propeller mechanism should be flushed with inhibiting oil, and all external parts of the propeller should be treated with lanolin or an approved rust preventative. The propeller operating mechanism should be covered with waxed paper, and all visible parts should be regularly inspected for corrosion.

7.2 **Uninstalled Propellers.** Uninstalled propellers should be stored in conditions which are clean, dry, warm, and free from corrosive fumes. Two-bladed propellers are usually stored in racks to permit free circulation of air, but propellers with more than two blades may be stored vertically, on stands, to minimise the amount of floor space they occupy. Propellers should be retained in the manufacturer's packaging whenever possible, or wrapped in mouldable wrap and waxed paper. The external parts of metal propellers should be coated with lanolin or an approved alternative. The pitch change mechanism of a hydraulically operated propeller should be inhibited with an approved oil, and all loose parts, such as oil tubes and mounting cones, should be coated with lanolin and wrapped in waxed paper.

7.2.1 When a variable-pitch propeller is disassembled for storage, individual mechanical parts should be immersed in inhibiting oil, then allowed to drain, bearings should be coated with mineral jelly, and electrical connections should be smeared with petroleum jelly. All electrical equipment, such as motors and slip rings, should be thoroughly cleaned, the connections smeared with petroleum jelly, external surfaces should be treated with a rust preventative, and each part sealed in a moisture vapour proof bag. All parts of the propeller should then be wrapped in waxed paper and, if possible, packed in a suitable carton or crate.

7.2.2 When assembled propellers or pre-loaded blade assemblies are held in storage, the bearings must be exercised after six months and nine months. At the end of twelve months in storage the bearings must be removed and examined for brinelling and corrosion, and, if they are found to be satisfactory, they should be cleaned, greased, and reassembled on the blade. They will then be satisfactory for a further six months storage.

7.2.3 The maximum storage period varies between different types of propellers, but generally, if a propeller is retained in the manufacturer's packing, it will, subject to the checks outlined in paragraph 7.2.2, remain in a satisfactory condition for three years. If the propeller, or individual components, are not retained in the original packing, they will normally require re-inhibiting every twelve months, and overhauling after three years.

7.2.4 Rubber components are normally subject to a specific life, counted from the cure date or assembly date, and must be discarded at the overhaul nearest to their life expiry. Details concerning the life of a particular component should be obtained from the relevant Maintenance Manual. Loose rubber components should be stored in the dark in an unstressed condition, and retained in the manufacturer's packing until required for use.

7.3 All propellers or propeller components retained in storage should be suitably labelled to show their part number, modification standard, original date of storage, and any other details relevant to the actions taken subsequent to the original storage date.

# PL/1-3

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# AIRCRAFT

## PROPELLERS

### FLUID DE-ICING SYSTEMS

1 INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of fluid de-icing systems for aircraft propellers. It should be read in conjunction with the Maintenance Manuals for the aircraft and system components concerned.

NOTE: This Leaflet incorporates the relevant information originally published in Leaflet PL/3-1, Issue 1, 1st December, 1950.

2 GENERAL The system provides a film of de-icing fluid to the propeller blade surfaces during flight which mixes with the water or ice and reduces the freezing point of the mixture. Where ice has already formed on the blades, the fluid penetrates under the ice and loosens it sufficiently for it to be thrown off by centrifugal action.

2.1 Fluid is distributed to each propeller blade from a slinger ring which is mounted on the back of the propeller hub. The fluid is pumped into this ring through a delivery pipe from a supply tank.

2.1.1 Some propellers have rubber overshoes fitted to the blades to assist the distribution of the fluid. On this type of installation fluid is fed from the slinger ring to a small trough, which is part of the overshoe, and is then forced by centrifugal action along longitudinal grooves in the overshoes.

2.1.2 On propellers which are not fitted with overshoes, fluid is fed from the slinger ring through a pipe to the root of the blade and is then distributed by centrifugal action.

2.2 The fluid may be pumped to the slinger ring from the supply tank by an independent electrically driven pump but air pressure is sometimes used.

2.2.1 The electric pump may be controlled by a switch and, in some installations, the pump speed may be varied by means of a rheostat. Non-return valves are sometimes provided to prevent loss of fluid when the pump is not operating.

2.2.2 Where air pressure is used to supply fluid, a relief valve is usually fitted to the air supply line and a control valve provided to regulate the fluid flow.

3 INSTALLATION The information contained in the following paragraphs outlines the checks and procedures necessary on initial installation of the system.

NOTE: Pipe-lines and supply tanks should be installed in accordance with Leaflets AL/3-13, AL/3-14 and AL/3-15. For guidance on the installation of electric cables and the testing of circuits, see Leaflets EEL/3-1 and EEL/4-1.

3.1 **Slinger Ring**

3.1.1 The pipe and nozzle which deliver fluid to the slinger ring should be positioned so that there is sufficient clearance between the pipe and the side of the ring to prevent interference when the propeller is rotating. This clearance is important as the tolerance is small and an error may render the system inoperative.

3.1.2 The feed pipes between the slinger ring and the propeller blades should be positioned so that there is sufficient clearance to prevent damage being caused by vibration during service.

3.1.3 On propellers which are not fitted with overshoes, correct distribution of fluid over the propeller blades depends on the shape of the feed pipes and, therefore, care should be taken that the pipes are not damaged or distorted in any way, particularly when fitting or removing the propeller.

3.2 **Pumps.** In some instances a pump may have several delivery outlets and where the number of outlets exceeds the number required, those which cannot be used are routed back into the inlet pipes. Alternatively, on some gear type pumps, outlets which are not used may be blanked off provided that the appropriate gear wheel is removed.

4 TESTING The following tests refer to systems in which the propellers are not fitted with overshoes and where the systems are operated by electrically-driven pumps: the tests may, however, be adapted to other systems. When applying the tests the system should be filled with the fluid specified in the Maintenance Manual for the aircraft concerned.

4.1 **Flow Test.** Before commencing the initial flow test, the pump filter should be checked for cleanliness. A check should also be made to ensure that the tank vent system is unobstructed. An ammeter should be fitted in the electrical circuit of the system. The voltage of the power supply should also be checked to ensure that it is at the correct level.

4.1.1 The delivery pipe-line should be disconnected at a convenient point near the slinger ring and a calibrated container positioned to receive the fluid. The pump should be operated and the fluid delivery rate and ammeter reading noted. On multi-engined aircraft the test must be applied to all propellers simultaneously in order to determine the delivery rate to each slinger ring.

4.1.2 The delivery rate of the fluid should be within the limits specified by the manufacturer. Where a rheostat control is provided for varying the delivery rate, the flow should be checked at the various settings.

4.1.3 If the amperage required to operate the pump exceeds the rated value, or the delivery rate of the fluid is less than the prescribed minimum, the slinger ring, pipe-lines and tank vent system should be checked for obstruction or damage. If these checks are satisfactory, the pump may be defective and should be removed for checking.

4.2 **Functioning Test**

4.2.1 If there is any doubt as to whether the propeller de-icing system is functioning properly it should be checked during an engine ground run.

4.2.2 The propellers should be painted with commercial whitewash and allowed to dry. A suitable dye should be added to the fluid so that when the de-icing system is operated the dyed fluid will stain the whitewash and indicate the distribution over the blades. Uneven distribution may be caused by the slinger ring being fitted eccentrically, by the feed pipes from the ring being incorrectly located or by obstructions in supply pipelines.

5 CLEANING THE SYSTEM When the de-icing system is likely to be out of use for a long period it is advisable to remove all traces of de-icing fluid. This may be done by draining the supply tank and re-filling with a mixture of 95% methylated spirits and 5% distilled water; the system should then be operated until the tank is empty. During this operation the propeller should be turned so that the feed pipes leading from the slinger ring to the blades receive an equal amount of fluid.

5.1 **Inhibiting.** The fluid used in de-icing systems is stable and non-corrosive but leaves a gummy residue on drying out. Inhibiting the fluid pump and system is at the discretion of the aircraft operator, but if it is not inhibited it is advisable that a certain level of de-icing fluid (approx. 2 gallons) is maintained in the tank and the system operated at regular intervals.

5.1.1 If the pump and system associated with a propeller utilising overshoes is to be inhibited, the propeller blades should be covered before commencing the process, to prevent deterioration of the overshoes which could result from contact with the inhibiting fluid. Similar precautions must also be taken when draining the system of inhibiting fluid and preparing it for use.

6 PERIODIC INSPECTION The following information should be related to the Maintenance Schedule for the particular aircraft.

6.1 **General**

6.1.1 After each flight when the system has been used, the propeller blades should be cleaned with methylated spirits or warm soapy water, as recommended by the manufacturer. The supply tank should be replenished with the fluid specified in the Maintenance Manual.

6.1.2 Examine overshoes for defects, paying particular attention to the following:—

(i) Check edges and tips of overshoes for adhesion failures. It should be borne in mind that the shoe tips and edges may lift in flight and it may not be easy to detect this defect.

(ii) Check for blisters. These should be repaired in accordance with the manufacturer's instructions. Deformations caused by irregularities in the cement film should not be mistaken for blisters.

(iii) Check for freedom from cuts especially at the leading edge.

6.1.3 Overshoes may be cut back slightly to remove damage caused by stones or grit; the manufacturer's instructions on this procedure and also on any necessary checks concerning propeller balance, must be closely followed.

6.1.4 The bottom of the trough, the longitudinal grooves, pipes and valves, as applicable to the system, should be free from gummy deposits.

6.1.5 The trough should be free from damage. Troughs are easily deformed but may be manipulated back to the correct shape; care should be taken to ensure that the correct clearance is maintained between the trough and the feed pipe. When the trough is damaged to such an extent that the beading wire has broken, a new part should be fitted.

6.2 **Filters.** At the period specified in the approved Maintenance Schedule, the pump filter should be dismantled and cleaned in methylated spirits. After re-assembly the system should be flow-tested as outlined in paragraph 4.1.

6.3 **Pumps.** When a pump has been dismantled for inspection, the valves, pistons, etc., should be cleaned in methylated spirits, and the gears and bearings in paraffin. On re-assembly parts such as bearings, gears and gear housings should be lubricated with the specified lubricants and functional tests of a pump carried out in the manner prescribed in the relevant Maintenance Manual.

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# AIRCRAFT

## PROPELLERS

### ELECTRICAL DE-ICING SYSTEMS

1 INTRODUCTION This Leaflet gives guidance on the inspection and maintenance of systems employed for de-icing certain types of propeller by an electrical heating method. Since these systems vary between different aircraft, the information given in this Leaflet is of a general nature and it is, therefore, important that it should be read in conjunction with the installation drawings, Maintenance Manuals, Overhaul Manuals and approved Maintenance Schedules for the aircraft and propeller concerned.

2 GENERAL In electrical systems, the basis for effective de-icing is formed by resistance wire heating elements bonded to the leading edges of the propeller blades; in the case of turbine engine propellers, wire woven or sprayed elements are also bonded to the front shell of the spinner. Depending on the type of aircraft, the power for heating the elements is either direct current or alternating current and is applied in a controlled sequence by a cyclic timer unit. In turbopropeller engine installations, the propeller heating circuit forms part of a power unit de-icing and anti-icing system, and the cyclic control is integrated with the engine air intake heating circuit.

2.1 **Construction.** The construction of the elements, or overshoes as they are sometimes called, varies between propeller types. In one commonly used propeller, the heating element wires are interwoven with glass threads which form a glass cloth base, this in turn, being cemented between sheets of rubber. A protective guard of wire gauze is cemented beneath the outer rubber covering. The overshoe is shaped to fit round the blade leading edge and is cemented to it. In some cases, the overshoe is cemented in a rebate machined in the leading edge, so that it lies flush with the blade surfaces.

2.2 **Power Supplies.** The power required for heating is conveyed to the elements via cables, slip rings and by brushes contained within a brush block housing. The slip rings are normally mounted at the rear of the propeller hub or on a starter ring gear, and the brush housing on the engine front casing, but in some systems the method of mounting may be the reverse way round. The cables are of sufficient length and are positioned so as to allow for movement of the blades throughout their designed pitch range.

2.3 **Heating Control.** Efficient operation of these systems necessitates a relatively high consumption of electrical power. This is, however, controlled by employing a cyclic de-icing technique whereby a short unheated period allows a thin film of ice to build up on the leading edges of the propeller blades. Before this film builds up sufficiently to interfere appreciably with the aerodynamic characteristics of the blades, the cyclic control applies heating power. The ice already deposited then acts as thermal insulation, and as the ice in contact with the blade surfaces melts, the main ice catch is carried away under the action of centrifugal and aerodynamic forces.

3 INSTALLATION AND MAINTENANCE Full details of the methods of installation and checks necessary for the inspection and maintenance of electrical de-icing systems for propellers, will be found in the relevant aircraft and propeller Maintenance Manuals, and approved Maintenance Schedules; reference must therefore be made to such documents at all times. The information given in the following paragraphs is intended only as a general guide to the procedures normally required.

3.1 **Overshoes**

3.1.1 Overshoes, and anti-erosion strips where fitted, should be examined for splits, wrinkling, tears, discolouration as a result of overheating, security of attachment to blades and general condition. To avoid corrosion, anti-erosion strips must be renewed as soon as there are signs of splitting or advanced erosion likely to cause failure before the next scheduled inspection. If a heater element is exposed as a result of damage in the overshoe, or if the rubber is found to be tacky, swollen or deteriorated (as a result of contact with oils or solvents) the overshoe should be removed and replaced by a serviceable one.

3.1.2 Cable assemblies should be examined for signs of cracking or fretting, security at the root ends of propeller blades, at sliprings and brush block housings. When blades have been turned through their operating pitch range, cables should also be checked for signs of strain.

3.1.3 In the case of an element having burned out, the overshoe must be removed. Before installing a serviceable overshoe, the metal of the relevant blade should be examined for signs of damage as a result of localised burning. Where element burn out has resulted in localised areas of damage to the blade, the repair should be carried out in accordance with the Maintenance and Overhaul Manuals for the propeller concerned before a serviceable overshoe is installed.

NOTE: Depending on the type of propeller, it may also be necessary for a blade to be crack tested prior to the installation of a serviceable overshoe.

3.1.4 When a heated spinner is removed, it should be examined for damage and security of the electrical contacts and heating elements, together with areas of local overheating and non-adhesion to ensure that the latter do not exceed the permissible limits specified in the Maintenance and Overhaul Manuals. On metal spinners, shallow and uniform dents are permissible provided the elements are secure in the region of any such indentations but may be blended out with the elements intact, provided every care is taken to avoid damage to the elements, and the rework is in accordance with specified procedures. After such rework the elements must be thoroughly examined for "lifting" and other damage, and checks should be made on the resistance values of the elements, and on the continuity and insulation resistance of complete overshoes. Fibreglass spinner shells should be examined for signs of delamination resulting from local overheating or damage.

3.2 **Brushes and Slip Rings**

3.2.1 Brushes should be checked for wear, damage, cleanliness and freedom of movement in their respective holders. Permissible wear limits, which are normally related to the length of brush extending beyond the face of the brush block housing, are given in the appropriate aircraft and propeller Maintenance Manuals together with the methods of measurement to be adopted. Special measuring gauges are provided for some brush gear assemblies and these should always be used. Brushes worn beyond limits, must be replaced by new ones together with new brush springs.

3.2.2 Before fitting a brush, the brush holder must be thoroughly cleaned with a dry cloth or small spiral hair brush; solvents must not be used.

3.2.3 Brushes must be free to slide in their respective holders, and particular attention must also be paid to their precise location with respect to each other. In some installations, a means of position identification is provided. For example, in one typical system, the brushes have a chamfered corner which must be nearest to the centre of the brush holder when the brushes are in the correct position.

NOTE: Brushes are fragile and care must be taken to avoid placing any side loads on them during installation.

3.2.4 When a new brush has been fitted, at least 80 per cent of the face must make contact with the slip ring. A typical method checking this is as follows:—

(i) Inspect and note the appearance of the brush surface.

(ii) Ensure that the brush is correctly positioned in its holder and that the holder is secure.

(iii) Turn the propeller by hand for several revolutions.

(iv) Remove the brush and examine the contact area which will be apparent from the changed appearance of the brush face.

3.2.5 Whenever a brush block, or pack assembly, has been fitted, the alignment of the brushes with the slip ring surfaces, and also the clearance between the main body of the brush block and slip rings, should be checked through a complete revolution of the propeller. If the clearances are not within the specified limits, the brush block should be repositioned on its mounting in the manner appropriate to the particular installation. In some installations, shims are provided for adjustment purposes; when a brush block or pack assembly is removed the shims must be retained with the assembly.

NOTE: The brush packs of propellers used with certain types of turbopropeller engines, are individually weight balanced on initial assembly. When installing or removing such packs, care must be taken not to interchange their component parts otherwise rebalancing will be necessary.

3.2.6 Following the installation of a new brush, functional testing of the complete de-icing system should be delayed until other engine ground running checks have been completed. This will allow brush bedding to take place before heating current is applied.

3.2.7 Slip rings should be checked for security of attachment, signs of scoring, discolouration as a result of burning and for deposits of oil, grease or dirt. The insulation filling fitted between the slip rings of certain types of propeller should also be inspected for separation from the slip rings, flaking and localised damage to the surface of the filling. If the defect is of a minor nature, a repair should be carried out in the manner prescribed in the relevant propeller Maintenance Manual.

NOTE: On completion of a repair to the insulation, an insulation resistance test must be carried out.

3.2.8 Dirty slip rings should be cleaned by wiping with a lint free cloth moistened with white spirit, or by spraying them with a specified cleaning fluid from an aerosol type container. The surfaces should be dried and cleaning operations completed using a clean, soft, lint free cloth.

3.3 **Electrical Checks and Tests.** The checks and tests necessary to ensure correct functioning of a complete propeller de-icing system consist of those mentioned in the following paragraphs. The information given is of a general nature only and should be read in conjunction with the relevant propeller Maintenance Manual and approved Maintenance Schedule.

3.3.1 **Continuity and Heater Resistance Checks.** Continuity checks and measurement of the resistance of individual heater elements must be carried out before installation of a propeller, at the prescribed inspection periods, and following any repairs to overshoes. The resistance values obtained must be within the limits specified for the type of propeller.

3.3.2 **Insulation Resistance Checks.** These checks are necessary to determine whether there is any breakdown of the insulation between heater elements, blades and, where appropriate, the propeller spinner. The insulation resistance between brush gear and earth must also be checked.

(i) During service, the insulation resistance of heater elements may vary as a result of moisture absorption caused by atmospheric conditions. Tests must therefore also be carried out at the prescribed inspection periods, to ensure that the resistances have not fallen below the specified minimum "in service" values (2 to 4 megohms are typical).

NOTE: When checking the insulation resistance of some types of propeller de-icing system, account must also be taken of the specification of cement used for bonding the elements to the blades since the cement has a direct bearing on the resistance values obtained. The limits relevant to the cement specifications are usually presented in the form of graphs, and are contained in the relevant propeller Maintenance Manual.

3.3.3 **Voltage Proof Check.** This check is required for some types of propeller following repairs to the heater element overshoes. The leads from all the heater elements are connected together and a high voltage (typical values are 1360 volts d.c. or 960 volts a.c.) applied between the leads and the blade. The voltage should be maintained for not less than one minute and a check made to ensure that there is no breakdown of insulation resistance.

NOTE: The voltage must be increased and decreased gradually.

3.3.4 **System Tests.** Functional testing of a complete de-icing system must be carried out at the check periods specified in the approved Maintenance Schedules, when a system malfunction occurs, when a new or overhauled propeller has been installed, after replacement of a component (e.g. a cyclic timer, heater element or brush pack) and also after repairs to an overshoe. A functional test consists principally of checking that heating current is applied to the blade elements and spinner elements, where applicable, at the periods governed by the operation of the cyclic time switch, and as indicated by an ammeter which forms part of the circuit in the majority of installations. Particular attention should be paid to any limitations on supply voltages to the propeller heating elements, and engine air intake elements where appropriate, engine speeds and duration of tests during ground running. If any protective devices or sections of circuit have been temporarily isolated for testing purposes, the circuit must be restored to normal operating conditions on completion of tests.

4 REPAIRS Damage to an overshoe in the form of cuts, nicks, tears, lifting edges, etc., may be rectified as a minor repair, provided the overshoe is electrically serviceable and the blade metal beneath the overshoe has not suffered damage. Cutting back or cropping a worn or damaged overshoe tip is not permissible. Damaged, worn or missing anti-erosion strips fitted along overshoe or blade leading edges, must be renewed as a minor repair. Any damage to blade leading edges beneath a strip, should be repaired before fitting a new strip. Where a metal guard is fitted along the leading edges of an overshoe and a blade, only local lifting at the edges of a guard should be re-bonded as a minor repair.

4.1 **Repair Methods.** The repair methods to be adopted and the nature of the work involved, depend largely on the extent of damage to the overshoes. Repair schemes, the materials required, and procedures to be adopted, are detailed in Maintenance Manuals and Overhaul Manuals for the relevant type of propeller; reference must therefore be made to these documents. In some cases, the necessary primers, cements, sealing paints, anti-erosion strips and general materials for carrying out minor repairs are available in kit form. The following summary serves as a guide to some important precautions and practical aspects common to repair methods.

4.1.1 It cannot be over-emphasised that chemical cleanliness of surfaces is absolutely essential to obtain good adhesion. All cleaning should be carried out, particularly in the repair area, with a clean lint-free cloth moistened in the cleansing agent specified, e.g. methyl ethyl ketone or acetone. Swabbing, or the use of excessive quantities of cleansing agent, should be avoided, and adequate masking should be employed, where necessary, to protect adjacent serviceable parts or components.

NOTE: Cleansing agents are highly flammable and some may be toxic. Cleaning should therefore be carried out in a well ventilated area, free from excessive heat, sparks or open flames and prolonged exposure to the fumes should be avoided.

4.1.2 After surfaces have been cleaned and the specified primer and cement applied, they must not be contaminated by foreign matter or moisture of any kind. To prevent contamination by handling, gloves made from polyvinylchloride (p.v.c.) should be worn.

4.1.3 To ensure that moisture is not trapped under repairs, all damaged areas must be completely dried out before repairing; failure to observe this precaution may lead to the start of corrosion under the repairs.

4.1.4 After cleaning, sufficient time must elapse to ensure that the cleansing agent has evaporated before applying the bonding medium to the surfaces.

4.1.5 Where anti-erosion components are being initially fitted to leading edges of painted blades, the paint should be removed from the relevant area with specified paint remover. Similarly, sealing paint must be removed from overshoes before initially fitting anti-erosion components.

4.1.6 When an overshoe has split, worn or lifted at its edges or tip, it should be carefully peeled back at the damaged portion and the exposed area of the blade carefully inspected for signs of corrosion. Any light corrosion within the exposed area should be cleaned out and the reworked area of the blade blended into the adjacent surface in accordance with the blade repair procedures specified in the propeller Maintenance Manual. The exposed metal surface and, if necessary, the under surface of the overshoe, should be cleaned with a cleansing agent and after drying, the overshoe should be rebonded to the blade.

NOTE: If corrosion is excessive or extends beyond the area exposed by lifting of the overshoe, the latter should be removed and following reworking and cleaning of the blade surface, a primer should be applied and a new overshoe bonded to the blade.

4.1.7 The cement specified for the repair of overshoes and their complete bonding to a particular type of propeller, may vary between a ready-to-use type and a type which firstly requires the mixing of two constituent parts in definite proportions. Details of the cement specification and the mixing procedure where appropriate, are given in the relevant propeller Maintenance Manual and reference should therefore be made to this document. The following points should be particularly noted:—

(i) The drying time should be correct in relation to local temperature and humidity conditions.

(ii) The bonding efficiency of a cement should be tested before final application. A typical test is carried out by firstly preparing one surface of a duralumin test plate in a similar manner to the surface of a blade, and also the surface of a 1 inch wide strip of rubber cut from an old overshoe. Cement is then applied to both surfaces and allowed to dry for the specified period. The surfaces are then pressed into contact and the test plate firmly mounted on a bench so that the test strip is in the vertical position. A 10 pound weight is then attached to the upper end of the strip and the rate at which the strip separates from the plate is noted. The rate should not exceed 1 inch per minute over a distance of 6 inches.

(iii) Prepared cements have a certain "life" after mixing (e.g. 2 hours) and they must, therefore, always be used within the time specified.

4.1.8 Small slits or nicks should be repaired by applying cement to the edges and, after allowing it to become tacky, the edges should be pressed firmly together. A bandage, made up of thin rubber strip and a soft pliable pad, may be used to apply pressure to local areas.

4.1.9 Where damage cannot be repaired in the manner described in paragraph 4.1.8, or where small portions of rubber are missing from an overshoe, repairs should be carried out by using a filler paste which is made up by mixing rubber dust with an epoxy resin adhesive.

(i) After removing all loose and damaged rubber from the area and after thorough cleaning, the paste should be applied and worked into the area by means of a suitable spatula. The filler should be allowed sufficient time to cure until hard and its surface should then be blended into that of the overshoe by using a medium grade file. The repair should be finished off with a fine grade silicon carbide paper.

NOTE: Uncured epoxy resin adhesives should not be allowed to come into contact with the skin or eyes. All other recommended precautions associated with the handling of these adhesives should be observed.

4.1.10 Before fitting a new overshoe, the bonding area of the blade should be masked off and then all traces of old cement and primer removed from the area by working over with a stiff brush and the specified cleaning agent. The bonded area should be finally cleaned with lint free cloth soaked in cleaning agent, and allowed to dry. Any traces of a solvent film, or of the cleaning agent, must be removed before applying a new coat of primer and bonding cement.

NOTE: In cases where an overshoe is to be bonded to a blade without a leading edge rebate, a template of the overshoe should first be prepared. After cleaning the blade, the template should then be laid over the area to be occupied by the overshoe with its centre line coincident with that of the blade leading edge, and the border of the bonding area marked out with a soft crayon.

4.1.11 Prior to applying cement to the bonding surface of an overshoe, the surface should be brushed with a fine steel wire brush and cleaned with the specified cleaning agent. No significant quantity of rubber should be removed during brushing as a reduction of rubber thickness may lead to an electrical failure of the heating element. The bonding surface must be allowed to dry out thoroughly.

4.1.12 A coat of cement should be evenly applied by means of a clean brush, to the prepared bonding surfaces of an overshoe and blade and then allowed to dry for the period determined for the particular type of cement being used (see also paragraph 4.1.7).

NOTE: To prevent the edges of an overshoe from curling while applying the cement, masking tape should be placed around the edges of the outer surface of the overshoe. The tape should be removed before installing the overshoe.

4.1.13 An overshoe should be positioned at the correct radial distance, and with its centre line coincident with that of the blade leading edge. Polyvinylchloride (p.v.c.) sheeting should be interposed between the flanks of the overshoe and blade to prevent premature adhesion of the bonding surfaces. Working from the leading edge towards the flanks, a rubber roller should be used to press the overshoe into contact with the blade, progressively removing the p.v.c. sheeting and taking care to prevent the formation of air pockets between the overshoe and blades. Any puckering or wrinkling of the edges of an overshoe must be worked out smoothly and carefully. Excess adhesive, which may have been rolled out at the overshoe edges, should be removed with a cloth moistened in a solvent, e.g. toluol.

NOTE: Metal or wooden rollers should not be used for the purpose of pressing overshoes into contact with blades as damage could be caused to the wire heating elements.

4.1.14 Cement should be allowed sufficient time to cure (a typical period is 24 hours at a minimum temperature of 20°C). When fully cured, a check should be carried out in the manner prescribed in the relevant Maintenance Manual, to ensure that the required standard of adhesion has been achieved. Following the satisfactory bonding of an overshoe, an insulation resistance check should be carried out (see also paragraph 3.3.2 (i)), the outer surfaces of the overshoe should be degreased and a coat of sealing paint applied.

4.1.15 Reference should be made to Maintenance Manuals and other relevant documents concerning any requirements for rebalancing a propeller after a new overshoe has been fitted. Propellers for some types of aircraft have moment-balanced overshoes to obviate rebalance of the hub and blade assembly after a new overshoe has been fitted.

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# AIRCRAFT

## ELECTRICAL EQUIPMENT

### BATTERIES—LEAD-ACID

1 INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of aircraft general purpose lead-acid batteries.

1.1 The information given should be read in conjunction with the Maintenance Manuals and Overhaul Manuals issued by the battery manufacturers, relevant aircraft Maintenance Manuals and approved Maintenance Schedules. Reference should also be made to the following Leaflets and British Standards which contain information closely associated with the equipment covered by this Leaflet.

**EEL/1-2** Carbon-Pile Voltage Regulators – D.C. Generator Systems

**EEL/1-4** D.C. Generators

BS 89 Electrical Indicating Instruments

BS G205 Part 1 Secondary Batteries (Acid and Alkaline) General Requirements

BS 3031 Sulphuric Acid for use in Lead-Acid Batteries.

2 GENERAL CONSTRUCTION Lead-acid batteries vary in type principally in the thickness of their plates and the type of separators employed. In the conventional type, groups of positive plates, negative plates and separators, are assembled in such a way that the electrolyte solution of sulphuric acid and distilled water can flow freely around the plates. In some types of battery however, the plates and separators are compressed to form a solid block, the separator material being such that it absorbs electrolyte and leaves only a small amount free above the block.

2.1 The cell groups are located within containers made of a shock-resistant and acid-resistant material, e.g., polystyrene, and are linked by terminal connecting strips. Vents and plugs are fitted to each cell and are designed to allow gas to escape without leakage of electrolyte. In batteries utilising solid block type cells, the cells are grouped into single blocks (e.g. a 24-volt battery has two single blocks each comprising six individual cells) and are usually enclosed within a polyester bonded fibreglass outer container which also supports the main terminal receptacle.

3 CHEMICAL PRINCIPLE During charging the active material on the positive plates of a cell is converted to lead peroxide and the material on the negative plates to spongy or porous lead. Sulphuric acid is returned to the electrolyte during the charge, gradually strengthening it until the fully charged state is reached. In the charged condition and after a battery has been standing for a specified time (e.g. 8 hours) the open circuit voltage of a cell should be 2·10 to 2·20 volts.

3.1 When discharging, both the positive and the negative plates are partially converted to lead sulphate. The sulphuric acid is diluted as part of the process by the formation of water. If lead sulphate in a more permanent form is produced on the plates due to excessive discharge, or other misuse, this will act as a high-resistance component impairing the efficiency and recoverability of the battery.

4 MAINTENANCE The information given in the following paragraphs is intended to serve as a general guide to maintenance practices and precautions to be observed. Precise details concerning a specific type of battery are given in the relevant manuals and approved Maintenance Schedules, and reference must be made to such documents.

4.1 **Safety Precautions.** Lead-acid batteries must be prepared for service, charged, tested, and generally maintained, in a well ventilated workshop area entirely separate from that used for the servicing of nickel-cadmium batteries. This also applies to servicing and test equipment, tools and protective clothing, all of which should be identified as being for use in lead-acid battery servicing only.

4.1.1 Alkaline solutions must not be allowed to come into contact with batteries, otherwise severe damage to cells will result.

4.1.2 When handling batteries, or acid, a rubber apron and rubber gloves should be worn; in addition, when dealing with acid, goggles should be worn. After use, these articles should be rinsed free of acid and dried thoroughly. To avoid cracking, or perishing, they should be stored in a cool place, the aprons being hung with as few folds as possible. The gases given off by batteries are highly explosive. Naked lights therefore, should not be used at any time to examine a battery.

4.1.3 Containers made of a suitable material such as glass, glazed earthenware or ebonite or, alternatively, utensils having a lead lining, should always be used for handling acid or distilled water. When transferring fluids from containers a suitable funnel should be employed.

NOTE: Containers filled with distilled water should be stored separately from those containing acid. All containers should be suitably marked, indicating their contents.

4.1.4 When acid has been spilt on the floor of the workshop area or on benches, it should be removed by firstly, washing the affected surfaces with water, then neutralised by washing with sodium bicarbonate solution and lastly, washed again with water.

NOTE: Water and neutralising solution should be soaked up with sawdust, which should afterwards be removed and buried or burned.

4.1.5 If electrolyte comes into contact with the skin, the affected area should firstly be washed with cold water, then neutralised by washing with a sodium bicarbonate solution and lastly, washed with warm water. In the event of electrolyte being splashed into the eyes, they should firstly be washed with cold water, then bathed with 5 per cent solution of sodium bicarbonate, and then again washed with cold water. Immediate medical attention should be obtained in the event of skin burns or eye injury.

4.2 **Inspection Before Charging.** All batteries must be inspected before charging and before installation. The following checks are typical of those comprising a battery inspection schedule:—

(i) The outside of the battery case should be examined for signs of damage and evidence of locally overheated areas.

(ii) The cover, sealing gaskets, or mats, as appropriate to the type of battery, should be in good condition.

(iii) There should be no evidence of arcing having occurred between the battery and the aircraft structure. If signs of arcing are present, the aircraft battery compartment should be checked to determine whether any insulation provisions have failed, and the necessary remedial action taken. The battery should be cleaned as necessary.

(iv) The tops of cells should be inspected for signs of electrolyte leakage, and cleaned and dried where necessary.

(v) The battery receptacle should be checked for evidence of burns, cracks and bent or pitted terminals. Defective receptacles should be replaced, because they cause overheating and arcing, and may depress output voltage, which will result in premature battery failure.

(vi) All terminals and any exposed cell connecting links must be checked for security, evidence of over-heating and corrosion. The terminal nuts, where appropriate, should be tightened to the specified torque values. An acid-free petroleum jelly (e.g. white vaseline) or a silicone base grease, should be lightly smeared onto terminal contacts, connector pins, etc.

NOTE: A loose cell link can generate heat and cause arcing which may ignite battery gases.

(vii) Vent caps should be checked for security and to ensure that gas exit holes are clear.

4.2.1 Extreme care must be exercised when working around the top of a battery with the cover removed to avoid dropping tools onto the cell connecting links as severe arcing will result, with possible injury to personnel and damage to the battery. Rings, metal watch straps and identification bracelets should not be worn, thereby preventing contact with connecting links and terminals.

4.3 **Initial Filling.** A dry uncharged battery must be filled with an electrolyte consisting of battery grade sulphuric acid (see BS 3031) at the relative density recommended by the manufacturer of the particular type of battery, this data being given with the other instructions for filling and charging.

NOTE: The relative density of the acid should not be more than 1·300. It is recommended that the acid suppliers be required to lower the relative density to 1·300 (corrected to a temperature of 15°C (60°F)) prior to delivery.

4.3.1 Filling should be carried out methodically to avoid missing any cells. This can be ensured by removing the plug from No. 1 cell and filling as required, then removing the plug from No. 2 cell and fitting it to No. 1 cell, after which No. 2 cell should be filled and fitted with the plug from No. 3 cell. This procedure should be followed for each cell in numerical order, until the last cell is fitted with the plug from No. 1 cell. On batteries that fill slowly, e.g. those with a solid block plate arrangement which fill by absorption, the vent plugs should be left off until no more electrolyte is absorbed and the free electrolyte level remains constant.

4.3.2 Although the required electrolyte level will vary with the type and make of battery concerned, in all cases it must cover the top of the plates.

NOTE: When poured into the cells, the electrolyte must be at, or only very slightly above, ambient temperature and, if it is obtained by diluting concentrated acid, it must be allowed to cool before use. When diluting concentrated acid, the acid must always be added to the water (at a controlled rate) and never vice versa, since the latter procedure can be extremely dangerous.

4.3.3 After filling, the battery should be allowed to stand for 6 to 8 hours (depending on the manufacturer's instructions for the particular type of battery) so that the battery can cool down, after which the electrolyte level should be restored by adding more electrolyte of the same relative density; the battery is then ready for initial charge.

4.3.4 The relative density of the electrolyte is generally related to a temperature of 15°C (60°F). Readings taken at other temperatures should, therefore, be corrected to 15°C (60°F) as follows:—For the Celsius scale, 0·003 (3 points) should be added to the hydrometer reading for each 4°C by which the temperature of the electrolyte is above 15°C, or 0·003 (3 points) should be subtracted from the hydrometer reading for each 4°C by which the temperature of the electrolyte is below 15°C. Similarly, for the Fahrenheit scale, to correct to 60°F, 0·001 (1 point) should be added or subtracted for every 2·5°F above or below 60°F.

4.3.5 For batteries which are to be used in climates where the temperature frequently exceeds 32°C (90°F) manufacturers sometimes recommend the use of an electrolyte of reduced relative density. For example, a battery may be filled with electrolyte of density 1·260 in temperate conditions, but in tropical conditions the density of the electrolyte may be reduced to 1·230 resulting in a fully charged density of 1·240 to 1·255.

4.4 **Charging Conditions.** When charging several batteries, they should be of the same capacity rating, at the same state of discharge and the same recommended charging rate, and connected in series. The number of batteries which may be so connected depends on the voltage available in the charging circuit.

4.4.1 Each group of batteries should be connected to a separate circuit containing an ammeter, voltmeter, variable resistance and other relevant controls.

NOTE: Ammeters and voltmeters should be of the moving coil type, or digital presentation type, and checked for accuracy at the periods specified for the charging equipment. Accuracy should be within the values specified for the appropriate type of instrument (see BS 89).

4.4.2 All supply leads and connecting cables must be well insulated, of ample cross-sectional area and kept as short as possible. Free ends of cable wires should not be connected to batteries; use should be made of cable end lugs or connector plugs of the type specified for the battery. All connections should be firmly made to give good electrical contact before switching on the charging equipment. To prevent reverse charging, the polarity of the supply leads should be checked with the aid of a centre zero type voltmeter.

4.4.3 It is preferable that neither pole of the charging circuit should be earthed, but if one pole is earthed, it is recommended that the controlling resistance should be between the battery and the unearthed pole.

4.4.4 Batteries requiring different charging rates should not be charged in series, but if this is not possible the limiting current should be that of the battery requiring the lowest charging current.

4.4.5 Vent plugs should be completely unscrewed and lifted, but left in the vent holes before charging is commenced. They should remain in this position during the whole period of charge.

4.4.6 When ready to charge, the variable resistance in the charging circuit should be set in the position of maximum resistance (i.e. minimum current) the charging circuit should be switched on, and the current should be adjusted to the value specified for the particular type of battery.

4.4.7 Charging should, when practicable, be continuous until a fully charged condition is indicated. If charging is interrupted, and batteries are to be left unattended after switching off, both positive and negative supply leads should be disconnected from the batteries.

4.4.8 When cells commence gassing, the voltage and relative density should be measured periodically. In the fully-charged state both values should remain steady.

4.4.9 If a battery in a group should reach the fully-charged condition before the others, the charging circuit should be switched off and the charged battery disconnected. The charging current should then be re-adjusted to a value suitable for continuing the charge of the remaining batteries, and the charging circuit switched on again.

4.4.10 If there is any indication of electrolyte spillage, the affected parts should first be rinsed with water, then with a solution of water and washing soda, and finally sponged with clean water and thoroughly dried. A re-check should be made after 24 hours for any further signs of electrolyte spillage, or corrosion.

4.5 **Charging.** The charging of batteries may be related to the three conditions under which they are normally available. The three conditions are: (a) dry and uncharged and requiring filling and initial charge, (b) filled but uncharged and requiring initial charge, and (c) in service and requiring recharging.

**NOTE: In tropical conditions it is often recommended that the batteries are charged at half the usual rate, with double the charging time.**

4.5.1 **Batteries Received Dry and Uncharged.** After filling in accordance with specified procedures (see also paragraph 4.3) batteries should be charged, using direct current of correct polarity, at the "initial" charging rate recommended by the battery manufacturer; this will vary from 1 ampere to 5 amperes for a total charging time of about 24 hours.

(i) The charge should not be considered complete until the voltage and the relative density (if applicable) of each cell remain constant for the period specified for the type of battery. This period is usually between 3 and 5 hours.

(ii) The electrolyte temperature should be checked frequently during the charging period and must not exceed the temperature specified by the battery manufacturer. If the maximum temperature is exceeded the charge should be stopped until the electrolyte temperature has dropped by the specified amount (usually about 12°C (22°F)); or the charging current may be halved and the charging time doubled.

(iii) On completion of the charge, any gas in the electrolyte should be released by gently rocking the battery, the electrolyte level then being adjusted as specified by the battery manufacturer.

4.5.2 **Batteries Received with Electrolyte.** A battery of the type which forms a solid block with the plates and separators is normally despatched already filled with electrolyte.

(i) On receipt of the battery the vent plugs should be removed and the level of the electrolyte checked to ensure that it is approximately ¼ in above the perforated strip and, if necessary, adjusted to this level using sulphuric acid of relative density 1·270.

(ii) The battery should receive a charge current at a value appropriate to the ampere-hour rating of the battery, until the voltage is stable over five consecutive half-hourly readings. Should the temperature of the electrolyte reach 60°C (140°F), the charge should be interrupted until the temperature falls below 43°C (110°F).

(iii) During the charge the vent plugs should be kept in, but not screwed down. If the battery was properly filled it should not require any topping up during this time. If the electrolyte level disappears, acid of relative density 1·270 should be added; if the electrolyte level is high the excess should be withdrawn.

4.5.3 **Re-Charging a Battery in Service.** The electrolyte level should be checked and, if necessary, adjusted with distilled water, and the battery put on charge at the normal rate recommended. In a fully charged condition, all the cells should gas freely and the relative density of the electrolyte should be within the limits given when corrected for temperature. The main terminal voltage should, under normal temperature conditions, be between 30 and 32·4 volts when measured with the charging current flowing. The charge should be continued until the readings are constant for 3 hours.

NOTE: At all times during charging, a check should be kept on the battery temperature to ensure that the maximum permissible limit is not exceeded.

4.6 **Electrolyte Level and Adjustments.** The periods at which adjustments to the electrolyte should be carried out vary largely with the state of charge and duty cycle of the battery.

4.6.1 The level in the cells must be maintained by the addition of distilled water, as only the water from the electrolyte is lost through electrolysis or evaporation. After initial charge the relative density of the electrolyte should not normally require adjustments, but, in exceptional cases, it may be adjusted in accordance with the manufacturer's instructions.

4.6.2 In order to ensure the mixing of acid with the distilled water, topping-up should be done immediately before a battery is put on charge. Adjustments must be to the correct level to prevent overflow of the electrolyte which could occur as a result of gassing and expansion during the charge. If a battery is to be exposed to very low temperatures, its charge after topping-up, should be prolonged for at least one hour. This will ensure thorough mixing of the electrolyte and thereby avoid the possibility of the water freezing. An additional precaution against freezing is to maintain the battery in a fully-charged state.

4.6.3 For some types of battery, special fillers may be necessary to ensure correct electrolyte level but, in general, the level is specified as a measurement taken from the top of the separator guards or plates.

4.6.4 After adding distilled water, it should be borne in mind that relative density readings cannot be relied upon until the electrolyte and water have been mixed by the gassing of the cells whilst on charge.

4.6.5 A record of the quantity of water added to battery cells should be maintained, since frequent additions are grounds for rejection of cells.

4.6.6 If, one hour after charging, the electrolyte level falls below the specified value, the battery should be reconnected to the charging equipment and the electrolyte level adjusted with the battery on a low charge and slightly gassing.

4.7 **State of Charge.** On reaching the fully-charged condition, a lead-acid battery displays three distinct indications: (i) the terminal voltage ceases to rise and remains steady (e.g. 31 volts for a new battery) with charging current flowing, (ii) the specific gravity of the electrolyte ceases to rise and remains constant, and (iii) both sets of plates gas freely. In the conventional type of lead-acid battery all three indications must be in evidence before the battery can be regarded as being completely charged.

NOTE: The terminal voltage at the end of charge normally diminishes with the age of a battery. If it is equal to, or below, 28·5 volts a battery should not be put back into service.

4.7.1 In the case of batteries using cells of solid block construction, the state of charge is indicated by the open circuit voltage and gassing. Relative density readings cannot be made since there is insufficient free electrolyte. The method of carrying out an open-circuit voltage check is given in the following paragraphs, the current and voltage values being based on a typical 24-volt 18 ampere-hour (one-hour rate) battery.

(i) Connect the battery to a load that will take approximately 20 amperes, and after current has been flowing for 15 seconds, measure the on-load voltage.

(ii) Disconnect the load and take an off-load voltage reading immediately; the increase in reading from on-load to off-load should be approximately 1 volt if the battery is in good condition.

(iii) The state of charge is assessed from the off-load voltage. If the voltage is between 25·1 volts and 25·8 volts the battery may be regarded as fully charged. An off-load voltage of between 24·5 volts and 25·1 volts indicates a battery that is from half to quarter discharged. A half-discharged battery will indicate an off-load voltage of between 24·2 to 24·5 volts.

4.8 **Capacity Tests.** A capacity test should be carried out after initial charge, and thereafter at intervals of three months, or at any time the capacity of a battery is in doubt. Details of test methods are given in the relevant manuals.

4.8.1 The battery should be fully charged (see paragraph 4.4) and then connected to a suitable discharge control panel incorporating a variable-load resistance, an ammeter and an ampere-hour meter. A separate voltmeter is necessary to measure voltage at the battery terminals, or cell connecting strips.

NOTE: If the control panel is not of the automatic type, or if no ampere-hour meter is incorporated, accurate monitoring and control of current must be maintained throughout the tests.

4.8.2 The battery should then be discharged at a rate corresponding to the rating of the battery (as detailed in the appropriate manuals, e.g. an 18 A.H. battery rated at the 1 hour rate would be discharged at 18 amps) until the battery reaches its fully discharged condition. This condition is denoted by the main terminal voltage, or the relative density of the electrolyte, falling to the respective fully discharged values for the particular type of battery. The minimum acceptable capacity for use on aircraft is 80 per cent which, in the case of the example rating quoted, provides a duration of discharge equal to 48 minutes. The result, however, should be compared with previous readings to assess rate of deterioration.

4.9 **Insulation Resistance Test.** This test should be carried out at the periods specified in the approved Maintenance Schedule and at any time that electrolyte leakage is suspected.

4.9.1 The battery should be fully charged (see paragraph 4.5) and the case and cell tops wiped dry. It should then be fitted to a metal base plate by the fixing method normally used in the aircraft. A test should be made between one terminal of the battery and the base plate, using a 250-volt insulation tester, and the minimum insulation resistance obtained must be not less than one megohm. If a reading below this value is obtained, the battery should be checked for presence of moisture, leaking case, or vented electrolyte, and remedial action taken in accordance with the procedures specified in the relevant manual.

4.10 **Leakage Test.** If there is no apparent visible damage to a battery, it should be given a leak test using the tester designed for the particular type of battery. Vent caps should be removed, and with the tester held firmly over each vent in turn, a pressure of $14kN/m^2$ ($2\ lbf/in^2$) should be applied by means of the pump on the tester. There should be no detectable leakage after a period of not less than 15 seconds.

**5** INSTALLATION Before installing a battery it should be ensured that it is of the correct type, fully charged and the electrolyte is at the correct level (see paragraphs 4.4 and 4.6). A capacity test and insulation resistance test must also have been carried out in the manner prescribed for the particular battery (see also paragraphs 4.8 and 4.9). In aircraft using batteries in parallel, it is important to ensure that all batteries are at the same state of charge. Reference should be made to the relevant aircraft Maintenance Manual for details of the battery system and associated installation instructions. Before coupling the battery connecting plug, a check should be made to ensure that the battery system is switched off and that all electrical services are isolated.

NOTE: Batteries are heavy units and require the use of approved and careful handling methods to prevent possible injury to personnel, and damage to the cases or components adjacent to the battery location.

5.1 The battery compartment should be clean, dry and free of any acid corrosion or damage. Apart from the mounting tray, which is usually made of an acid-resistant material, the structure adjacent to the battery compartment should be treated with an acid-resistant paint as a protection against the corrosive acid fumes from the battery.

5.2 When a battery is located in its compartment, it should be ensured that it is securely attached and that the appropriate clamps, or bolts are not over-tightened.

5.3 Terminal contacts or connector pins should be lightly coated with an acid-free petroleum jelly (e.g. white vaseline) or a silicone base grease.

5.4 The supply cables from the battery should be checked for signs of chafing or other damage; connecting terminals or plugs must be secured without any strain on the terminals, plugs or cables.

5.5 Battery installations are normally designed so that in flight, sufficient air is passed through the compartments to dilute the gases given off by the battery, to a safe level. Ventilation systems should therefore be checked to ensure there is no obstruction or, if integral venting is used, the system connections should be checked for security and freedom from leaks.

NOTE: In some ventilation systems, non-return valves are incorporated in the battery compartment vent lines. These valves should also be checked for security and correct location.

5.6 After installation, a check should be made that the electrical connections of the battery supply cables have been correctly made by switching on various electrical services for a specific time period and noting that readings of the aircraft voltmeter remain steady.

6 MAINTENANCE OF INSTALLED BATTERIES Batteries should be inspected at the periods specified in the approved Maintenance Schedule. The details given in the following paragraphs serve as a guide to the checks normally required.

6.1 The battery mounting should be checked for security and the outside of the battery base examined for signs of damage and evidence of local overheating. The latches of the cover should operate smoothly and firmly secure it in position.

6.2 Connector lugs or plug pins, should be checked for security and for signs of contamination, burns, cracks, bending or pitting.

6.3 Cables should be examined to ensure that their protective covering has not been damaged, and that they have not been affected by dampness or by general climatic conditions prevailing in the battery compartment.

6.4 The tops of all cells and vent caps should be inspected for signs of electrolyte leakage and cleaned where necessary.

NOTE: When removed, the cover of a battery and cell vent caps should not be placed on any part of the aircraft structure or equipment.

6.5 Depending on the type of battery installed, either the relative density, or open-circuit voltage, should be checked to ensure that the values obtained are within the permissible limits.

6.6 The electrolyte level should be checked and, if necessary, adjusted with distilled water (see also paragraph 4.6). The amount of water added to the cells should be recorded. A cell requiring more than the specified amount should be regarded as suspect and the battery should be replaced by a serviceable unit.

NOTE: Batteries should be removed from aircraft in order to carry out electrolyte level adjustments.

6.7 The battery ventilation system should be checked to ensure security of connections and freedom from obstruction. Acid drain traps, where fitted, should be checked for signs of acid overflow and, if necessary, removed for cleaning.

6.8 During checks on a generator voltage regulator system, it must be ensured that the voltage setting does not cause excessive charging current to be fed to the battery system. A voltage set higher than the specified value, coupled with high ambient temperature, is the most common cause of battery overheating, resulting in a 'thermal runaway' condition and damage to the battery. In some cases consideration may have to be given to aircraft operating in extremely hot climates and the system voltage may have to be reduced. In such cases, the battery may then have to be operated slightly below its maximum capacity.

NOTE: Other factors which may cause 'thermal runaway' are inadequate battery ventilation, high relative density of the electrolyte or a low end-of-charge reading.

6.9 At the periods specified in the approved Maintenance Schedule, the battery must be removed from the aircraft for capacity and insulation resistance tests (see paragaphs 4.8 and 4.9).

7 BATTERY RECORDS A technical or service record should be maintained for each battery in service and should provide a fairly comprehensive history of each battery, so that in the event of a malfunction it will assist in determining the problem. The example shown in Figure 1 is intended only as a guide.

## LEAD-ACID BATTERY—SERVICE RECORD

MANUFACTURER: ................................
DATE OF MANUFACTURE: ....................
PART No. & RATING: ............................
SERIAL No.:..........................................

AIRCRAFT TYPE: ................................
AIRCRAFT REGISTRATION:....................
DATE INSTALLED: ..............................

| DATE | REASON FOR SERVICE S—Scheduled F—Failure | ELECTROLYTE LEVEL & ADJUSTMENTS (c.c. added) | ELECTRICAL CHECKS | | LEAK TEST | CHARGE | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | | | CAPACITY | INSULATION RESISTANCE (ohms) | | RATE | RELATIVE DENSITY | END-OF-CHARGE VOLTS | |
| | | | | | | | | | |

*Figure* 1

8 STORAGE AND TRANSPORTATION Lead-acid batteries should be stored in a clean, dry, cool, well-ventilated area entirely separate from nickel-cadmium batteries. The area should also be free from corrosive liquids or gases. New batteries may be stored either dry and uncharged, or filled and charged. Batteries of solid block construction may also be stored in the condition in which they are despatched by the manufacturer i.e. filled and uncharged. In this condition only the positive plates are formed so that the batteries remain inert until they are prepared for use. Batteries removed from service must always be stored in the fully-charged condition (see also paragraph 8.1.1). The appropriate storage limiting periods must be in accordance with those specified in the relevant manuals. Typical periods are 5 years in a temperate climate for charged or uncharged batteries and from 2 to 3 years in a tropical climate for uncharged batteries, and 18 months for charged batteries. If the storage limiting periods have been exceeded, uncharged batteries should be charged, bench checked or returned to the manufacturer for examination and re-lifing.

8.1 Charged batteries should be periodically inspected and given a freshening charge every 2 to 4 weeks. The capacity of batteries should also be checked during the storage period at a frequency which is dictated mainly by their condition. It is recommended that capacity tests be carried out every 6 months for new batteries, and every 3 months for batteries returned from service.

8.1.1 Batteries which have been in use and are discharged, should not be allowed to remain, or be stored in this condition, because of the danger of sulphation of the plates. The lower main terminal voltage limit appropriate to the type of battery should be checked and recharging carried out as necessary; a typical lower limit is 21·6 volts.

8.2 If it is necessary to return a battery to the manufacturer, or to an approved overhaul Organisation, it should be prepared in accordance with the transportation requirements specified by the manufacturer for the appropriate battery condition i.e. charged or uncharged. An up-to-date service record should accompany the battery and "This Way Up" international signs affixed to the container.

NOTE: If transportation is to be by air, the container must comply with IATA regulations concerning the carriage of batteries.

EEL/1-2

*Issue* 3.

*June*, 1979.

# AIRCRAFT

## ELECTRICAL EQUIPMENT

## VOLTAGE REGULATION

1 INTRODUCTION This Leaflet gives guidance on the operating principles, installation and maintenance of voltage regulators. As details can vary between types of regulator, and as a result of the electrical power supply requirements of a particular type of aircraft, the information is of a general nature only, and is based on some typical voltage regulators in current use. This Leaflet should, therefore, be read in conjunction with the Maintenance Manuals and other approved documents for the voltage regulators concerned, and for the type of aircraft in which they are installed. Reference should also be made to the following Leaflets which contain information closely associated with voltage regulators.

EEL/1-1 Batteries—Lead-Acid
EEL/1-3 Batteries—Nickel-Cadmium
EEL/1-4 D.C. Generators
EEL/1-5 Power Supply—A.C. Generators
EEL/1-6 Bonding and Circuit Testing
EEL/1-8* Power Supply Systems
EEL/1-9* Circuit Protection Devices
EEL/3-1 Cables—Installation and Maintenance

1.1 The adjustments specified in this Leaflet form part of voltage regulator maintenance and checking procedures, and it is emphasised that manufacturer's recommendations should always be carefully followed as a mal-adjustment may cause extensive damage not only to the regulators but also to the associated generators and batteries.

2 GENERAL Voltage regulators are used in aircraft primary power supply systems to maintain the system voltage within the limits necessary for the correct operation of the associated electrical services. In addition, they are, in some cases, used to control the sharing of load between generators operating in parallel.

2.1 Depending on the size of the aircraft and design of the generating system, regulators may be of the single unit type operating in conjunction with separate reverse current cut-out relays, voltage differential sensing relays and paralleling relays, or integrated with these components to form special control units or panels.

3 PRINCIPLES The basic requirement of maintaining a substantially constant voltage in an aircraft power supply system is achieved by the automatic control of the generator field strength, using various types of voltage regulator. The principles of operation of some of these types are contained in the following paragraphs.

*Leaflets **EEL/1-8** and **EEL/1-9** will be published in a later batch of Leaflets.

3.1 **Carbon-pile Voltage Regulator.** The operation of the carbon-pile type of voltage regulator is based on the fact that the contact electrical resistance between faces of carbon discs varies not only with actual area of contact, but also with the pressure by which disc faces are held together. If therefore, a 'pile' of carbon discs or washers is connected in series with the shunt field winding of a generator (Figure 1) the resistance of the field circuit can be varied by adjusting the pressure applied to the 'pile'.

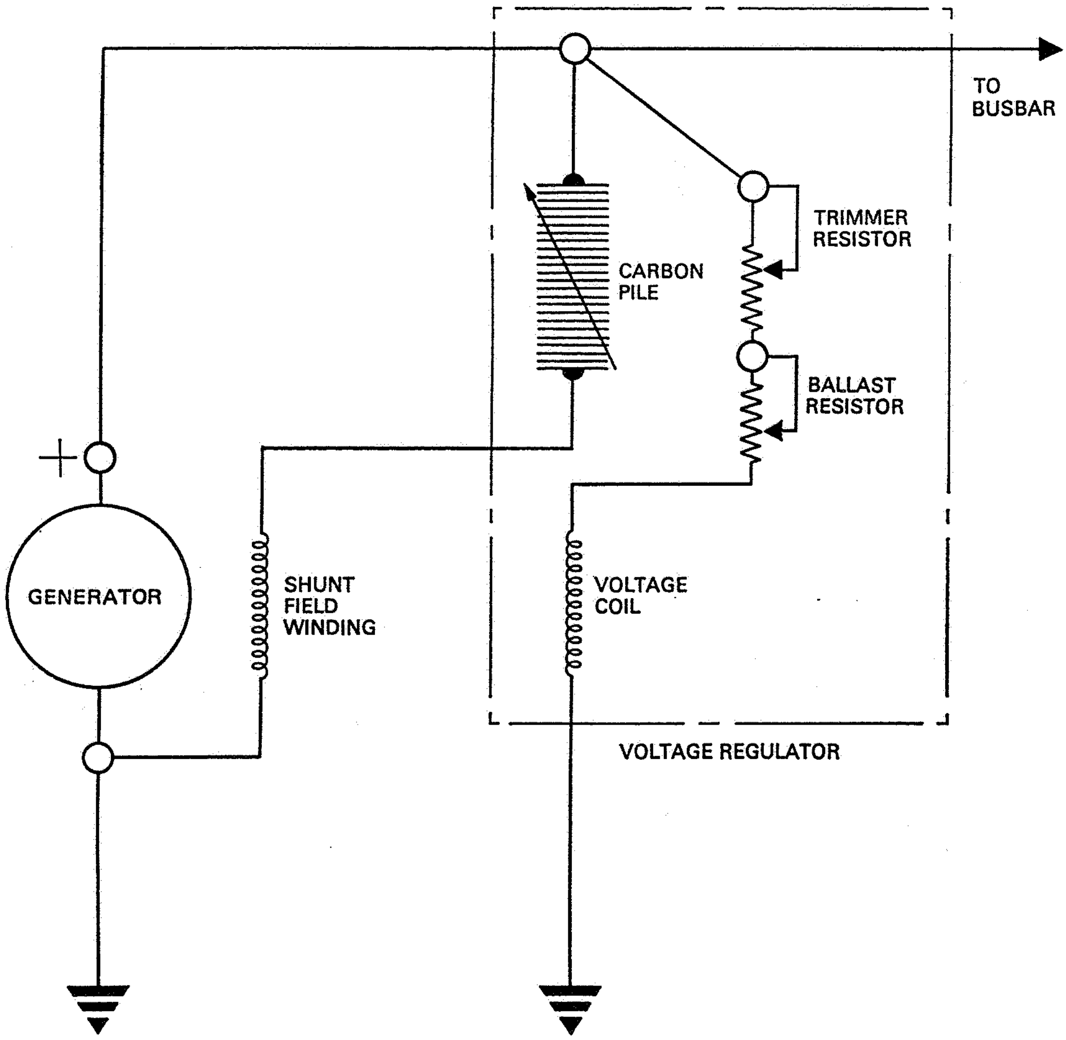


*Figure* 1 CARBON-PILE VOLTAGE REGULATOR PRINCIPLE

3.1.1 The necessary variation of pile compression is made through the medium of an electromagnet which opposes the compressive effect of a plate-type control spring (Figure 2). Under static conditions the compressive effect is at a maximum and carbon-pile resistance is at some minimum value. The electromagnet is energised by a voltage coil which is connected across the generator output terminals so that coil current and, consequently, electromagnetic force are substantially proportional to generator output voltage. As the rotational speed of the generator increases, the progressive increase in its voltage results in an increase of electromagnetic force until, at a pre-set voltage level, the electromagnetic force is balanced by the plate-type control spring. If the generator output voltage exceeds the pre-set level, the increase in electromagnetic force overcomes the force of the plate-type control spring and reduces the pile compression, thereby increasing the resistance of the generator shunt field circuit and thus checking the rise in output voltage.

3.1.2 **Construction.** The construction of a typical carbon-pile voltage regulator is shown in Figure 2. The pile unit is housed within a ceramic tube which, in turn, is enclosed in a solid casing or, more generally, a finned casing for dissipating the heat generated by the carbon pile. Electrical contact at each end of the pile is made by carbon inserts. The initial pressure on the pile is set by a compression screw acting through the pile on the armature and spring plate which is supported on a bi-metal washer. This washer compensates for temperature effects on voltage coil resistance and on any expansion characteristic of the regulator, thus maintaining constant pile compression. The electromagnet assembly comprises a cylindrical yoke in which is housed the voltage coil, a detachable end-plate and an adjustable soft-iron core (see also paragraph 3.1.3(b)). The cables from the voltage coil and carbon pile terminate at a connector block or plug on the end plate of the regulator.

3.1.3 **Regulator Adjustments.** Three separate adjustments are normally provided in carbon pile-voltage regulators: (a) voltage coil circuit resistance, (b) magnet core airgap and (c) carbon pile compression.

(a) **Voltage Coil Circuit Resistance.** Adjustment of voltage coil circuit resistance is accomplished by a ballast resistor, pre-set by the manufacturer, to give the correct ampere turns in the voltage coil at the nominal voltage to be controlled. In addition to the ballast resistor, a trimming resistor is also provided for raising or lowering the regulated voltage level within certain limits, after the regulator is installed in an aircraft.

(b) **Magnet Core Airgap.** The airgap between the magnet core and the armature is pre-set by adjusting the position of the magnet core within the end-plate of the electromagnet housing (Figure 2). The adjustment provides for optimum regulation at the nominal controlled voltage.

NOTE: In some older types of regulator a screw passes through the magnet core, limiting excessive armature movement and preventing the armature from adhering to the face of the core. In later designs this screw is not fitted.

(c) **Carbon Pile Compression.** Initial compression of the carbon pile is adjusted by the compression screw (Figure 2) to give the correct setting of the plate-type control spring, so that, over the working range of the pile, the spring and magnetic forces exactly counterbalance at any position of the armature. The setting of the screw may be regarded as the characteristic setting of the regulator, and determines the degree of regulation and the stability factor.

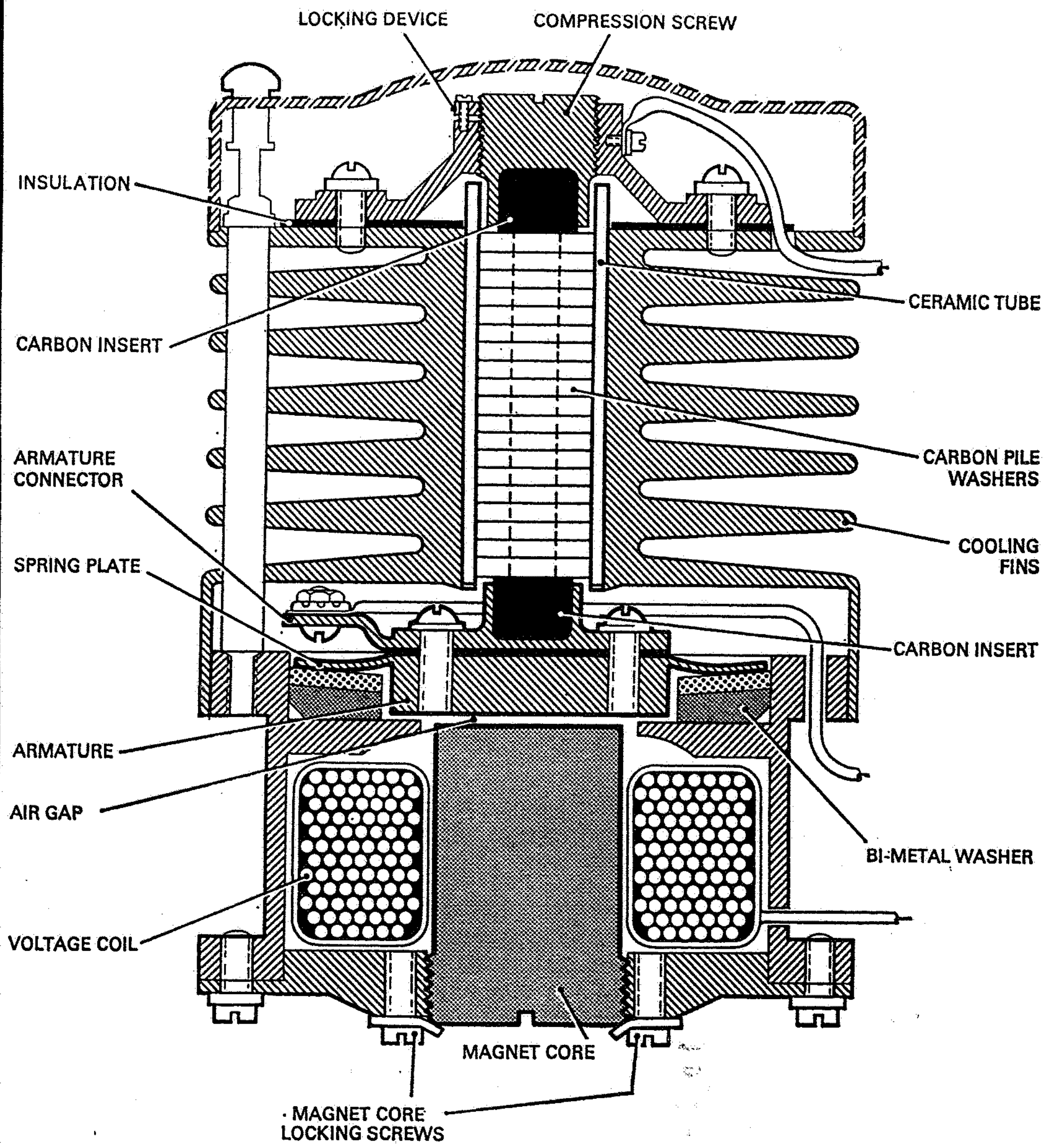


*Figure* 2 CARBON-PILE VOLTAGE REGULATOR CONSTRUCTION

3.2 **Vibrator-type Voltage Regulator.** This type of voltage regulator usually consists of a voltage regulator, a current limiter, and a reverse current cut-out relay housed in the one metal container.

3.2.1 **Principle of Operation.** The output from the generator armature, entering through terminal G (Figure 3) passes through the heavy coil of the current limiter and the current coil (series winding) of the reverse current cut-out relay, then to earth.

No current can flow to the battery or the load busbars until the points of the cut-out relay close. As the generator output voltage rises, the magnetic strength of the voltage coil (shunt winding) of the cut-out relay increases enough to close the contacts and put the generator 'on line'. Load current flowing through the cut-out relay current coil now aids the voltage coil in maintaining the contacts closed. The field coils of the generator are excited from the output of the armature, and the earth circuit of the field is completed through the contacts of both the voltage regulator and current limiter. When the voltage rises to its regulated value, the magnetic pull produced by both coils of the voltage regulator opens the regulator contacts. With the regulator contacts open, the earth circuit of the field now includes the resistor, and the field current drops, as will the output voltage. When the contacts open, the accelerator winding circuit is opened and its field collapses completely, rapidly decreasing the flux, so the spring can close the contacts more rapidly than if this winding were not used.

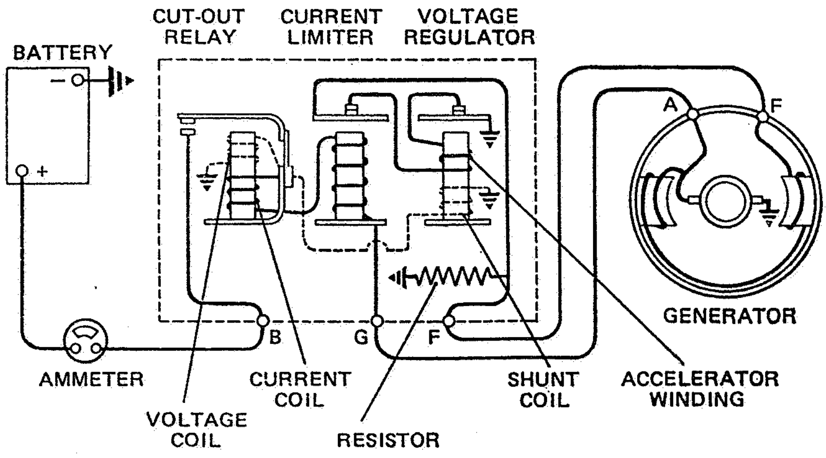


*Figure* 3 THREE-UNIT VIBRATOR-TYPE VOLTAGE REGULATOR

(a) Some regulators employ a second resistor in the regulator housing, in parallel with the generator field. When the field circuit is open-circuited and the field current begins to fall, the inductance of the coil will produce a voltage surge which would tend to cause arcing at the contact points; the purpose of the resistor, therefore, is to suppress the arcing. In normal operation, the contacts open and close between 50 and 200 times per second to maintain the voltage at a constant value.

(b) In some generators one end of the field is connected to the earthed brush, and a positive potential is on the field in the regulator to control the voltage (Figure 4). Before the voltage reaches the regulated level, current flows through the field from the armature of the cut-out relay, through both the voltage regulator and current-limiter contacts and through the earth in the generator. When the voltage rises to the pre-set value, the regulator contacts open, and resistor $R_1$ is inserted in the field circuit and reduces the generator output voltage. When the field circuit is opened and the current drops, the induced voltage surge would tend to cause arcing at the contacts, but since resistor $R_2$ is in parallel with the field coils, it will shunt off some of the current and minimise the arcing.

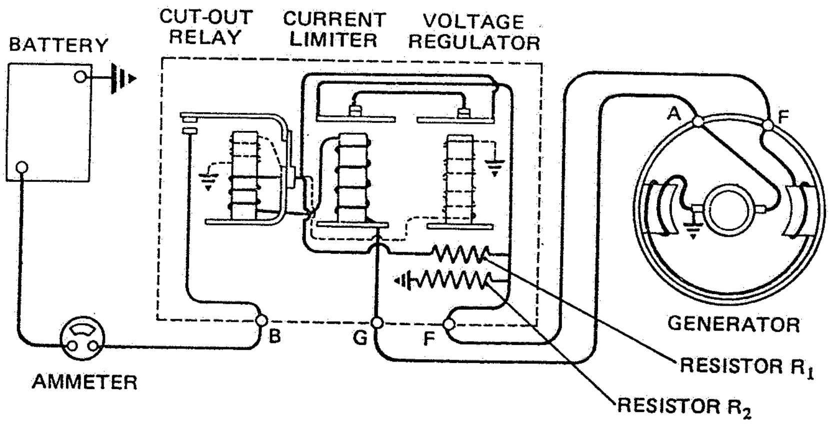


*Figure* 4 THREE-UNIT VIBRATOR-TYPE VOLTAGE REGULATOR CONNECTED BETWEEN THE POSITIVE SIDE OF THE GENERATOR ARMATURE AND THE FIELD

(c) Some types of vibrator-type voltage regulator have two sets of movable contacts and one fixed contact (Figure 5). When the engine is running at a relatively slow speed and the field current demands are high, the regulator vibrates between the centre and lower contacts. As the voltage rises to the regulated setting, the contacts open and a resistor is inserted into the field circuit. When the engine speed is high and field current demand is low, the magnetic pull of the voltage regulator is strong enough to cause the contacts to vibrate between the centre and top contacts. When the contacts are open, the resistor is in the field circuit, but when the voltage is high enough to close the top contacts, the field windings are shorted out and no field current flows.

3.2.2 **Current Limiting.** At any time the current drawn by the load reaches the pre-set value, the magnetic field produced by the heavy coil of the current limiter will open the limiter contacts and insert a resistor into the generator field circuit. The increased field resistance will, therefore, lower the output voltage and decrease the current. When the current drops, the contacts close and the voltage again increases. As long as the demands for current exceed the pre-set value, the current-limiter contacts will vibrate.

3.2.3 **Reverse Current Cut-out Relay.** When the generator voltage rises above that of the battery, the magnetic field of the voltage coil in the reverse current cut-out relay will close the contacts and place the generator on line. Load current then flows through the current coil and produces a magnetic field, which aids that produced by the voltage coil and holds the contacts tightly closed. When engine speed decreases and the generator output drops below that of the battery, current will flow from the battery into the generator armature. Current flowing through the current coil of the cut-out relay produces a magnetic field which opposes the field of the voltage coil, and a spring will now open the contacts, taking the generator off line.

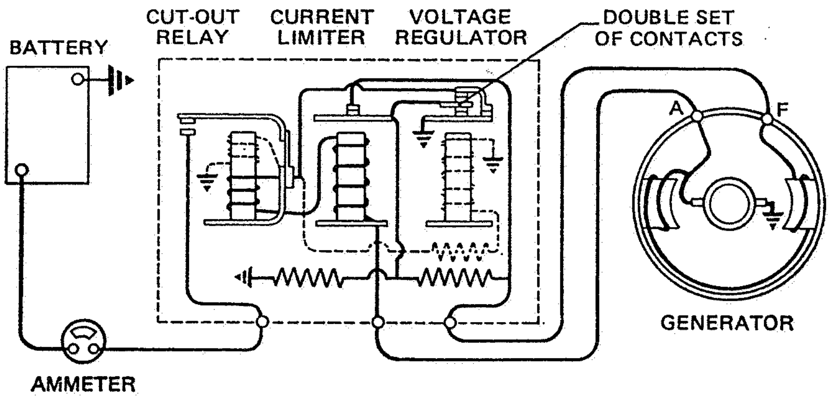


*Figure* 5 THREE-UNIT VIBRATOR-TYPE VOLTAGE REGULATOR WITH A DOUBLE SET OF CONTACTS

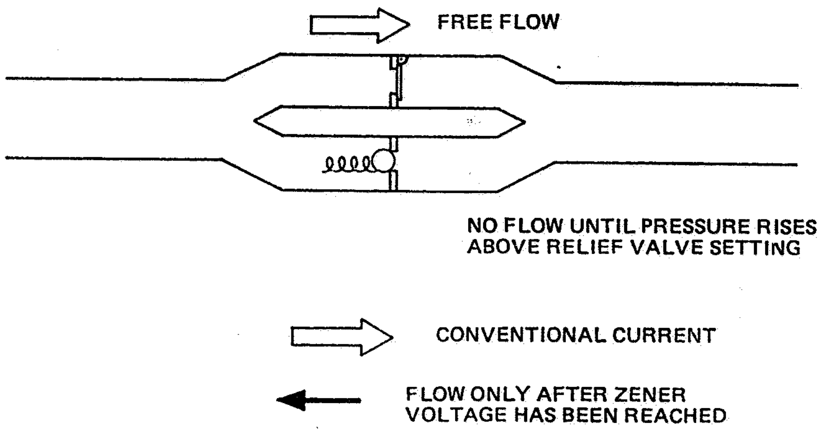


*Figure* 6 PRINCIPLE OF A ZENER DIODE

3.3 **Solid-state Voltage Regulators.** These generally fall into two categories: transistorised voltage regulators, which use a transistor to actually control the flow of field current but an electromagnetic coil is used to sense the voltage, and transistor voltage regulators, which are fully solid-state and sense the voltage by a zener diode.

3.3.1 **Transistor Voltage Regulators**

(a) **Zener Diode.** The principle of operation of a zener diode is that it will allow a free flow of electrons in one direction, but will block the flow in the reverse direction until the voltage has risen to its breakdown, or zener, voltage. This breakdown action does not damage the properties of a zener diode in any way (Figure 6).

(b) **Principle of Operation.** A complete basic circuit of a typical transistor voltage regulator is shown in Figure 7. The output of the generator is connected across the voltage divider network of resistors $R_1$, $R_2$ and $R_3$. The zener diode $D_1$ senses the volts drop across $R_1$ and a portion of $R_2$. When the voltage across $D_1$ is low, there is no current flow through the base of driver transistor $T_1$; with no base current there will be no emitter-collector current to produce a volts drop across $R_5$. Base current can flow through the output transistor $T_2$ and will conduct, giving a current flow to the generator field. With the field receiving its full field excitation current, the output voltage will rise, and at the regulation level the voltage across the zener diode will cause it to breakdown. With this breakdown, base current will now flow in $T_1$, which causes an emitter-collector current to flow through $R_5$. The voltage build-up across $R_5$ brings the base of $T_2$ to the same potential as its emitter and shuts it off, so no field current can flow through $T_2$, causing the generator terminal voltage to fall. Diode $D_2$ provides a constant voltage drop, so the emitter of $T_2$ will be sufficiently below the level of the line voltage, permitting the current through $R_5$ to bring the base voltage of $T_2$ up to that of its emitter so that $T_2$ is shut off. Diode $D_3$ protects the transistors against voltage surges when field current is suddenly cut off. The rapid collapse of the field would induce a voltage high enough to damage the transistors but is prevented from doing so by $D_3$ conducting the voltage to earth. Diode $D_4$ is a transient suppression diode that protects the transistors from any externally-generated voltage surges, while capacitors $C_1$ and $C_2$ smooth out pulsations and cause the regulator to operate smoothly.

3.4 **Magnetic Amplifier Voltage Regulator**

3.4.1 **General.** This voltage regulator is essentially a two-stage magnetic amplifier which derives its a.c. power from the generator output and supplies rectified power to the generator exciter field. The reactive load division circuitry provides balanced kVAR loading during parallel operation. In case of either a three-phase symmetrical line-to-line or line-to-earth fault, the regulator can usually supply sufficient excitation to enable the generator to supply current to operate protective devices. During an unbalanced fault condition, negative sequence sensing circuitry limits the highest phase voltage to specified limits. The regulator performs all of its functions with the a.c. generator and integral exciter as its only power supply.

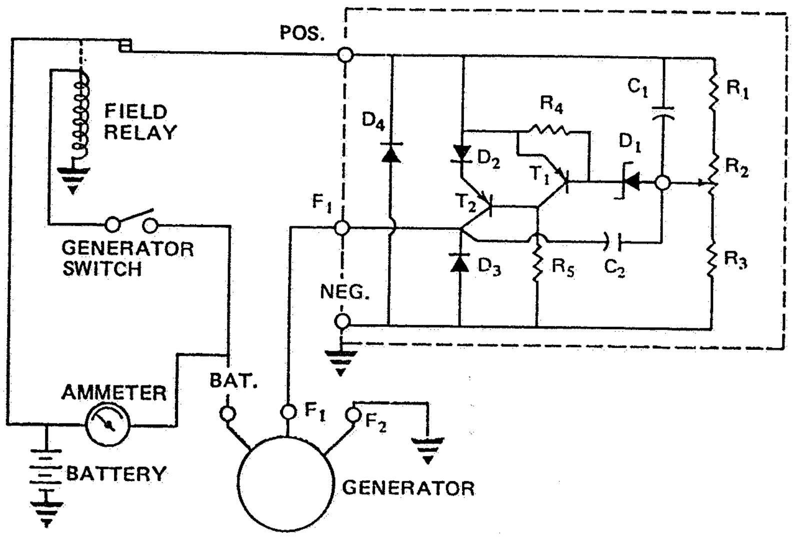


*Figure* 7 TRANSISTOR VOLTAGE REGULATOR

3.4.2 **Operation.** Figure 8 is a block diagram of the regulator/generator circuitry. The regulator can be considered as four basic parts: the voltage error detector and reactive load division section, the pre-amplifier, the d.c. bias supply and negative sequence sensing unit, and the power amplifier. When full load is applied to the generator, line voltage will start to decrease and an error signal is introduced to the pre-amplifier. An amplified error signal is then fed into the signal winding of the power amplifier, resulting in additional core saturation, thus allowing more current to flow through the load winding and to the exciter field. The increased exciter field current results in increasing generator output voltage towards the desired level.

3.4.3 **Voltage Error Detector**

(a) The voltage error detector monitors or 'senses' the average three-phase output of the generator and provides an error signal proportional to the variation of that voltage above or below a nominal pre-set or reference value.

(b) **Reactive Load Division.** During parallel operations a current transformer and reactor package provide a corrective signal to the error detector to maintain proper reactive load division between generators. In parallel operation all generator output voltages are common regardless of differences in excitation applied to the various generators. However, since those generators with more excitation are producing more kVAR than those with less excitation, reactive current will flow from those with more excitation to those with less. One of the functions of the regulator is to sense the difference in reactive load division, by means of the direction and magnitude of reactive current flow, and to balance the system by increasing the excitation on each generator as required. In single generator operation, output voltage varies with the excitation applied.

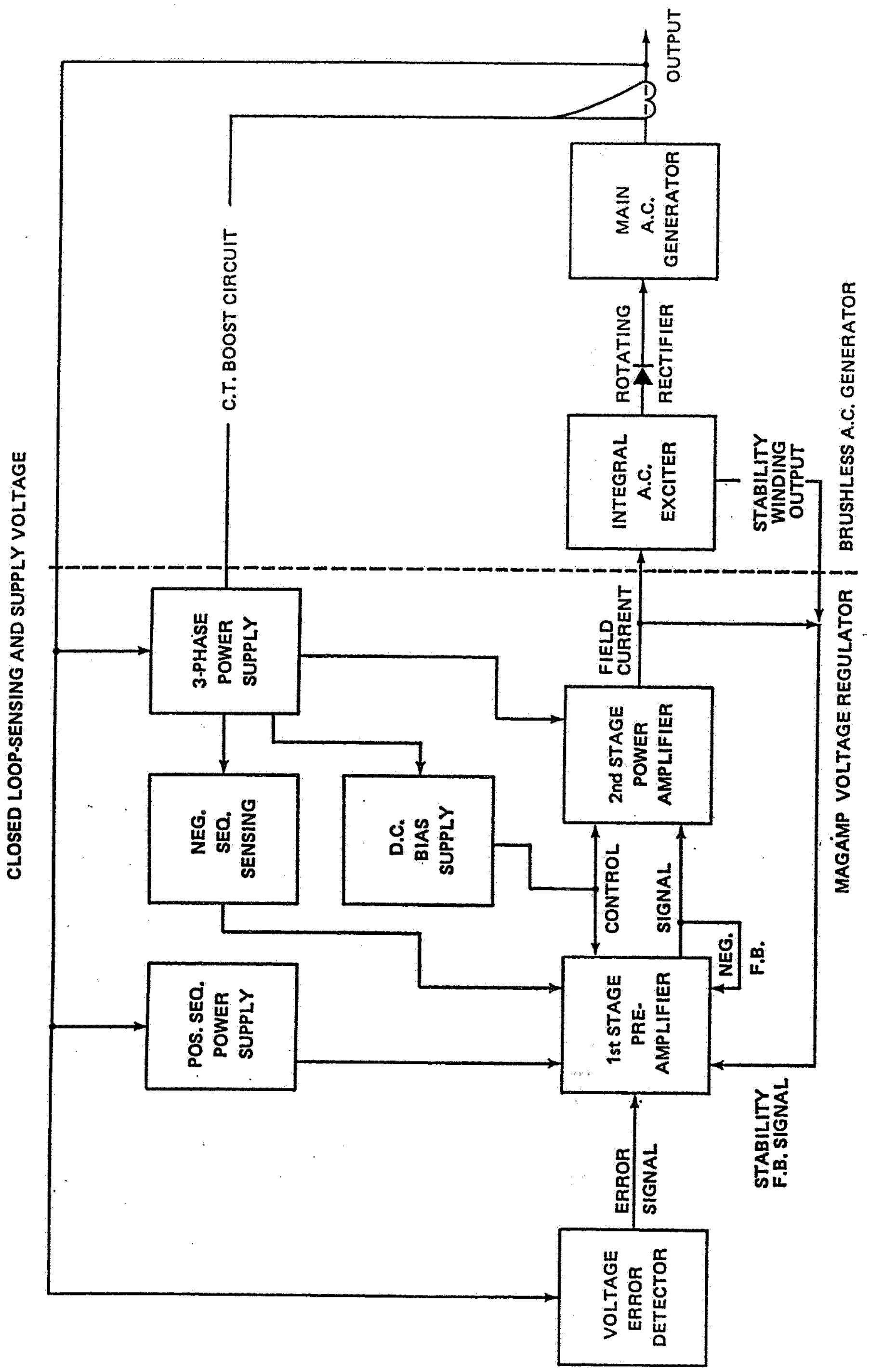


*Figure* 8 VOLTAGE REGULATOR/GENERATOR CIRCUIT IN BLOCK DIAGRAM FORM

**(c) Negative Sequence Sensing Unit**

(i) Under balanced three-phase voltage conditions, only a positive sequence vector rotation is present, i.e. vector rotation is ABC, assuming generator output rotation to be ABC. However, during an unbalanced three-phase condition, both positive sequence (ABC) and negative sequence (CBA) vector rotation will exist (Figure 9).

(ii) The negative sequence sensing filter (Figure 10) is designed to allow only the CBA rotation to be sensed. Thus, unbalanced three-phase voltages can be detected.

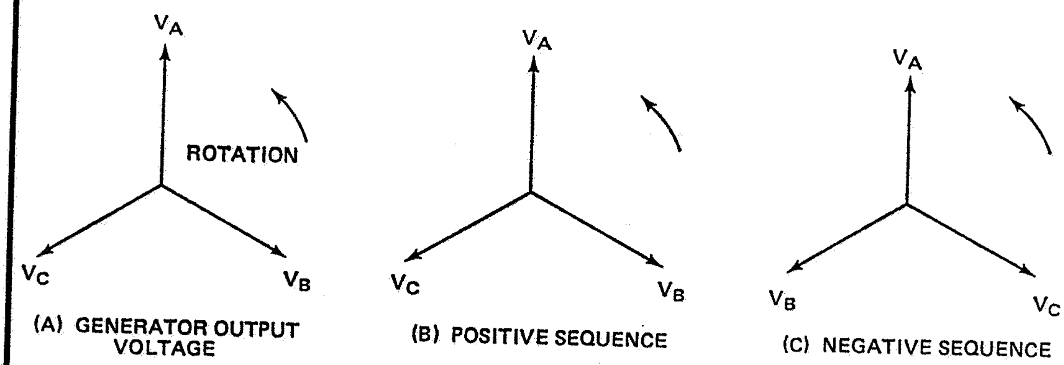


*Figure* 9 POSITIVE AND NEGATIVE SEQUENCE VOLTAGE VECTOR DIAGRAMS

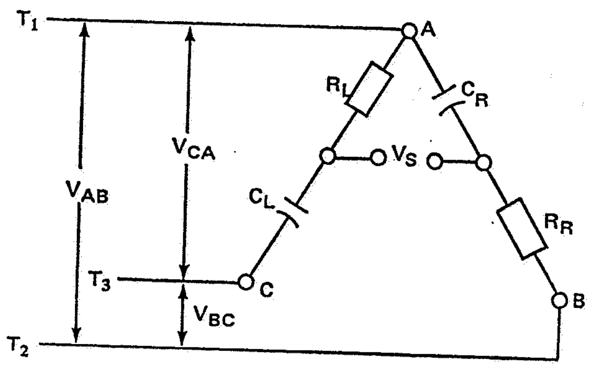


*Figure* 10 SCHEMATIC DIAGRAM OF NEGATIVE SEQUENCE SENSING FILTER

(d) **Positive Sequence Power Supply**

(i) A positive sequence sensing filter is used to obtain a power supply for the pre-amplifier load winding as it will not deviate greatly under unbalanced line conditions. The positive sequence voltage magnitude changes little in comparison with the change between line voltages under a wide range of unbalanced fault conditions.

(ii) The positive sequence sensing filter (Figure 11) is identical with the negative sequence sensing filter (Figure 10) except that the input connections have been reversed. This, in essence, takes the ABC rotation of the generator output and reverses it to CBA, thus the positive sequence voltage of the generator has been reversed to negative sequence voltage by reversing the leads, and fed into the filter to obtain an output signal.

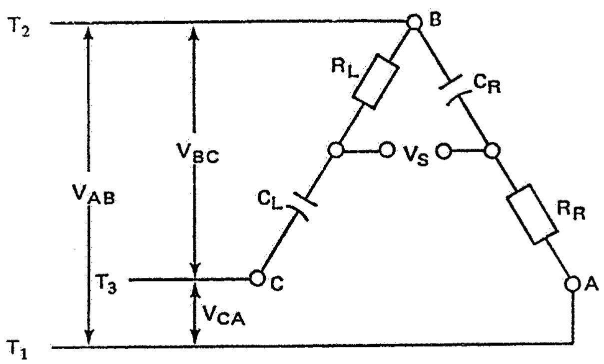


*Figure* 11 SCHEMATIC DIAGRAM OF POSITIVE SEQUENCE SENSING FILTER

3.4.4 **D.C. Bias Supply.** The d.c. bias supply obtains power from a three-phase transformer, which is connected to the generator terminals and fed into a three-phase, full-wave silicon rectifier bridge. The d.c. bias supply provides power to the bias windings of the pre-amplifier and the power amplifier.

3.4.5 **Pre-amplifier**

(a) **Load and Bias Windings.** Basically the pre-amplifier consists of a push-pull, parallel, self-saturating, load-winding circuit and four matching sets of control windings, all wound on four common cores. Each control winding functions as described in (b) to (e):—

(b) **Error Winding.** The error, stability, and negative feedback control windings are wound uni-directionally, whereas the load and bias windings are wound push-pull or opposing. Therefore, a current flow in the uni-directional windings will tend to add to the net flux, and hence increase the load current, in one half of the load circuit while decreasing the net flux and the current flow in the other half. The opposing voltage, dropped across resistors, will differ and a resultant voltage will appear across the amplifier output. The polarity and proportional magnitude of the output voltage will vary with that of the input or control signal, thus high gain voltage amplification is obtained. A d.c. input signal of a few milliamperes at very low voltage applied to the error winding, controls a substantial output signal voltage.

(c) **Negative Feedback Winding**

(i) Like any high gain amplifier, the magnetic pre-amplifier is subject to drift or slight change in output with respect to fixed input, due to temperature and other variables. In order to minimise such drift and to provide a convenient gain control, a negative feedback circuit is provided.

(ii) As indicated by Figure 8, a portion of the pre-amplifier output is taken from the load circuit and fed into the negative feedback windings. These windings create a control flux opposing that created by the error signal winding. The effects of this action should be noted:

—In the case of amplifier drift, the output tends to vary with no change in the error signal. In this case a portion of the output is fed back in opposition to the direction of change and automatic correction takes place.

—Since a portion of the output signal is fed back in opposition to the error signal, a large error signal is required to obtain the same output. Since a variable resistor controls the amount of feedback, it therefore controls the required input for a given output and hence the gain of the amplifier. This resistor may be used to control the overall gain of the regulator to provide the required degree of generator output voltage control.

(d) **Stability Winding.** The purpose of a stability circuit is to oppose sudden changes in error signal and thereby to minimise or damp out generator voltage overshoot and prevent system oscillation. As Figure 8 indicates, it obtains its signal from the exciter field and from the pre-amplifier output. Usually a special stabilising or damping winding is provided in the exciter field of a.c. brushless generators. By transformer action, this winding picks up a rate-of-change signal from the current supplied to the exciter field. Whereas a steady state of slowly changing exciter field current will have little effect on the winding, a sudden increase or decrease will immediately create a signal in the stabilising winding, which, when applied to the stability winding of the pre-amplifier, will oppose the direction of the change and hence tend to damp it out.

(e) **Negative Sequence Winding**

(i) The negative sequence winding is wound in such a fashion that a signal from the negative sequence unit will produce a flux in the pre-amplifier in such a direction as to reduce the voltage regulator output. In this way, the highest phase voltage can be limited to a safe value during unbalanced faults.

(ii) A negative sequence voltage is produced only during an unbalanced line-to-line or unbalanced line-to-earth fault. Although a negative sequence voltage is produced during an unbalanced fault, a diode is usually put in series with the negative sequence winding to prevent the winding from being energised unless approximately a one-third balance of one phase, in comparison with the average phase voltage, exists.

### 3.4.6 Power Amplifier

(a) The power amplifier comprises a three-phase, full-wave bridge magnetic amplifier, supplied from the combination of a three-phase power transformer and three current transformers, the latter being a part of a current transformer package (paragraph 3.4.7). The power amplifier supplies current to the exciter field of the generator. Silicon rectifiers are used in the self-saturated circuits of the amplifier, to maintain minimum size and weight, and to reduce reverse currents to a very low level; because of the high-gain, square loop core materials are used in the amplifier. Utilisation of current transformers as an integral part of the regulator electrical design causes the power output capabilities of the regulator to increase in accordance with the load on the a.c. generator, and hence the excitation demands of its rotating exciter. When the a.c. generator is subjected to a three-phase fault, all power for the exciter field is supplied via the current transformers and the power amplifier in the regulator. This method of supplying field power improves voltage recovery time after load switching, or removal of fault.

(b) **Load Winding.** Power obtained from the transformer package and the boost current transformers is fed directly through the six load windings and to the exciter field.

(c) **Bias Winding.** Power is obtained from the same d.c. bias supply that feeds the pre-amplifier bias winding. The load circuit would be self-saturating in the absence of other control and maximum current would flow at all times. To prevent this and to provide a range of control, d.c. bias is applied through the bias winding such that the induced flux opposes the load flux and the output is reduced by approximately one-half. Adjustment is normally provided for initial setting up.

(d) **Signal Winding.** The output signal from the pre-amplifier varies from zero for nominal generator output voltage to positive for below nominal, and to negative for above nominal. For a below-nominal generator voltage, the signal applied to the signal winding causes an increase in flux in the six cores, thus approaching saturation and increasing the field current to the generator exciter. For an above-nominal signal, the signal is negative; the core flux and the excitation current are reduced.

### 3.4.7 Current Transformer Boost Current

(a) The three current transformers mounted on the generator feeders are connected in series with the low potential ends of the power transformer secondary windings. One of the regulator requirements, generally, is that it shall furnish excitation to the generator during a three-phase system fault or line-to-earth fault. During such a fault, generator voltage drops to near zero, but a very high current flow occurs through the generator feeders and, by means of the current transformer boost circuit, power is taken from the current in the generator feeders and fed into the power amplifier power supply. In the absence of bias and signal voltage, the power amplifier load windings tend to self-saturate the cores and full load current flows to the exciter field, proportional to the fault current.

(b) The current transformer boost circuit also performs two other functions. During normal operation a small but significant amount of voltage is added to the power supply and, since the amount added is proportional to the load current, this aids the power amplifier and hence the regulator in compensating for load instabilities.

The current transformers are also sensitive to the phase relation of the generator output current to voltage; the function is much the same as that of the reactive load division circuit and tends to increase or reduce the excitation as required to provide reactive load equalisation in parallel operation.

3.4.8 **Temperature Compensation.** As the power amplifier is single-ended, whereas the pre-amplifier is push-pull or self-balancing, some temperature compensation is required. This is usually provided by positive temperature coefficient resistors (TCR) built into the saturable reactor cases and connected in series with the d.c. bias winding. This temperature compensation takes care of core shift and control winding resistance changes due to temperature variation.

3.4.9 **Commutating Rectifier.** The output of a magnetic amplifier normally contains a sawtooth a.c. ripple component in addition to the d.c. component. Since the output current is uni-directional by virtue of the silicon rectifiers, and since the exciter shunt field is inductive, the field winding will tend to store energy. If there were no way to discharge this energy the apparent resistance would increase, increasing the voltage and decreasing the current to the field to the point where failure of one or more of the silicon rectifiers may occur due to high inverse voltage. To prevent this, another silicon rectifier is usually connected across the output, opposed in direction to the d.c. amplifier output. This rectifier, called the commutating rectifier, provides a convenient path for discharge of stored energy in the field winding and permits the exciter field load to appear resistive rather than inductive to the magnetic amplifier.

3.4.10 **Closed Loop Operation of the Voltage Regulator**

(a) The process of actual regulation of a.c. generator voltage may be more easily understood by means of idealised curves as shown in Figure 12. The operating characteristic curves for the detector, pre-amplifier, power amplifier and exciter-generator combination are shown in their relationship to one another.

(b) During initial adjustment of the complete regulator, the coupled sections are so aligned that, when generator output voltage equals its rated or nominal value, the error detector signals $I_S = 0$, the pre-amplifier output $E_O = 0$, and the power amplifier output to the exciter field is approximately one half its maximum value.

(c) When the system is disturbed in some manner to cause a momentary increase in a.c. generator voltage to some new value, which is higher than rated value, the detector sends a negative $I_S$ signal to the pre-amplifier. The pre-amplifier produces a negative $E_O$ output to the power amplifier, which in turn drives the power amplifier to a new lower value of field current $I_F$. The lower field current permits the generator to drop to a new value lower than the previous value. As shown, the condition rapidly repeats itself around the loop until an equilibrium condition is reached.

(d) It should be noted that there is theoretically only one condition of generator speed, loading, etc., at which the system can operate with zero per cent voltage regulation; that is, the generator output remains exactly at rated value, and the detector and pre-amplifier output signals remain zero. At all other conditions a steady state error must exist; that is, the output voltage will remain slightly above or below its rated value and a corrective signal passes through the regulator. The maximum error which can occur under specified conditions, compared with rated output, is the per cent regulation. The amount of continuous fluctuation which occurs in the output voltage as a result of hunting of the regulation circuits, compared with rated output, is termed the per cent modulation.

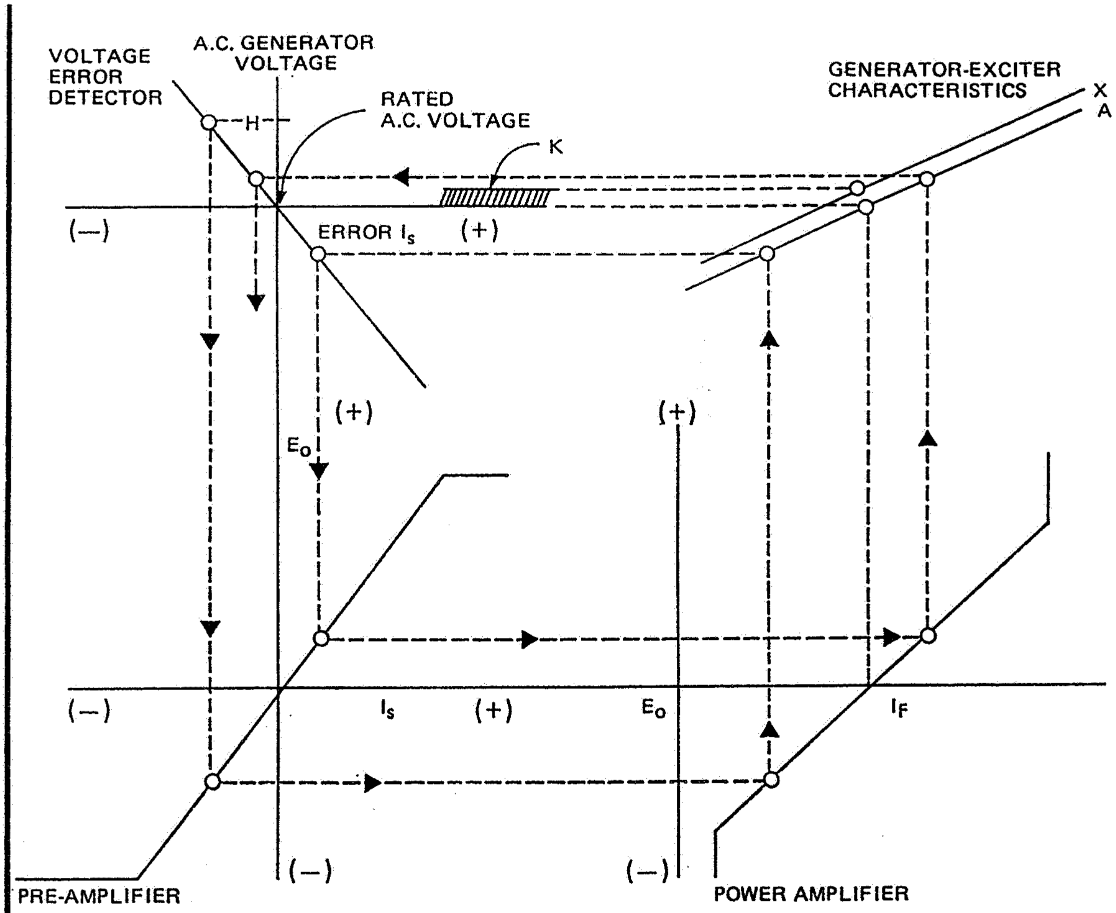


*Figure* 12 GENERATOR/REGULATOR CLOSED LOOP OPERATION

## 4 MAINTENANCE PRACTICES

4.1 **General.** The maintenance practices for voltage regulators will depend upon their type and on the type of aircraft installation; reference must, therefore, be made to the relevant aircraft Maintenance Manual for the specific instructions. The information given in the following paragraphs serves only as a general guide.

4.2 **Removal/Installation**

4.2.1 **Removal.** Carry out electrical safety procedures as detailed in the relevant aircraft Maintenance Manual. Disconnect electrical connections, identifying if necessary. Refit all terminal covers and fit blanks as required. Carefully remove the voltage regulator from its mounting, taking care not to cause damage to the regulator or any items of equipment or fittings in the area.

4.3 **Pre-installation Checks.** Regulators should be inspected for damage or deterioration which may have occurred in storage or transit. New or overhauled regulators are normally kept in their special packaging containers until required and these should be carefully examined for signs of damage before removing the regulator. It must be verified that the shelf life, where specified, has not been exceeded.

4.3.1 **Regulator Installation.** In general, regulators should be mounted in accordance with the relevant Maintenance Manual. In the case of carbon-pile voltage regulators, these should normally be mounted with the axis of the carbon pile horizontal, and located so that there is minimum vibration and no restriction to the free circulation of air over the casing and through the cooling fins. All connections must be secure and made in accordance with the relevant Maintenance Manual and aircraft installation wiring diagrams.

4.4 **Adjustment/Tests**

4.4.1 **General.** The checks to be carried out after installation and during specified inspection periods are detailed in the relevant aircraft Maintenance Manuals and Maintenance Schedules, and reference must be made to such documents for the procedures to be adopted. In general, the checks involve the measurement and adjustment of voltage output with associated generator systems operating singly and/or in parallel, at selected speeds, and under no-load and selected load conditions. The details given in the following paragraphs are based on the checks specified for typical generating systems and are intended to serve only as a general guide to checking procedures.

NOTES: (1) Voltage measurements must be made by a first-grade voltmeter connected in the aircraft system at the measuring points specified in the Maintenance Manual.

(2) Throughout the checking procedures all engine speed limitations and generator ratings must be strictly observed.

4.4.2 **Voltage Output Checks.** Each generator should be run and the system checked and adjusted strictly in accordance with the relevant aircraft Maintenance Manual instructions. On installations that include carbon-pile voltage regulators, there is usually a period of warm-up to allow the drying out of any moisture absorbed by the carbon pile.

(a) Each generator output voltage should be checked to ensure that it is within the limits specified in the relevant aircraft Maintenance Manual. Where necessary, the trimmer resistance of the appropriate voltage regulator should be adjusted to bring the voltage within the limits. In installations with carbon-pile voltage regulators, the magnet cores or pile compression screws must not be touched.

(b) When the output voltages have been set, a check should be made to ensure that they remain stable and within limits when a generator is switched on and off, and also when run under specified load and speed conditions.

4.4.3 **Paralleling Checks.** In multi-generator system installations, it is also necessary to carry out paralleling checks and adjustments to ensure not only that generator output and busbar voltages remain within limits, but also that electrical loads are shared equally between generators. These checks and adjustments should be carried out strictly in accordance with the relevant aircraft Maintenance Manual, and the following procedures are intended only as a general guide.

(a) Generators should be run at the speed corresponding to normal cruising and switched on in pairs and in combinations appropriate to the installation. A specified maximum electrical load should then be switched on and the readings on the ammeters, or kW/kVAR meters for an a.c. system, of the relevant generator systems noted. The readings should be steady and should indicate that each generator is carrying its share of the load within the tolerance quoted in the aircraft Maintenance Manual.

(b) If such a load distribution is not obtained, it should be determined from the readings of the ammeters, or the kW/kVAR meters for a.c. systems, which generator has the greater error in the division of load current and further off-load checks made on the relevant voltage regulating circuit. If necessary, the voltage settings should be re-adjusted to bring them to within the tolerances quoted in the relevant aircraft Maintenance Manual.

(c) The load should again be switched on and the load-sharing check repeated.

NOTES: (1) Before carrying out any adjustments necessary to correct an unbalance in load sharing, the possibility of high-resistance faults having occurred in a generator supply circuit should be investigated and rectified.

(2) During adjustments, the specified electrical load, once selected, must not be altered.

**EEL/1-3**

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# AIRCRAFT

## ELECTRICAL EQUIPMENT

## BATTERIES—NICKEL-CADMIUM

1 INTRODUCTION This Leaflet gives general guidance on the maintenance and installation of nickel-cadmium batteries (in particular of the semi-open type), which provide a standby source of d.c. power in aircraft. It should be read in conjunction with the Maintenance Manuals and Overhaul Manuals issued by the battery manufacturers, relevant aircraft Maintenance Manuals and approved Maintenance Schedules.

1.1 The information provided by this Leaflet is set out as follows:—



**NOTE: This Leaflet incorporates the relevant information previously published in Leaflet EEL/1—5, Issue 1, dated 15th June 1962.**

2 GENERAL DESCRIPTION Nickel-cadmium batteries may be divided into three ranges of basic design, as described in the following paragraphs.

2.1 **Sealed Batteries.** This range of batteries consists of those having the cells completely sealed. In general the batteries are of small capacity, and may be used for emergency lighting purposes.

2.2 **Semi-sealed Batteries.** The cells in this range of batteries are usually mounted in steel containers and are fitted with safety valves. The batteries may be charged fairly rapidly but are very sensitive to overcharge, thus, for aircraft usage, they are usually fitted with a thermal protective device. Under normal conditions the battery requires practically no maintenance beyond periodic cleaning and capacity checks.

2.3 **Semi-open Batteries.** These batteries are generally used as the main aircraft batteries. The cells are similar in appearance to those of the semi-sealed type, but are deliberately allowed to 'gas' to avoid excessive heating should the battery be on over-charge. The cell cases are usually manufactured from nylon. Because of gassing, the electrolyte has to be 'topped-up' at periods which vary according to the duty cycle of the battery and the conditions under which it is operated. 'Topping-up' periods are specified in the approved Maintenance Schedule for the aircraft concerned (see also paragraph 4.3).

3 CONSTRUCTION The plates comprise a sintered base on a nickel-plated steel support. The active materials are nickel hydroxide on the positive plates, and cadmium hydroxide on the negative plates, and these are impregnated into the sintered base by chemical precipitation. This type of plate construction allows the maximum amount of active material to be employed in the electrochemical action.

3.1 After impregnation with the active materials, the plates are stamped out to the requisite size. The plates are then sorted into stacks according to the type of cell into which they are to be mounted. Usually there is one additional negative plate for a given number of positive plates. The plates are then welded to connecting pieces carrying the cell terminals, after which a separator is wound between the plates and the insulation is checked under pressure. The plate group is then inserted in the container, the lid secured and pressure-tested for leaks. The separators are usually of the triple-layer type, one layer being made from cellophane film, the other two being woven nylon cloth. Cellophane is used because it has low electrical resistivity and is a good barrier material which contributes to the electrical and mechanical separation of the positive and negative plates, and keeps finely divided metal powder particles from shorting out the plates while still permitting current flow. It also acts as a gas barrier, preventing oxygen given off at the positive plate during overcharge from passing to the negative plate where it would combine with active cadmium, reduce cell voltage, and produce heat as a result of chemical reaction. The cellophane is prone to damage at high operating temperatures, and failure will result in an adverse change in the operating characteristics of a battery (see also paragraph 4.5.8 (a)).

3.2 The electrolyte is a solution of potassium hydroxide and distilled water, having a relative density of 1·24 to 1·30. It is impregnated into cells under vacuum, after which the cells are given three formation cycles, re-charged, and then allowed to stand for a minimum period of 21 days. The discharge characteristics at the end of this period enable the cells to be matched.

3.3 In a typical battery each component cell is insulated from the others by its moulded plastic case. All the cells are interconnected via links secured to the terminals of the cells, and are contained as a rigid assembly in the battery case. A vent cap assembly is provided on the top of each cell and, in general, is constructed of plastic, and is fitted with an elastomer sleeve valve. The vent cap can be removed for adjustment of the electrolyte level, and acts as a valve to release gas pressure generated during charging. Except when releasing gas, the vent automatically seals the cell to prevent electrolyte spillage and entry of foreign matter into the cell.

3.3.1 Two venting outlets, a pair of carry-strap shackles, and a two-pin plug for quick-release connection of the aircraft battery system cables, are embodied in the battery case. A removable cover completes the case, and incorporates a pair of slotted lugs which engage with attachment bolts at the battery stowage location.

3.4 **Chemical Principle.** During charging an exchange of ions takes place; oxygen is removed from the negative plates and is added to the positive plates, bringing them to a higher state of oxidation. These changes continue in both sets of plates for as long as the charging current is applied or until both materials are converted; i.e. all the oxygen is driven out of the negative plates and only metallic cadmium remains, and the positive plates become nickel hydroxide.

3.4.1 The electrolyte acts only as an ionized conductor and is forced out of the plates during charging. It does not react with either set of plates in any way, and its relative density remains almost unchanged. Towards the end of the charging process and during overcharging, gassing occurs as a result of electrolysis which reduces only the water content of the electrolyte. Gassing is dependent on the temperature of the electrolyte and the charging voltage (see also paragraph 4.5.5).

3.4.2 During discharge, the chemical action is reversed; the positive plates gradually losing oxygen while the negative plates simultaneously regain lost oxygen. The plates absorb electrolyte to such an extent that it is not visible at the top of the cells.

**4** MAINTENANCE Nickel-cadmium batteries must be prepared for service, charged, tested and otherwise generally maintained, in a well ventilated workshop area which is entirely separate from that used for the servicing of lead-acid batteries. This also applies to servicing and test equipment, tools and protective clothing, all of which should carry some form of identification. Anything associated with lead-acid batteries (acid fumes included) that comes into contact with a nickel-cadmium battery or its electrolyte can cause severe damage to this type of battery.

4.1 Precise details of inspection and maintenance procedures, and the sequence in which they should be carried out, are given in the relevant battery maintenance and overhaul manuals, and other approved supplementary servicing instructions; reference should, therefore, always be made to such documents. The information given in the following paragraphs is intended to serve as a general guide to the procedures to be carried out appropriate to battery service life and condition, and also to the precautions to be observed.

4.2 **Inspection.** The following checks are typical of those comprising a battery inspection schedule:—

(a) The battery should be identified to establish any known history. If the battery is a new one a servicing record card should be raised (see paragraph 7).

(b) The outside of the battery case should be examined for evidence of damage, and of locally overheated areas.

(c) The battery cover should be removed and its rubber lining inspected for condition. Cover latches should operate smoothly and provide proper security of the cover. Extreme care must be exercised when working around the top of a battery with its cover removed. Tools should not be dropped onto the cell connecting links, as severe arcing will result with possible injury to personnel and damage to the battery. Such personal items as rings, metal watch straps and identification bracelets should be removed, to avoid contact with connecting links and terminals.

(d) There should be no evidence of arcing having occurred between the battery and the aircraft structure. The section near the bottom of the case and the slotted lugs of the cover tie-down strap are areas which are most likely to be affected. If signs of arcing are present, the aircraft battery compartment should be inspected and the battery should be completely dismantled and overhauled.

(e) The battery should be inspected for signs of electrolyte leakage and should be cleaned where necessary (see paragraph 4.4).

(f) The battery receptacle should be checked for evidence of burns, cracks and bent or pitted terminals. Defective receptacles, which can overheat, cause arcing and depress output voltage, should be replaced.

(g) All cell links should be checked for security and evidence of overheating, and their terminal nuts should be tightened to the specified torque values. Any cell link showing damage to its plating should be replaced.

(h) Vent caps should be checked for security and also to ensure that gas exit holes are free from dirt or potassium carbonate crystals. Clogging of vents causes excessive pressures to build up, resulting in cell rupture or distortion of parts. Cell valves, when fitted, should also be checked for security and freedom from dirt or crystal formation. Dirty vent caps or valves should be removed and cleaned (see paragraph 4.4.3).

NOTE: Potassium carbonate is a white crystal formed by the reaction of potassium hydroxide with carbon dioxide in the air; it is non-corrosive, non-toxic, and non-irritating.

(j) Temperature sensing devices, when installed, should be checked for secure attachment with leads and connectors showing no signs of chafing or other damage. Electrical checks and/or calibration of these devices should be carried out at the periods specified in the approved Maintenance Schedule.

4.3 **Electrolyte Level and Adjustments.** The level of the electrolyte should, depending on manufacturer's recommendations, only be adjusted when a battery is at the end of charge, while still charging, or after a specified standing time. If electrolyte level adjustments were to be made in the discharged or partially discharged condition, then during a charge electrolyte would be expelled from the cells, resulting in corrosive effects on cell links, current leakage paths between cells and battery case, and a reduction of electrolyte density. The manufacturer's instructions regarding checks on electrolyte level and adjustments should be carefully followed and the maintenance kit equipment designed for a particular type of battery should be used.

NOTE: Adjustments should not be made when batteries are installed in aircraft.

4.3.1 Only the purest water available, preferably pure de-mineralised or distilled water, should be used for adjusting electrolyte levels, and a record of the quantity added to all cells should be maintained, because it is largely on this evidence that periods between servicing are determined (see also paragraph 7). The 'consumable' volume of electrolyte is normally specified in manufacturer's manuals, but in the absence of such information, a useful guide line is that batteries should not be left for periods which would require the addition of water to any cell by an amount in excess of 1 cc per ampere-hour capacity.

4.3.2 In the event that the electrolyte becomes contaminated, particularly with oil, foaming of the electrolyte will occur. In such cases, a neutralizing fluid, which is available from the relevant battery manufacturer, should be added to the electrolyte, strictly in accordance with the manufacturer's instructions.

4.3.3 Additional potassium hydroxide should not normally be required, but if electrolyte in solution is necessary for topping-up it must be ensured that it is in the proportions specified in the relevant manual.

NOTE: Contamination of the electrolyte with tap water, acids, or other non-compatible substances, will result in poor performance or complete failure of a battery.

4.3.4 Potassium hydroxide should be kept in special containers, and because of its caustic nature, should be handled with extreme care to avoid contamination of the person or clothing. Rubber gloves, a rubber apron and protective goggles should always be worn. If contamination does occur, the affected parts should be immediately rinsed with running water. If available, vinegar, lemon juice or a mild boric acid solution may also be used for treatment of the skin. Immediate medical attention is required if the eyes have been contaminated. As a first-aid precaution, they should be bathed with water or a weak boric acid solution, applied with an eye bath.

4.4 **Battery Cleaning.** Dirt, potassium carbonate crystals, or other contaminating products, can all contribute towards electrical leakage paths (see also paragraph 4.6) and be a prime cause of unbalanced cells. Cleanliness of batteries is therefore essential.

4.4.1 Deposits should be removed from the tops of cells by using a cloth soaked in de-mineralised or distilled water and a stiff fibre bristle brush. Wire brushes or solvents should not be used. If any contaminating product is caked under and around cell connecting links, the links should be removed, if necessary, to facilitate cleaning. Care should always be taken to ensure that debris is not forced down between cells, and in some cases it may be better to scrape deposits loose and then blow them with low-pressure compressed air. The air itself should be clean and dry, and goggles should be worn to protect the eyes.

4.4.2 Some manufacturers specify periodic flushing of cell tops and battery case with de-mineralised or distilled water while brushing away deposits. This method is not recommended, and batteries in a dirty condition, or showing low resistance, should be dismantled and completely serviced.

4.4.3 When it is necessary to clean vent caps and valves, they should be removed from the cells, using the correct extractor tool, and should be washed in warm water to dissolve any potassium carbonate crystals which may have accumulated within the outlet orifices. They should then be rinsed in de-mineralised or distilled water, dried and re-fitted. Valves should also be tested for correct functioning in accordance with manufacturer's instructions before re-fitting.

NOTE: Cells should not remain open for longer than is necessary.

4.5 **Charging of Batteries.** New nickel-cadmium batteries are normally delivered complete with the correct amount of electrolyte, and in the fully discharged condition. Following a visual check for condition, they must, therefore, be charged in accordance with the manufacturer's instructions before being put into service. Once in service, batteries must then be charged at the periods stated in the approved aircraft Maintenance Schedule. The following information on charging methods and associated aspects is of a general nature only. Precise details are given in relevant manufacturer's manuals and reference must, therefore, always be made to such documents.

4.5.1 **Constant-Current Charging.** This method is the one which should normally be adopted for the workshop charging of batteries, the charging equipment being adjusted and monitored throughout the charging period to supply current at either a single rate, or at several different rates in a stepped sequence. Although more time-consuming than the constant potential method which is often adopted in aircraft battery systems, constant current charging is more effective in maintaining cell balance and capacity. The hour rate of charge current required must be in accordance with that specified by the relevant battery manufacturer.

NOTE: The 'hour rate' of a battery refers to the rate of charge and discharge expressed in multiples of 'C' amperes, where 'C' is the 1-hour rate. For example, if a battery has a capacity of 23 ampere-hours, then 'C' would be 23 amperes and for a 10-hour rate the charge or discharge current rate would be $\frac{C}{10}$ amperes, i.e. 2·3 amperes.

4.5.2 **Vent Caps.** Before charging, the battery cover should be removed, and with the aid of the special wrench provided in the battery maintenance kit, the vent cap of each cell should also be removed.

4.5.3 **Connection to Charging Equipment.** Charging equipment should not be switched on until after a battery has been connected and the charging circuit has been checked for correct polarity connections.

4.5.4 **Electrolyte Level.** The electrolyte level should be checked and adjusted, as necessary, in accordance with the manufacturer's recommendations (see also paragraph 4.3).

4.5.5 **Gassing.** Gassing of cells occurs within the region of final charge, as a result of the electrolysis of water into hydrogen and oxygen gases. When gases escape from a cell, the quantity of fluid electrolyte is reduced; vigorous prolonged gassing should therefore be avoided. A "dry" cell is more likely to suffer separator damage, and any cell running hotter than its neighbours should be investigated.

(a) The gassing/temperature phenomena provide a useful indication of impending failure of cells; e.g. a cell that gasses sooner and more actively than its neighbours is going to lose more electrolyte, and as a result will run hotter and tend to dry out. Minor differences in gassing are hard to detect, but large differences should be noted and investigated.

4.5.6 **State of Charge.** The state of charge cannot be determined by measurement of the electrolyte relative density or battery voltage. Unlike the lead-acid battery, the relative density of the nickel-cadmium battery electrolyte does not change. Except for 'dead' batteries, voltage measurements at either open circuit or on-load conditions do not vary appreciably with state of charge. The only way to determine the state of charge is to carry out a measured discharge test (see paragraph 4.7).

4.5.7 **Charging of Individual Cells.** Individual cells must be in an upright position and adequately supported at the sides parallel to the plates during charging. A special frame may be built to fit a cell, or boards or plates may be placed on each side and held together with a clamp. After charging and removal from its support, the sides of a cell should be inspected to ensure there are no bumps or bulges which would indicate an internal failure.

NOTE: Cells should always be fully discharged before removal from a battery and before re-assembly.

4.5.8 **Thermal Runaway.** In some small aircraft the battery may be charged by constant potential supplied directly from the d.c. bus-bar. Under correct conditions of temperature and voltage, the internal voltage of the cells rises gradually as the electro-chemical action takes place, and it opposes the charging voltage until this is decreased to a trickle sufficient to balance continuous losses from the cells. The energy supplied to a fully charged battery results in water loss by electrolysis and in heat generation. For a battery in good condition, a point of stability will be reached where heat as a result of trickle current will just balance radiated and conducted heat losses. At low temperatures, a battery will appear to have a limited capacity, and will require more voltage to accept a given amount of charge. As the battery becomes warm, however, its responses return to normal. Operation at high temperatures also limits the capacity, but in such conditions, a battery is subjected to the danger of a 'thermal runaway' condition.

(a) At higher than normal temperatures, the heat loss of the battery through radiation and conduction is lower than the heat generating rate and this results in a higher battery temperature. This, in turn, reduces the internal resistance of the battery, so that higher than normal charge current is admitted resulting in an increase in chemical activity, additional heat and a further increase in charging current. This recurring cycle of temperature rise, resistance and voltage drop, and charge current rise, progressively increases the charging rate until sufficient heat is generated to completely destroy a battery.

(b) Other factors which can cause overheating of a battery are as follows:—

(i) Voltage regulator of aircraft generating system incorrectly adjusted.

(ii) Frequent or lengthy engine starts at very high discharge rates.

(iii) Loose link connections between cells.

(iv) Low electrolyte level (see also paragraph 4.3).

(v) Leakage currents between a cell and battery container and the airframe structure. Periodic measurement of leakage current and removal of any electrolyte that may have accumulated around and between cells should be carried out to prevent high leakage and short circuits from developing (see also paragraph 4.6).

(vi) Use of unregulated, or poorly regulated, ground support equipment to charge a battery, particularly a battery which has become hot as a result of excessive engine cranking or an aborted engine start.

(vii) High initial charging currents imposed on a hot battery.

(viii) Unbalanced cells. Cell unbalance (see paragraph 4.9) refers to an apparent loss of capacity and to variations in cell voltage at the end of charging cycles. These variations can develop over a period of time, particularly when subjected to operating conditions like those occurring in aircraft utilising charging circuits of the constant potential type. Other factors which may also contribute to cell unbalance are cell position in the battery, e.g. centre cells run warmer than outer cells, and the self-discharge of individual cells.

(c) In some types of aircraft, the batteries specified for use incorporate a thermostat type detector which illuminates a warning light at a pre-set temperature condition. In addition, a thermistor type sensing network may also be incorporated. The network operates in conjunction with a special solid-state, pulse-charging unit, and its function is to monitor the charging current and to de-energize the charging circuit when the battery temperature exceeds a safe operating limit. Detection devices should be checked at the periods stated in the approved aircraft Maintenance Schedule and in accordance with the relevant manufacturer's instructions.

4.6 **Electrical Leakage Check.** Electrical leakage refers to current flowing in a path other than that desired, and in connection with batteries, this means current between the terminals or connectors of cells and any exposed metal on the battery case. The only pertinent measure of leakage of importance to a cell is the rate of discharge caused by the leakage, and this is only significant when its value approaches that specified for the particular type of battery. In one type for example, a leakage of up to 0·020 amps is quoted as the permissible value. Typical methods of determining electrical leakage are described in the following paragraphs.

4.6.1 The positive lead from the terminal of a multi-range testmeter should be connected to the positive terminal of the battery and, after selecting the appropriate scale range (usually the one amp. range) the negative terminal lead from the testmeter should be touched on any exposed metal of the battery case. If a pointer deflection is obtained it will denote a leakage and the testmeter scale setting should be adjusted, if necessary, to obtain an accurate reading which should be within the limits specified.

The foregoing check should be repeated between the battery negative terminal and battery case, when again any readings obtained should be within limits. If either of the readings obtained exceed the specified limits the battery should be thoroughly cleaned (see paragraph 4.4) and the checks again repeated.

4.6.2 If, after thorough cleaning, the leakage current is in excess of the limits it is probable that one of the cells is leaking electrolyte and is therefore defective. This cell may be found by measuring the voltage between each cell connecting link and the battery case. The lowest voltage will be indicated at the connecting links on each side of the defective cell which should be replaced (see also paragraph 4.12).

4.7 **Capacity Test.** The capacity or state-of-charge of a fully-charged battery is checked by discharging it at a specified rate (preferably automatically controlled) after it has been standing for a certain time period, and noting the time taken for it to reach a specified on-load voltage. For example, a 23 ampere-hour battery is left to stand for 15 to 24 hours and is then discharged at 23 amperes, i.e. the 1-hour rate, to 20 volts. A battery should give at least 80% of the capacity specified on its nameplate, or the minimum authorised design capacity, whichever is the greater.

NOTE: Some batteries of U.S. origin have initial capacity ratings which are significantly higher than those specified on their nameplates. When the nameplate ratings are no longer obtainable such batteries are rejected.

4.7.1 True capacity must always be recorded, meaning that a full discharge is required, and not one which is terminated when the minimum acceptable level has been reached. Because it is essential to monitor a number of cell voltages very closely, the service of two persons is desirable towards the end of discharge for measurement and recording. At this stage, voltages fall very quickly, and it is highly desirable that measurements be made with a digital voltmeter.

NOTE: No cell should be allowed to go into reverse polarity before the measured discharge is complete, and the terminal voltage should not go below 1 volt per cell, since excessive gassing may result.

4.8 **Capacity Recycling Procedures.** The purpose of recycling is to restore a battery to its full capability and to prevent premature damage and failure. The discharge rates and voltage values appropriate to the recycling procedures vary between types of battery, and reference should always be made to the relevant manual. The figures quoted in the following paragraphs are typical, and serve only as a guide to the limits normally specified.

4.8.1 The battery should be discharged at a current equal to or less than the one-hour rate, and as each cell drops below 0·5 volts (measured by a digital voltmeter) it should be shorted out by means of a shorting strip. The cells should remain in this condition for a minimum period of 16 hours, preferably 24 hours.

NOTE: A battery should not be discharged at an excessively high rate and cells then short-circuited, since this produces severe arcing and excessive heat generation.

4.8.2 The shorting strips should then be removed, and the battery charged for 24 hours at the specified recycling charging rate. After approximately five minutes of charge, individual cell voltages should be measured and if any cell voltage is greater than 1·50 volts, distilled water should be added. The amount of water required depends on the rated ampere-hour capacity; a typical maximum value is approximately 1 cc per rated ampere-hour.

4.8.3 After approximately 10 minutes of charge, individual cell voltages should again be measured. Any cell measuring below 1·20 volts or above 1·55 volts should be rejected and replaced.

4.8.4 After 20 hours of charging, individual cell voltages should be measured and recorded, and, if necessary, distilled water should be added to the normal level appropriate to the type of battery.

4.8.5 At the end of the 24 hours charge period, cell voltages should again be measured and compared with those obtained after 20 hours. If the 24 hour voltage reading is below the 20 hour reading by more than 0·04 volts, the cell concerned should be rejected and replaced.

4.9 **Cell Balancing.** If a battery fails to give 80% capacity on test, and if premature ageing of some cells is suspected, a cell balancing test should be carried out. The procedure for carrying out the test appropriate to a particular type of battery is prescribed in the relevant manual, and reference should always be made to such document. The following details, based on the test specified for a typical 23 ampere-hour battery, are given only as a general guide.

4.9.1 Note the time, and discharge the battery at 23 amperes until the terminal on-load voltage falls to 20 volts, then stop the discharge. During the discharge, the voltage of each cell should be frequently checked with a digital voltmeter. A zero reading early in the discharge indicates a short circuit cell; a reverse reading indicates a weak cell. In either case the discharge should be stopped, even if the overall battery voltage has not yet fallen to 20 volts. The weak or faulty cell should be shorted out, preferably through a 1 ohm resistor.

4.9.2 Note the time and recommence the discharge at the lower rate of 2·3 amperes. Frequently check the voltage of the cells and short out each cell (with individual shorting strips) as it falls below 1 volt. Record the lapsed time of discharge for the cell to fall below 1 volt, thereby obtaining an indication of the relative efficiency of the cells.

(a) Some manufacturers specify 0·5 volts as the point at which shorting of the cells should be carried out. This is satisfactory providing that sufficient time is available to permit shorting of all cells before any are subjected to reverse voltage resulting from the charging effect of stronger cells.

4.9.3 The discharge should be stopped when all the cells are shorted out. The battery should be left in this condition, and also with the main terminals shorted together, for as long as possible, but never less than 16 hours.

4.9.4 The battery should then be charged and the cell-balancing procedure repeated. The discharge times recorded for each cell to fall below 1 volt should show an improvement over those previously recorded.

4.9.5 Weak and internally short-circuited cells should be replaced in accordance with the instructions detailed in the relevant battery Maintenance Manual (see also paragraph 4.12).

4.10 **Voltage Recovery Check.** This check, which should be made at a given time after shorting strips have been removed from the cells or main battery terminals, provides a ready means of detecting high resistance short-circuits and damaged connections within a battery. A typical procedure for this check is given in the following paragraphs.

4.10.1 Shorting strips of one ohm resistance should be connected between cells, and the battery should be allowed to stand for 16 to 17 hours. At the end of this period, the voltage of individual cells should be measured to ensure that they do not exceed the minimum value specified for the battery (a typical minimum value is 0·20 volts).

4.10.2 The shorting strips should then be removed, and after a further standing period of 24 hours, individual cell voltages should again be measured to check their recovery to within normal operating values. A typical minimum value specified as a basis for rejection of a cell is 1·08 volts.

4.11 **Insulation Resistance Test.** A test for insulation resistance may be specified by some manufacturers as the means of checking for electrical leakage. Reference should, therefore, be made to the appropriate maintenance manual for the procedure to be adopted, for permissible values, and for any remedial action to be taken.

4.12 **Cell Removal and Replacement.** Cells should be removed from a battery whenever they are suspected of leakage of electrolyte, internal short-circuits, when they fail to balance (see also paragraph 4.9) or if the insulation resistance is found to be below the value specified for the particular battery. The method of removing and replacing cells may vary between types of battery, and the instructions issued by the relevant manufacturers must, therefore, always be carefully followed. The information given in the following paragraphs, although based on a specific type of battery, is intended to serve only as a guide to the practical aspects generally involved.

4.12.1 The battery should be discharged and the cell links disconnected and removed both from the faulty cell and from the adjoining cells. The cell position should be noted for subsequent entry in the battery record card.

4.12.2 The vent cap should be loosened using the special key provided with the battery maintenance kit.

4.12.3 A cell extractor tool should then be fitted to the cell on the terminals normally used for connecting the cell links. The battery is then held firmly and the cell withdrawn vertically upwards without using undue force. When one cell is removed and all other cell links are disconnected, it is relatively simple to withdraw the remaining cells without the aid of the extractor.

NOTE: After removing a cell, its vent cap should be re-tightened.

4.12.4 Cells and the inside of the battery case should be thoroughly cleaned and dried (see paragraph 4.4).

4.12.5 After carrying out all necessary checks, serviceable cells should be replaced in the battery case in their correct positions, and a cell-to-cell voltage check should be carried out to ensure that polarities are not reversed. It must be ensured that any new cells are of the same manufacture, part number, and are of matched capacity rating.

NOTE: A steady force should be used on terminals to press cells into place. Tight cells should not be hammered into place. For easiest assembly, the cell at the middle of a row should be inserted last.

4.12.6 The surfaces of cell terminals and connecting links should be clean, and, after ensuring the correct positioning of links, terminal nuts should be tightened to the specified torque value, and in a sequence commencing from the battery positive terminal. Care should always be taken to ensure that nuts actually tighten the connector assemblies, and are not binding as a result of thread damage or bottoming.

NOTE: Once a tightening sequence has been started it should be completed, thereby ensuring that a nut has not been overlooked. One loose connection can permanently damage a battery and may cause an explosion.

4.12.7 On completion of cell replacement procedures, the battery should be re-charged, tested for insulation resistance, and, if any new cells have been fitted, a capacity test should also be carried out.

4.13 **Rejected Batteries or Cells.** Any batteries or cells which are rejected should be conspicuously and permanently marked on their cases to indicate that they are to be used only for general ground use.

5 INSTALLATION It should be ensured that the battery is of the correct ampere-hour rating, fully charged, and that the electrolyte is at the corrrect level. Depending on the service history of the battery, appropriate tests, e.g. capacity test, capacity recycling and cell balancing, must also have been carried out in the manner prescribed for the particular battery. Reference should be made to the relevant aircraft Maintenance Manual for details of the battery system and associated installation instructions. Before coupling the system connecting plug, a check should be made to ensure that the battery system switch is OFF, and that all electrical services are isolated.

NOTE: Batteries are heavy units, and they require the use of approved handling methods to prevent possible injury to personnel and damage to the cases or components adjacent to the battery location. Vent pipes should not be used for lifting purposes.

5.1 The battery compartment should be thoroughly clean and dry, and the battery should be securely attached in its mounting. Clamp nuts should not be over-tightened since distortion of the battery cover may result, which could affect the venting arrangements.

NOTE: If a battery compartment has been previously used for lead-acid batteries, it should be washed out with an acid neutralising agent, dried thoroughly, and painted with an alkaline-resistant paint.

5.2 The supply cables from the battery, and, where appropriate, thermostat and battery charging system cables, should be checked for signs of chafing or other damage. Cable connecting plugs should be securely made, without any strain on the plugs or cables.

5.3 Battery installations are normally designed so that in flight, sufficient air is passed through the compartment to dilute the hydrogen gas given off by a battery, to a safe level. Ventilation systems should therefore be checked to ensure there is no obstruction or, if integral venting is used, the connections should be checked for security and leaks.

NOTE: In some ventilation systems, non-return valves are incorporated in the battery compartment vent lines. These valves should also be checked for security and correct location.

5.4 After installation, a check should be made that the electrical connections of the battery supply cables have been correctly secured by switching on some electrical services for a specific time period and noting that readings of the aircraft voltmeter remain steady. A typical load and time is 30 amperes for 30 seconds. For battery systems having a separate 'in-situ' charging unit, the unit should be switched on and its electrical settings checked to ensure proper charging of the battery.

6 MAINTENANCE OF INSTALLED BATTERIES Batteries should be inspected at the periods specified in the approved aircraft Maintenance Schedule. The details given in the following paragraphs serve as a general guide to the checks normally required.

6.1 The battery mounting should be checked for security, and the outside of the battery case should be examined for signs of damage and for evidence of locally overheated areas. The latches of the cover should operate smoothly and should firmly secure the cover in position.

6.2 Connecting plugs of the battery receptacle, thermostat and battery charger units, where fitted, should be checked for signs of contamination, burns, cracks, and bent or pitted terminal fittings.

6.3 The tops of all cells and vent caps should be inspected for signs of electrolyte leakages and should be cleaned where necessary.

6.4 The electrolyte level should be checked, and if any adjustments are necessary, these should be made after removing the battery from the aircraft and checking that it is in the fully charged condition. The amount of water added to the cells should be noted on the battery record card. A cell requiring more than the specified amount should be regarded as suspect, and the battery should be replaced by a serviceable unit. In aircraft having an independent charging unit, the unit should be switched on and the battery charged in accordance with the procedure specified in the relevant aircraft Maintenance Manual.

NOTE: When removed, the battery cover and cell vent caps should not be placed on any part of the aircraft structure or equipment.

6.5 The battery ventilation system should be checked to ensure security of connection, and freedom from obstruction.

7 BATTERY RECORDS A technical or service record should be maintained on each battery in service. Discretion may be exercised as to the layout of such a record and the extent of the details it should contain. It should, however, provide a fairly comprehensive history of the specific battery, so that in the event of a malfunction it will assist in establishing the fault. The example shown in Figure 1 is intended only as a guide.

8 STORAGE AND TRANSPORTATION Nickel-cadmium batteries should be stored in a clean, dry, well-ventilated area and should be completely segregated from lead-acid batteries. The area should also be free from corrosive liquids or gases. It is recommended that they should be stored in the condition in which they are normally received from the manufacturer, i.e. filled with electrolyte, discharged and with shorting strips fitted across receptacle pins. Cell connecting strips and terminals should be given a coating of acid-free petroleum jelly (e.g. white vaseline).

8.1 The temperatures at which batteries may be stored are quoted in the relevant manuals, and reference should therefore be made to these. In general, a temperature of 20°C is recommended for long-term storage.

8.2 If batteries are to be stored in a charged condition, they must be trickle charged periodically in order to balance the inherent self-discharge characteristic. Since this discharge is temperature sensitive, the trickle charge rate is therefore dependent on the storage temperature conditions.

8.3 If it is necessary to return a battery to the manufacturer or to an approved overhaul organisation, it should be discharged, but not drained of electrolyte. It should be packed in its original container, together with its service record (see paragraph 7) and 'This Way Up' international signs affixed to the outside.

NOTE: If transportation is to be by air, the container must comply with IATA regulations concerning the carriage of batteries containing alkaline electrolyte.

## NICKEL-CADMIUM BATTERY SERVICE RECORD

### BATTERY AND AIRCRAFT DATA

Manufacturer ..............................

Part No......................................

Serial No....................................

Rating: Volts............... Ah............

Mod. State..................................

Aircraft Type................................

Registration ................................

Battery Function (e.g. Standby, A.P.U. Starting)

..................................................

Date Installed................................

Hours Flown................................

### SERVICING DATA

Date Removed..............................

Date Serviced ..............................

Workshop Ambient Temp..............

Reason for Removal........................

Servicing Instructions Used..............

Date Released ..............................

| Operation | Results/Comments | Initials | |
|---|---|---|---|
| | | Mech. | Insp. |
| *Details of operations performed and measurements required—* | | | |
| | | | |

### CELL DATA

| Position in Battery | Serial No. | Water Added (c.c.) | Voltage | Temperature | Final Voltage | Capacity (Ah) |
|---|---|---|---|---|---|---|
| 1<br>2 | | | | | | |
| 19<br>20 | | | | | | |

MAIN TERMINAL VOLTAGE..............................

I hereby certify that the inspection/overhaul/repair/replacement/modification specified above has been carried out in accordance with the requirements of Chapter A4—3 of British Civil Airworthiness Requirements.

Signed...........................................

Firm.............................................

CAA Approval Ref.
or Licence No. ................................

Date ...........................................

*Figure* 1

# AIRCRAFT

## ELECTRICAL EQUIPMENT

### POWER SUPPLY—D.C. GENERATORS

1 INTRODUCTION This Leaflet gives general guidance on the installation and maintenance of engine-driven generators used to provide direct-current power supplies for the various electrical consumer services installed in some aircraft. It should be read in conjunction with the relevant aircraft Maintenance Manual and the approved Maintenance Schedule; such documents providing full details of construction, servicing, repairs and test procedures relevant to specific types of generators. Reference should also be made to the following Leaflets which contain information closely associated with the equipment covered by this Leaflet.

**EEL/1-1** Batteries—Lead-Acid
**EEL/1-2** Voltage Regulation
**EEL/1-3** Batteries—Nickel-Cadmium
**EEL/1-6** Bonding and Circuit Testing
**EEL/3-1** Cables—Installation and Maintenance

1.1 There are a number of variations in the design and construction of generators and to provide full information would be beyond the scope of this Leaflet. The constructional and operating details given in the relevant paragraphs are based on some typical machines and are therefore intended to serve only as a general guide to the methods adopted.

2 CONSTRUCTION AND OPERATION Figure 1 illustrates a typical generator of the self-excited shunt-wound type. It consists of two major assemblies: a fixed stator, or yoke assembly, and a rotating armature assembly. The yoke assembly houses the magnetic field poles and associated coil windings. The armature assembly comprises a solid or hollow steel shaft upon which is mounted a stack of laminations, slotted to accommodate insulated copper wire or strip armature windings, and the commutator. The complete assembly is statically and dynamically balanced. One end of the shaft is serrated, splined or keyed, either internally or externally, for coupling to the relevant drive shaft of an engine. In some types of light aircraft, the generator employed is driven by a belt fitted around pulleys at one end of the armature shaft and the engine crankshaft. The armature shaft is supported in bearing assemblies housed in frames secured at the commutator end and drive shaft end of the yoke.

NOTE: A typical input speed range for generators installed on turbo-prop aircraft is 4500-8500 rev/min. A typical generator rating for a medium-sized turbo-prop aircraft requiring a d.c. power supply at 28 volts nominal would be:
Continuous: 30 volts 300 amps; cooling air 152 mm (6 in) water gauge.
Continuous: 30 volts 375 amps; cooling air 254 mm (10 in) water gauge.
15 Minutes Emergency Overload: 30 volts 400 amps; cooling air 254 mm (10 in) water gauge.

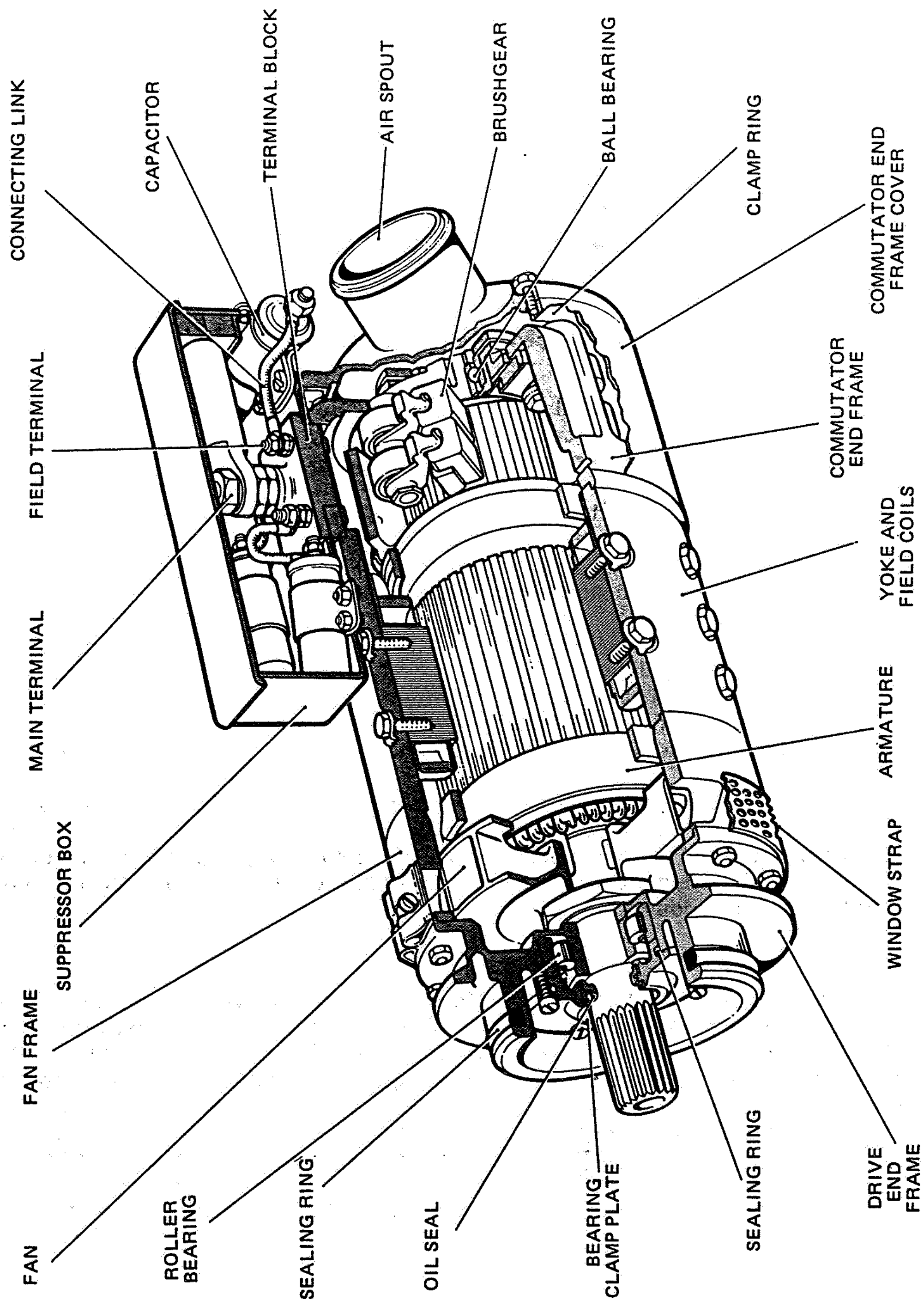


*Figure* 1 TYPICAL D.C. GENERATOR

2.1 The commutator end frame is a substantial cast component which, in addition to supporting the armature shaft, provides an attachment for the brushgear and main output terminal assembly. Depending on the type of generator, the brushgear assembly may consist of either two brushes, or four brushes mounted in boxes in diametrically opposite pairs on a support ring. Four double brush-box assemblies are also employed in some types. A brush spring post is fitted adjacent to each brush-box, and the brush springs are fitted to sleeves assembled to the spring posts. The sleeves are adjustable to permit setting of brush pressure. The brushgear support ring is also adjustable to provide for the setting of the brushes to the optimum position. Apertures are provided in the commutator end frame to allow access to the brushgear for inspection purposes. Under normal operating conditions the apertures are covered by a window strap. Interference to radio reception signals is suppressed by capacitors which are housed in a section of the terminal box and connected between the output terminals and frame. In some generators the capacitors may also be connected between the field terminals and frame.

2.2 The drive end frame is secured by nuts fitted on studs fixed in the end of the yoke, and has an integral flange for securing the generator to the associated engine mounting. Depending on the type of generator and engine mounting, the flange may be drilled for fixing over mounting studs, or machined for fixing by a special 'manacle' ring.

2.3 To obtain the maximum rated output under continuous running conditions, generators must be satisfactorily cooled, and the method most commonly employed for this purpose utilises the ram effect due to propeller slipstream or the normal airstream set up in flight. An air duct facing into the airstream is joined to a spout which is secured to the commutator end cover. The air passes over the commutator and windings at a predetermined pressure and rate of flow, and escapes through apertures in the window strap and an outlet union positioned at the drive end of the generator. In order to assist cooling under minimum air conditions and when operating at ground level, some generators may also incorporate an impeller type fan secured to the armature shaft at the drive end. In some types of generator, a thermally-operated switch unit is located in the yoke assembly. This is set to operate at a pre-determined temperature and is connected to an overheat warning light circuit.

2.4 When the armature is rotated within the yoke assembly, the armature windings cut the weak magnetic field set up by the residual magnetism of the pole shoe assemblies, and small voltages are induced in the windings. The armature windings are connected in parallel with the shunt field windings and are terminated at the commutator in such a manner that the voltage generated across the brushes is always of the same polarity. The small generated voltages therefore cause a flow of direct current through the field windings to increase the flux density. The increased field density, in turn, builds up the value of the voltages induced in the armature windings and also the voltage picked off by the brushes. The build-up of generated voltage progresses until a value predetermined by the setting of the associated voltage regulator connected in the shunt field circuit is reached. The voltage regulator automatically adjusts the resistance of the shunt field circuit in proportion to changes in generated voltage, thereby controlling the excitation current to maintain a constant voltage output essential for the efficient operation of associated consumer services.

**3 INSTALLATION** The arrangements for the installation of generators depend primarily upon the type of engine and, in some cases, also upon the particular type of aircraft. Reference should therefore always be made to the relevant Maintenance Manuals in which the specific installation instructions are given. The information given in the following paragraphs serves as a general guide to the methods to be adopted and to the checks to be carried out prior to installation.

3.1 Before installing any generator a check should be made to ensure that its type, part number and direction of rotation are correct for the particular installation. These details are given on a name plate attached to the generator yoke or casing. The rotation is specified as the direction of armature rotation when viewed from the driving end.

3.2 Housings and terminals should be checked for cleanliness and freedom from corrosion, distortion, cracks or other damage. The movement of armatures should also be checked for freedom by manually rotating the appropriate assembly at the driving end.

3.3 On generators employing drive shafts, a light coating of grease or engine oil should be applied to the splines after first removing any protective compound from the shaft. Reference should always be made to the relevant generator and aircraft Maintenance Manuals for details of the type of lubricant to be used.

3.4 In belt-driven generator installations, drive pulleys and belts should be checked for security and condition. After installation, belts should also be checked to ensure that they have the correct tension. Low tension will permit belt slippage, with a resulting rapid belt wear and low or erratic generator output, while excessive tension will cause rapid wear on the belt and on the generator bearing. The tension may be checked either by measuring the torque required to slip the belt at the generator pulley, or by measuring the amount of belt deflection caused by a predetermined load. Reference should always be made to the Maintenance Manuals for details of the measuring procedure and permissible limits.

3.5 The appropriate generator mountings at engine drive units should be inspected for cleanliness and damage, paying particular attention to mounting studs and drive shafts. If gaskets are employed between mounting faces these should be checked for serviceability and renewed as necessary.

3.6 When locating generators of the splined drive type they should be turned slightly in each direction about the drive axis to facilitate proper engagement of the splines. After a generator has been correctly orientated on its mounting it should be secured by the appropriate method (e.g. self-locking nuts and studs, bolts, or 'manacle' ring), paying particular attention to any torque values specified for tightening.

NOTE: Generators which are to be mounted horizontally should be adequately supported during installation and not be allowed to hang on their drive shafts or mounting studs.

3.7 Generator cables should be checked to ensure that they are free from damage to terminations, fraying and chafing of insulation covering. The alignment of cable ends should also be checked to ensure that cables are not subjected to strain particularly at points of entry to terminal boxes. The identification of terminations should be checked and connections made in accordance with relevant generator and aircraft installation wiring diagrams.

3.8 Before connecting cooling ducts they should be inspected for cleanliness, signs of damage and for correct orientation. Gaskets, where applicable, should also be inspected for condition and renewed as necessary. Where cooling ducts or scoops are fitted to movable cowlings, the alignment of cooling duct to generator cooling air entry should be checked.

3.9 After installation, a check should be made that all associated electrical circuits are in a safe condition for operation, and a generator function test carried out to the requirements specified in the relevant aircraft Maintenance Manual.

4 INSPECTION AND MAINTENANCE The information in the following paragraphs is a guide to the general practices adopted for the inspection and maintenance of generators at specified inspection periods, and whenever their serviceability is suspect. Precise details of all necessary checks and tests are given in the relevant Maintenance Schedules and Maintenance Manuals, and reference should always be made to such documents.

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

(a) Security of mounting and signs of damage.

(b) Security of all electrical connections, signs of cracks in terminal boxes and damage to terminal post threads.

(c) Signs of damage or corrosion at cable terminations, fraying and chafing of insulation and outer coverings; cables should be renewed as necessary.

(d) Security of cooling ducts and cleanliness of air outlet screens around generator.

(e) Evidence of oil having entered generator casings. This may be checked by shining a light into air outlet screens and brush inspection apertures. If oil is present it is possible that oil seals have failed and the generator should be removed for examination.

(f) Condition and correct tension of drive belts (see also paragraph 3.4).

4.2 **Commutators.** Commutators should be inspected for signs of excessive arcing, scoring, proud mica and carbon deposit. Carbon dust should be removed with a supply of clean, dry compressed air from a low pressure source.

4.2.1 In some generators, brushes are employed which have been specially developed to eliminate brush wear at high altitudes. The brushes in one particular category form a dark film on the surfaces of commutators. This film may give the impression that the surfaces are dirty but it is, in fact, a protective semi-lubricating surface which, so far as is practicable, should not be disturbed.

NOTE: The cleaning of commutators should be carried out in accordance with the relevant Maintenance or Overhaul Manual. Under no circumstances should an abrasive material be used.

4.3 **Brushgear.** Covers should be removed from inspection apertures or housing and the brushgear checked for condition and settings. Each brush should be examined for condition and wear.

4.3.1 The length of each brush should be measured on the longest side and sufficient allowance made to ensure a satisfactory performance until the next inspection period.

4.3.2 Brushes should be free but not slack in their boxes. If brushes are tight as a result of carbon deposits having formed in the boxes, the brushes should be removed and the boxes cleared of deposits by means of a soft cloth moistened in the recommended cleaning fluid. Before refitting the brushes, low-pressure, dry compressed air should be directed around the boxes and brushgear housing to remove any remaining carbon deposits.

4.3.3 If brushes are found to be contaminated by oil or grease they should be renewed. If this is not done, lubricant will be exuded when the brushes become warm during subsequent operation of the generator, thus affecting the combined efficiency of brushes and commutator.

NOTE: Serviceable brushes should be subjected to the minimum amount of handling, and be labelled to identify their positions when removed from their boxes.

4.3.4 The pressure exerted by brush springs should be checked to ensure that it is within specified permissible limits. The check is carried out by using a suitably calibrated spring balance in the manner prescribed in the relevant Maintenance Manual.

NOTE: The pressures are the same for each of the brushes employed in a generator.

4.3.5 An essential prerequisite to good commutation of d.c. generators is the correct positioning of brushes around the commutator. For this reason, the rocker containing the brush boxes is adjustable within a limited number of degrees of arc. Adjustments are pre-set and, during inspection, a check should be made to ensure that the rocker is secure in the position determined for the specific type of generator. The position is normally indicated by the alignment of datum marks painted or engraved on the rocker and commutator end frame. For details of the method of obtaining the requisite positions of brushgear, reference should always be made to the relevant generator Overhaul Manual.

4.3.6 When new brushes are fitted, they should be bedded down in accordance with the procedures specified in Overhaul Manuals to suit the contour of a commutator, thus obtaining the necessary surface finish over a maximum arc of contact. In general, the procedure is carried out in two stages; preliminary bedding and final bedding run.

(a) At the preliminary stage, the brushes are approximately shaped to the required contours by an interposed thin abrasive strip affixed around the commutator. After checking that brush spring pressures are within the limits specified, the armature should be turned by hand in the normal direction of rotation until the approximate contours are obtained. The brushes should then be withdrawn from their boxes and the abrasive strip removed. After removing traces of carbon deposits with clean, dry compressed air, the brushes should be refitted to make direct contact with the commutator in preparation for final bedding.

(b) For final bedding of brushes, a generator is usually run as a motor, ensuring correct direction of rotation, until every brush is evenly bedded over its entire contact area. It is then driven at a specified rev/min and loaded progressively from zero to full load current at the rated voltage, avoiding severe sparking. With properly bedded brushes the commutation should be such that only light pin point sparking is evident at full rated load.

NOTE: In the initial stages of a bedding run, care should be taken to avoid the application of heavy currents which might cause damage to armatures or brushes because of the high current density through the small areas of contact surface available. Prolonged running on light load should also be avoided since this practice causes glazing of brush and commutator surfaces to the detriment of subsequent operation.

4.4 **Electrical Tests.** All generators should be subjected to certain functional tests prior to their installation, at periods specified in Maintenance Schedules, and at any time their operation is suspect. The nature of the tests and permissible limitations varies with each type of generator and aircraft installation; reference should, therefore, always be made to the relevant Maintenance and Overhaul Manuals.

5 STORAGE AND TRANSIT Generators should be stored, preferably in their original packing, in conditions which are clean, dry, of even temperature, well ventilated and free from corrosive fumes. Limiting periods of storage are quoted in manufacturer's Maintenance and Overhaul Manuals and, provided recommended storage and packing conditions are met, generators will not require attention throughout these periods. At the end of the storage periods, or whenever there is evidence of deterioration of the packing, generators should be inspected and tested in accordance with the instructions contained in the relevant Overhaul Manuals. Protection covers are provided for attachment to drive end frames and air inlet spouts and these should be fitted to generators prior to packing and transit.

EEL/1-5

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# AIRCRAFT

## ELECTRICAL EQUIPMENT

### POWER SUPPLY—A.C. GENERATORS

1 INTRODUCTION This Leaflet briefly outlines the construction and operating fundamentals of alternating current generators, and also gives guidance on their installation and maintenance. As relevant details can vary between different types of generators, and on the electrical power supply requirements of a particular type of aircraft, the information is of a general nature only, and is based on typical generators in common use. The Leaflet should, therefore, be read in conjunction with the Maintenance Manuals and other approved documents for the particular generators concerned, and for the type of aircraft in which they are installed.

1.1 Reference should also be made to the following Leaflets which contain information associated with electrical power generation.

**EEL/1-1** Batteries—Lead-acid

**EEL/1-2** Carbon-Pile Voltage Regulators—D.C. Generator Systems

**EEL/1-3** Batteries—Nickel-Cadmium

**EEL/1-6** Bonding and Circuit Testing

**EEL/1-8*** Power Production Systems

**EEL/1-9*** Circuit Protection Devices

**EEL/3-1** Cables—Installation and Maintenance

NOTE: The previous Leaflet **EEL/1-5** was entitled "Batteries (Nickel-Cadmium, Sintered-Plate)"; all relevant information is now incorporated in Leaflet **EEL/1-3.**

2 GENERATOR TYPES Alternating current generators are generally of two types; those designed for operation over a wide variable speed and variable frequency range (frequency-wild generators), and those designed for constant speed and constant frequency operation (constant-speed generators).

2.1 **Frequency-wild Generators.** These fall into two categories; those used on small aircraft to provide a direct current voltage output, and those used to provide an alternating current voltage output to supply systems that do not require a fixed frequency supply. Figure 1 illustrates a generator the output of which is rectified to provide direct current. Generators of this type are utilised in a variety of small aircraft requiring direct current as the primary power source. The principal components of the generator are the rotor, the stator, and a rectifier assembly. The rotor comprises two extruded steel pole pieces pressed on to a shaft against each end of a field coil. Each pole piece has six 'fingers', so shaped that when the pole pieces are in position, the 'fingers' mesh with, but do not touch, each other. Two slip rings are pressed onto one end of the rotor

*Leaflets **EEL/1-8** and **EEL/1-9** will be published in May, 1979.

shaft and are electrically connected to the rotor field coil. The rotor is rotated by a driving belt and pulley driven by the engine, or by coupling the generator directly to the engine gearbox drive shaft. The stator comprises three star-connected coils wound around a laminated core; one end of each coil is connected to the rectifier assembly while the other ends are joined together to form the 'star' or neutral point. The rectifier assembly is located opposite to the drive-end of the generator, and consists of six silicon diodes connected to form a full-wave bridge rectifier circuit. Three of the diodes (negative) are mounted on the end frame, while the other three (positive diodes) are mounted on a 'heat sink' plate on the inside of the end frame. Spring-loaded brushes are located inside the end frame and make contact with the rotor slip rings to complete the field or excitation coil circuit.

2.1.1 These small generators do not usually incorporate permanent magnets and are not self excited. They therefore require a supply of direct current from an independent source for the initial excitation of the rotor field windings. In the type illustrated in Figure 1, this is provided from the busbar of the electrical system of the aircraft when the battery, or an external power supply, is connected to that busbar. The current passing through the field coil circuit causes the 'fingers' of the rotor pole pieces to become alternately north and south electro-magnetic poles. As it rotates, the magnetic field set up in the rotor poles induces a three-phase alternating voltage in the stator windings at a frequency dependent on rotor speed. The output is supplied to the rectifier assembly, and the direct current thus obtained is then supplied to the electrical system busbar, thereby maintaining excitation of the field coil. The rectified output is also fed to a voltage regulator which is pre-set to regulate the generator voltage, within the limits specified for the generator and aircraft electrical system.

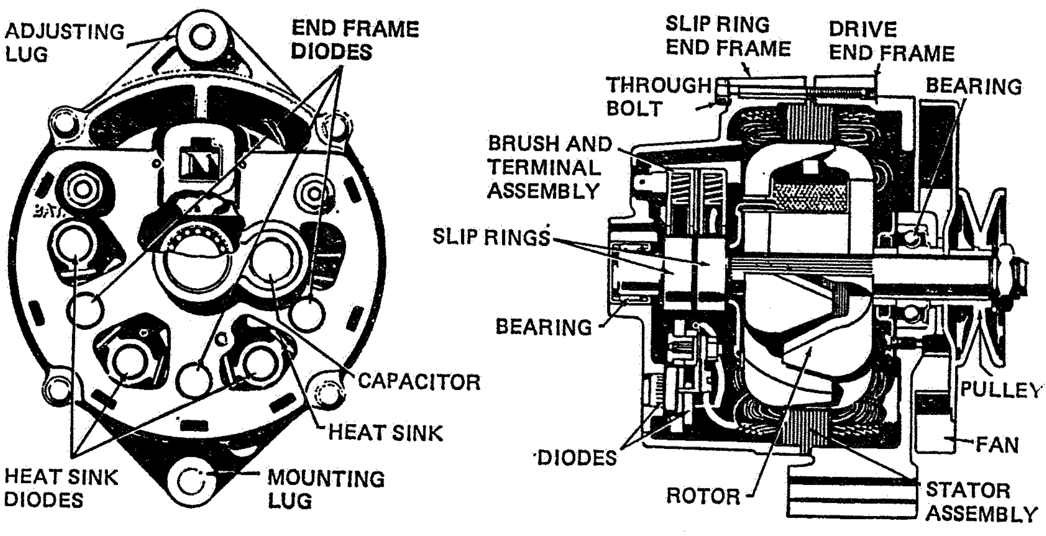



*Figure* 1 TYPICAL SMALL BRUSHLESS D.C. GENERATOR

2.1.2 Figure 2 illustrates a typical three-phase, frequency-wild generator, which is used in some aircraft for the supply of alternating current to electrical systems that do not require a fixed frequency supply, such as resistive load circuits for de-icing and anti-icing systems. This generator has a power output of 15 kVA at 208 volts, and its frequency and driven speed ranges are 335 to 535 Hz and 6700 to 10 700 rpm, respectively. The generator consists of two major assemblies; a rotor assembly and a fixed stator assembly. The rotor assembly has six poles, each of which is wound with a field coil; the coils terminate at two slip rings secured at one end of the rotor shaft. Three spring-loaded brushes are equi-spaced on each slip ring, and are contained within a brushgear housing. The brushes are electrically connected to direct current input terminals housed in an excitation terminal box mounted on the outside of the brushgear housing. The terminal box also houses capacitors connected between the terminals and earth, to suppress interference which may affect, for example, the reception of radio signals. The rotor shaft is splined at the drive end, and supported in a roller bearing fitted in the main housing. An oil seal is provided to prevent the entry of oil from the driving source into the main housing. The stator windings are star-connected, and an end frame clamps the whole assembly in the main housing, which has an integral flange for mounting the generator at the corresponding drive shaft outlet of the engine accessory gearbox. The ends of the stator windings are brought out to a three-way output terminal box mounted on the end frame. The generator is cooled by ram air passing into the main housing via an inlet spout; the air escapes from the main housing through ventilation slots at the drive end, from where it is usually ducted overboard.

(a) Direct current for the initial excitation of the rotor field windings is provided from the main busbar via a 'start' switch in the circuit to the excitation terminals and brushgear. As the generator rotates, a three-phase alternating voltage is induced in the stator windings which is supplied to the busbar distribution. The output voltage is controlled by feeding it to a voltage regulator, and to a three-phase bridge rectifier, which together with other protection circuits, are contained within a separate control unit. At a pre-determined output voltage, the generator is able to run as a self-excited machine, and could operate independently of the direct current supply from the main busbar.

2.2 **Constant-speed Generators.** These generators are utilized in those types of aircraft requiring (i) a much wider application of alternating current, (ii) a considerable amount of electrical power, and (iii) generator system load-sharing capability. Generators designed for such applications are currently of the brushless type, and are driven by an engine through the medium of a special constant-speed drive unit. In most applications, the generators may be removed and installed separately and with the drive unit 'in-situ', but for certain types of aircraft, the generators are integrated with the drive unit so that removal and installation as a complete assembly is necessary. Examples of both types are illustrated in Figures 3 and 4, respectively. The constant-speed drive is basically a differential gear transmission system which converts variable input speed of an engine to a constant output speed appropriate to the generator rating. The output speed of the generator is controlled by a hydromechanical governor system. The construction of generators varies, but, in general, they consist of three principal components; a pilot exciter, a main exciter and rotating rectifier, and a main generator. All three components are contained within a casing made up of an end bell section and a stator housing section. A mounting flange, which is an integral part of the stator housing section, provides for attachment of the generator to the constant-speed drive unit by means of either studs and retaining nuts, or a quick attach/detach type of coupling.

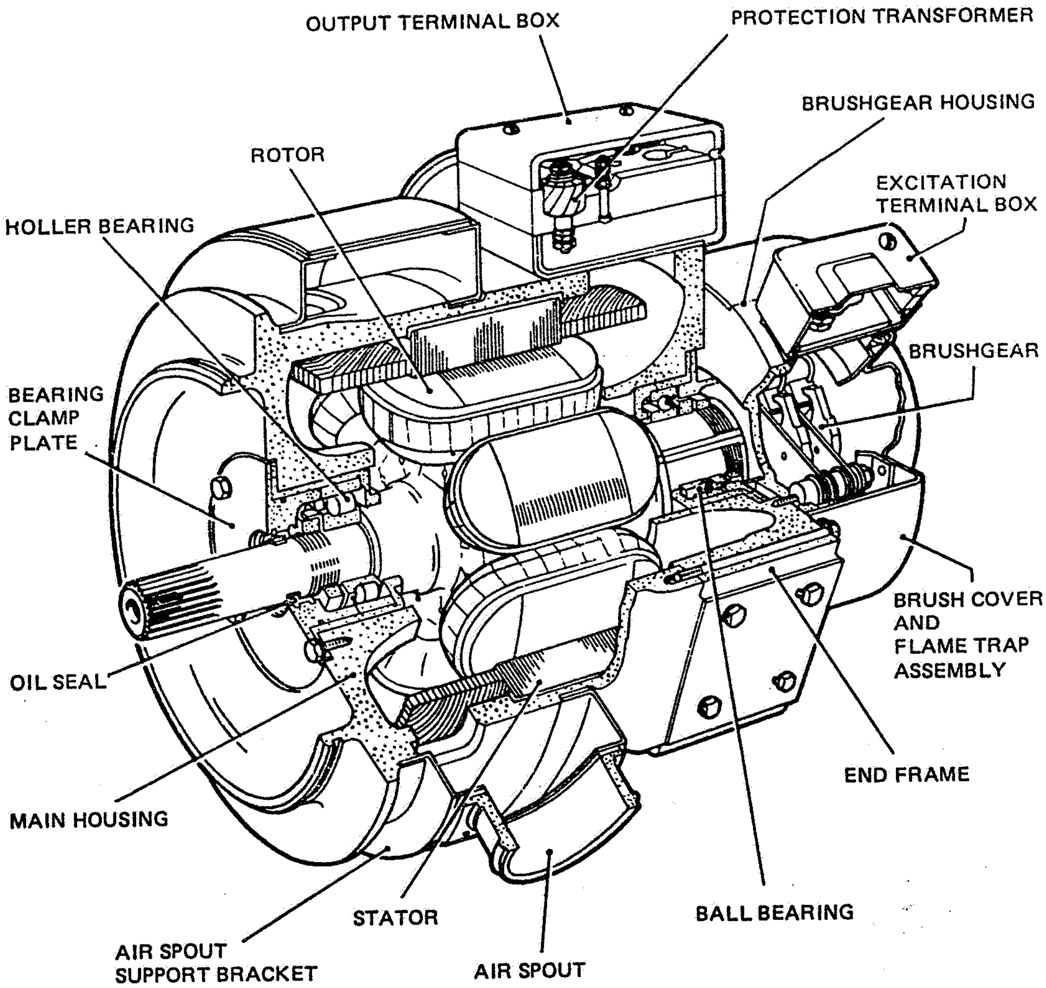



*Figure* 2 TYPICAL LARGER FREQUENCY-WILD GENERATOR

2.2.1 The purpose of the pilot exciter is to provide the magnetic field necessary for initial excitation of the main exciter. It comprises a stator, and a permanent magnet rotor which is mounted on the same shaft as the main exciter and main generator rotor. The a.c. output from the pilot exciter is fed to the main exciter field via a control and protection unit.

2.2.2 The rotating rectifier assembly supplies excitation current to the main generator rotor field coils from the main exciter rotor, and eliminates the need for brushes and slip rings. It usually consists of six silicon diodes connected as a three-phase, full-wave bridge rectifier circuit, sometimes contained within a tubular insulator located in the hollow shaft on which both the exciter rotor and main generator rotor are mounted, but can be mounted in any convenient position on the rotor, provided the radius from the centre line is not excessive.

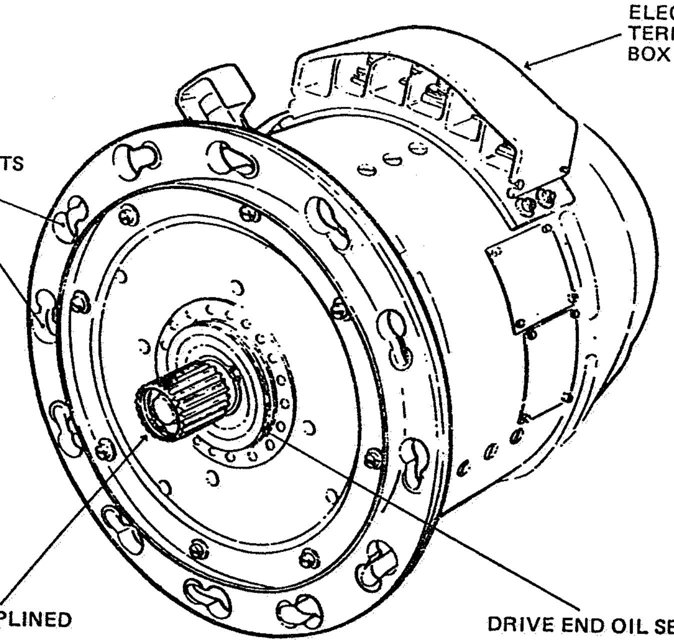



*Figure* 3 TYPICAL CONSTANT-SPEED GENERATOR

2.2.3 The main generator consists of a three-phase, star-wound stator, a rotor and associated field windings, which are connected to the rotating rectifier assembly. The leads from the three stator phases are connected to a terminal block, which permits connection of the generator to the aircraft power distribution system.

2.2.4 When a generator starts operating, an initial flow of current is provided to the field of the main exciter via the control and protection unit, and a three-phase voltage is produced in the exciter rotor. This voltage is then supplied to the rotating rectifier assembly, the direct current output of which is, in turn, fed to the field coils of the main generator rotor as the required excitation current. A rotating magnetic field is thus produced which induces a three-phase voltage output of 200 volts, at a frequency of 400 Hz, in the main stator windings. The output voltage is sensed at the busbar by the voltage regulator, which controls the amount of excitation current required by the main generator section to maintain the desired a.c. output.

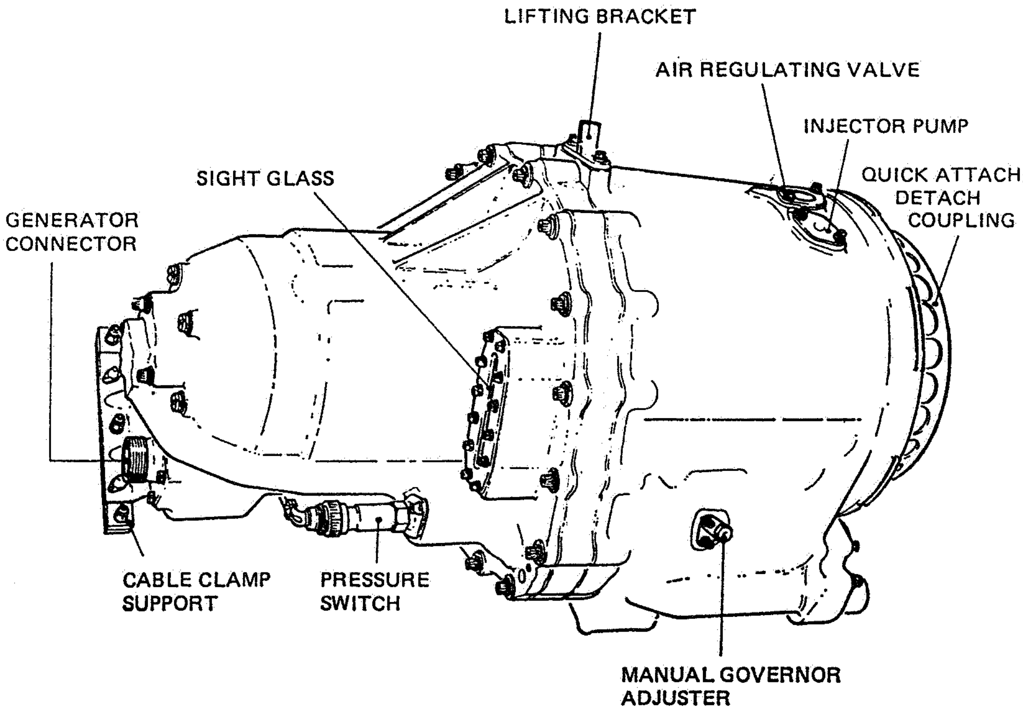



*Figure* 4 TYPICAL INTEGRATED DRIVE GENERATOR

2.2.5 Generator cooling is normally provided by ram air which enters through the end bell section of the casing, and passes through the windings, the rotor shaft, and the rectifier assembly. The air is exhausted through a perforated screen around the periphery of the casing, at a point adjacent to the main generator stator, then usually ducted overboard. In the case of integrated drive generators, cooling of the windings and rectifier assembly is provided by oil which is also used for the speed governing hydraulic system. The oil is supplied from a reservoir which is integral with the casing of the integrated drive generator, and is circulated by a charge pump driven by the output shaft of the hydraulic transmission system. The oil is passed through an oil cooler mounted on the engine, and, depending on the installation, the cooling medium for the oil may either be air tapped from a low-pressure stage of the compressor or fuel from the fuel system of the aircraft.

## 3 MAINTENANCE PRACTICES

3.1 **General.** Maintenance practices to be adopted for generators will depend upon their type and on the type of aircraft in which they are installed. Reference must, therefore, be made to the relevant aircraft Maintenance Manuals for the specific details. The information on adjustment of belt tension for belt-driven generators is given in Leaflet **EEL/1-4.** The information given in the following paragraphs is to serve only as a general guide.

### 3.2 Removal

3.2.1 As a generator may be too heavy to lift with safety or without injury, approved handling methods must be used. Care should be taken to avoid damaging other equipment located in and around the area, such as fire detection elements which are highly susceptible to damage. The remaining checks and precautions can be summarised as follows:—

(a) Carry out electrical safety procedures as indicated in the Maintenance Manual.

(b) Where necessary, electrical connections should be identified when disconnected. Refit terminal covers and fit blanks if required.

(c) In the case of integrated drive generators, drain the cooling oil from the unit (see paragraph 3.5.4). Disconnect cooling system oil lines and blank off to avoid contamination.

(d) For other than integrated drive generators, disconnect the cooling ducts and blank off.

(e) Install a component hoist, if it is required, and adjust so that the weight of the generator is just being supported and correctly balanced by the hoist, then release the generator attachment fasteners.

(f) Carefully remove the generator from its housing/mounting, taking care not to damage the drive coupling and adjacent items of equipment or engine structure.

(g) Following the removal of the generator, check drive belts or drive coupling splines for wear against the wear limits in the aircraft maintenance manual.

NOTE: Damage can result if the generator is allowed to hang on splined drive couplings.

### 3.3 Pre-installation Checks

3.3.1 Before installing any generator a check should be made to ensure that it is the correct unit for the particular installation.

3.3.2 Housings, terminals and electrical connections should be checked for cleanliness and freedom from corrosion, distortion, cracks or other damage.

3.3.3 The rotational movement of generator rotors should be checked for freedom by manually rotating them at the driving end.

3.3.4 Rotor shaft splines should be checked for signs of damage and wear. A similar check should also be made on the mating splines of the drive shafts of an accessory gearbox or constant-speed drive unit as appropriate. A light coating of lubricant of the type specified in the relevant Maintenance Manual should be applied to rotor shaft splines before installing a generator.

3.3.5 On installations in which belt-driven generators are employed, the security and condition of drive pulleys and belts should be checked.

3.3.6 The mountings appropriate to the type of generator should be checked to ensure that they are clean and free from damage. Where specified, a coating of anti-corrosion compound should also be applied to mounting surfaces.

3.3.7 Where appropriate, new gaskets should be fitted between mounting faces, and new O-rings should also be fitted on generator drive shafts.

3.3.8 Generator cables should be checked for signs of damage to terminations, for fraying, and for chafing of insulation covering. The coincidence of cable ends should also be checked to ensure that cables will not be subjected to strain particularly at points of entry to terminal boxes or other forms of connector.

## 3.4 Installation Procedures

3.4.1 When locating generators of the splined drive shaft type, they should be turned slightly in each direction about the drive axis to facilitate proper engagement of the splines.

3.4.2 After a generator has been correctly orientated on its mounting, it should be secured, paying particular attention to any torque values specified for tightening retaining nuts or quick attach/detach couplings as appropriate to the installation. Before finally tightening the retaining nuts of generators having buttonhole-shaped slots in their mounting flanges (see Figure 3) the generators should be rotated on the mounting studs until the latter are concentric with the slotted sections.

3.4.3 Generators which are to be mounted horizontally should be adequately supported during installation and not be allowed to hang on their drive shafts or on mounting studs. In some aircraft in which constant-speed generators may be removed and installed separately from their drive units, or which are of the integrated drive type, a special hoisting rig is provided and this must be used in the manner specified in the relevant aircraft Maintenance Manual.

3.4.4 Integrated drive generator units are usually provided with an electrically-operated disconnect mechanism which permits isolation of the generator from the engine in the event of malfunction of either the transmission system, the constant-speed drive or the generator. The mechanism is controlled by a switch in the flight compartment, and a solenoid which, on being energised, disengages the constant-speed input drive clutch from the input gear thus preventing rotation of the transmission. The constant-speed drive can normally only be re-engaged by manually operating a reset handle located at the bottom of the integrated drive unit.

NOTE: This should only be done with the engine at rest or damage may result.

3.5 **Cooling Systems.** Whenever servicing is carried out on an integrated drive generator the following information should be carefully observed.

(a) An integrated drive generator which has recently been running may contain hot oil under pressure.

(b) Do not overfill. Overfilling can cause overheating and oil sludging, resulting in transmission damage.

(c) The minimum number of components should be in the line when flushing is carried out. This is to prevent the debris that usually accumulates in the oil cooler from contaminating them: never flush with new components connected into the system.

(d) Specific maintenance procedures for each type of generator and aircraft installation will be found in the relevant Maintenance Manual, to which full attention should be given. The following procedures are therefore to serve only as a general guide.

3.5.1 Before connecting cooling ducts to an air-cooled generator, the ducts should be inspected for cleanliness, signs of damage and for correct orientation. Where a cooling-air duct or scoop is fitted to a removable cowling panel, the duct or scoop should be checked for correct alignment with the air inlet connection of the generator.

3.5.2 As stated in paragraph 2.2.5, the oil supplied to integrated drive generators passes through an oil cooler mounted on the engine. Before installation of a replacement integrated drive generator it is necessary to ensure that the cooler inlet and outlet pipelines are free from any contamination. Flushing should be carried out to ensure that debris from a previous failure will not contaminate the replacement (see paragraph 3.5.3). On completion, the pipelines should be correctly orientated and their connections to the generator unit tightened to the specified torque values, and wire locked. This also applies to vent pipes and drains. On completion of the installation procedure, the oil system must be filled and primed (see paragraph 3.5.5).

3.5.3 **Flushing.** This should be carried out with the minimum number of components in the lines to prevent the debris, that usually accumulates in the oil cooler, from contaminating them. A system should never be flushed with new or replacement components connected into the lines. A preferred method would, therefore, be to remove the system for flushing in the workshop. The general procedure for flushing the aircraft system, when required, should be carried out in accordance with the following steps:—

(a) Fill and prime the system as listed in paragraph 3.5.5 but do not carry out the topping-up section of the procedure.

(b) Drain the system as listed in paragraph 3.5.4.

(c) Fill and prime the system as listed in paragraph 3.5.5.

3.5.4 **Draining**

(a) Place a suitable container beneath the magnetic drain plug.

(b) Vent the integrated drive generator by pressing in the case pressure vent valve, after first allowing the oil to cool.

(c) Clean the area around the magnetic drain plug.

(d) Remove the magnetic drain plug.

(e) Inspect the magnetic drain plug for contamination.

(f) Fit the drain hose in place of the magnetic drain plug; oil will flow through the drain hose. When the oil content has drained into the container, remove the drain hose.

NOTE: This oil should never be used to refill the system.

(g) Ensure that serviceable sealing rings are fitted to the magnetic drain plug, then refit. Place a warning placard on the integrated drive generator stating that it is drained of oil.

3.5.5 **Fill and Prime**

(a) Vent the integrated drive generator case.

(b) Connect the delivery hose of the replenishing gun to the re-oiling coupling.

(c) Carefully fill with oil until the oil reaches the top of the oil level mark on the sight glass.

(d) Close the case pressure vent valve.

(e) Disconnect the re-oiling delivery hose and assemble the quick-release cap to the re-oiling coupling.

(f) Pull the disconnect reset handle to ensure that the integrated drive generator is engaged.

(g) Carry out an engine dry motoring cycle, to ensure that the system is fully primed.

(h) Vent the case and allow the specified time for the oil levels to equalise. Check that the oil level is within the oil level mark on the sight glass. If the oil level is correct, close the case pressure vent valve by pulling it out to its fullest extent.

(j) If the level is not correct, repeat steps (a) to (g) for low level or carry out the drain procedure for high level.

3.6 **Adjustment/Test**

3.6.1 All generators must be subjected to certain functional tests following their installation, at periods specified in Maintenance Schedules, and at any time their operation is suspect. The nature of the tests, permissible limitations and adjustments that may be made varies with each type of generator and aircraft installation; reference must, therefore, always be made to the relevant aircraft Maintenance Manual.

# AIRCRAFT

## ELECTRICAL EQUIPMENT

### BONDING AND CIRCUIT TESTING

1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide guidance and advice on the inspection and testing of bonding and electrical circuits after installation and at the periods specified in the Approved Maintenance Schedule for the aircraft concerned.

1.2 Subject headings are as follows:—



1.3 Related CAIP Leaflets:—

**AL/3-7** Control Systems
**AL/3-9** Fire Detection Equipment
**BL/6-1** Soft Soldering
**EL/3-9** Piston Engines — Magnetos
**EL/5-2** Piston Engine Ignition Cables and Harnesses
**EEL/1-1** Batteries — Lead-Acid
**EEL/1-3** Batteries — Nickel-Cadmium
**EEL/1-7** Fire Detection and Extinguishing Systems — Electrical Tests on Systems
**EEL/3-1** Cables — Installation and Maintenance

2 GENERAL

2.1 As each test normally requires specified equipment, care should be taken that it is correctly used (e.g. good electrical contact should always be made). The methods of testing and inspection will vary with different types of aircraft and the equipment fitted, therefore reference must be made to the appropriate Maintenance Manuals for detailed information.

2.2 To ensure the reliability of test equipment, it should be carefully serviced and certified at the periods recommended by the manufacturer. The performance of equipment should also be checked before and after use.

2.3 After completion of all tests, the installations should be inspected to ensure that all connections have been re-made and secured, and that test equipment, tools, etc., have been removed. This should be carried out immediately prior to the fitting and securing of panels, covers, etc., as appropriate. As far as the installation permits, the circuits should then be proved, by making ground functioning checks of the services concerned. A dated record of all relevant figures obtained during the checks should be retained. Any disconnections or disturbance of circuits associated with flying or engine controls, will require duplicate inspection and functioning tests as outlined in Leaflet **AL/3-7**.

## 3 BONDING

3.1 Bonding is the electrical interconnection of metallic aircraft parts (normally at earth potential) for the safe distribution of electrical charges and currents.

3.2 **Function of Bonding.** Bonding provides a means of protection against charges as a result of the build-up of precipitation, static, and electrostatic induction as a result of lightning strikes so that the safety of the aircraft or its occupants is not endangered. The means provided are such as to (a) minimise damage to the aircraft structure or components, (b) prevent the passage of such electrical currents as would cause dangerous malfunctioning of the aircraft or its equipment, and (c) prevent the occurrence of high potential differences within the aircraft. Bonding also reduces the possibility of electric shock from the electrical supply system, reduces interference with the functioning of essential services (e.g. radio communications and navigational aids) and provides a low resistance electrical return path for electric current in earth-return systems.

3.3 **Primary and Secondary Conductors**

3.3.1 Primary conductors are those required to carry lightning strikes, whilst secondary conductors are provided for other forms of bonding. The current British Civil Airworthiness Requirements (BCAR) for bonding paths are as follows:—

(a) BCAR Section D **D4-6** and Section K **K4-6**;

(i) 'The cross sectional area of Primary Conductors made from copper shall be not less than 0·0045 sq in, i.e. 0·25 in by 26 swg, except that, where a single conductor is likely to carry the whole discharge from an isolated section, the cross sectional area shall be not less than 0·009 sq in, i.e. 0·5 in by 26 swg. Aluminium Primary Conductors shall have a cross sectional area giving an equivalent surge carrying capacity.'

(ii) The cross sectional area of secondary conductors made from copper must not be less than 0·001 sq in which corresponds to 44 strands of 39 swg for braided conductors. Where a single wire is used its size must be not less than 18 swg.

(b) BCAR 23 **ACB 23.867** and JAR-25 **ACJ 25X899 (4.2)**;

(i) 'Where additional conductors are required to provide or supplement the inherent primary bonding paths provided by the structure or equipment, then the cross sectional area of such primary conductors made from copper should not be less than 3 $mm^2$ except that, where a single conductor is likely to carry the whole discharge from an isolated section, the cross sectional area would be not less than 6 $mm^2$. Aluminium primary conductors should have a cross sectional area giving an equivalent surge carrying capacity.'

(ii) Where additional conductors are required to provide or supplement the inherent secondary bonding paths provided by the structure or equipment, the cross sectional area of such secondary conductors made from copper should be not less than 1 $mm^2$. Where a single wire is used its size should be not less than 1·2 mm dia.

**3.4 Bonding of Aircraft of Metallic and Non-Metallic Construction**

3.4.1 The skin of an all-metal aircraft is considered adequate to ensure protection against lightning discharge provided that the method of construction is such that it produces satisfactory electrical contact at the joints.

NOTE: An electrical contact with a resistance less than 0·05 ohm is considered satisfactory.

3.4.2 With regard to aircraft of non-metallic or composite construction, a cage, consisting of metallic conductors having a surge carrying capacity at least equal to that required for primary conductors and to which metal parts are bonded, forms part of the configuration of the structure and must conform to the requirements of BCAR.

3.4.3 The earth system, which in the case of aircraft of metallic construction is normally the aircraft structure and for aircraft of non-metallic construction is the complete bonding system, must be automatically connected to the ground on landing. This is normally achieved through the nose or tail wheel tyre, which is impregnated with an electrically conducting compound, to provide a low resistance path.

NOTE: On some aircraft, a static discharge wick or similar device trailed from a landing gear assembly is used to provide ground contact on landing.

3.4.4 The reduction or removal of electrostatic charges which build up on such surfaces as glass fibre reinforced plastic, can be achieved by the application of a paint, e.g. PR 934, which produces a conductive surface.

**3.5 Bonding Connections**

3.5.1 When a bonding connection is to be made or renewed, it is essential that the conductor has the specified current-carrying capacity, since the bond may have been designed to carry relatively high electrical loads, e.g. under circuit fault conditions.

3.5.2 The manufacturers of solid bonding strip and braided bonding cord usually quote the cross-sectional area on the relevant data sheet. However, in the case of renewal or repair, if the original conductor cannot be matched exactly, a replacement manufactured of the same type of material, but of greater cross-sectional area, should be selected.

3.5.3 Braided copper or aluminium cords fitted at each end with connecting tags or lugs (usually referred to as 'bonding jumpers'), should be used for bonding connections between moving parts or parts subjected to vibration, and these are suitable both as primary and secondary conductors.

3.5.4 The tags or lugs on bonding jumpers are generally fitted by the 'crimping method', see Leaflet **EEL/3-1** and only the correct form of crimp and crimping tools should be used for the particular connection. During assembly of the connections to aluminium cords, anti-oxidant (crimping) compound consisting of 50% by weight of zinc oxide in white petroleum jelly, and complying with DTD 5503, should be applied to the connections.

3.5.5 Where applicable, the soldering of tags or lugs fitted to braided copper cord should be in accordance with Leaflet **BL/6-1**, using a resin flux. Special care is necessary because overheating and cooling of conductors will cause brittleness, whilst a loss of flexibility up to 25·4 mm (1 inch) from the lug may occur as a result of the capillary action of the molten solder.

NOTE: Primary flexible conductors are often made of 600 strands of copper wire, 0·0048 inch in diameter, and formed in a flat braid approximately 0·625 inch wide.

3.5.6 All bonding connections should be properly locked to prevent intermittent contact which may be caused by vibration.

NOTE: Intermittent contact is worse than no contact at all.

3.5.7 Bonding connections should not interfere mechanically or electrically with any associated or adjacent equipment, and bonding jumpers should not be excessively tight or slack.

3.5.8 The run of all primary conductors should be as straight as possible; sharp bends must be avoided.

3.5.9 The number and location of bonding connections to the various components is important and this should be checked and verified by reference to the relevant drawing, e.g. where an engine is not in direct electrical contact with its mounting it should be bonded with at least two primary conductors, one on each side of the engine.

3.5.10 In most instances the following joints are considered self-bonding, provided that all insulating materials (e.g. anodic finish, paint, storage compounds, etc.), are removed from the contact faces before assembly, but if any doubt exists regarding the correctness of the bonds, a bonding test should be carried out:—

(a) Metal-to-metal joints held together by threaded devices, riveted joints, structural wires under appreciable tension and bolted or clamped fittings.

(b) Most cowling fasteners, locking and latching mechanisms.

(c) Metal-to-metal hinges for doors and panels and metal-to-metal bearings (including ball bearings).

(i) In the case of bearings for control surface hinges it should be ascertained which bearings are classified as self bonding, e.g. metal-to-metal, nylon with conducting grease.

(ii) Where applicable, bonding jumpers for control surfaces should be as flexible and as short as possible, of as low impedance as is practicable and should not be tinned. The possibility of a jumper jamming the controls must be avoided.

3.6 **Flexible Bonding Connections**

3.6.1 Flexible hose connections used for joining rigid pipes should be bonded by fitting clips around the pipes approximately 13 mm (½ inch) away from the hose, and bridging with a corrugated bonding strip or jumper; the practice of tucking the ends of bonding strips between the hose and the pipe is not recommended. To obtain good electrical contact the area under each clip should be cleaned and, after the clip has been fitted, protection should be restored.

3.6.2 Not only must the flexible hose connection be bridged, but each pipe run should be bonded to earth at each end, particularly within a radius of 2·42 metres (8 feet) of any unscreened radio equipment or aerial lead, where earthing bonds should not be more than 1·5 metres (5 feet apart), or less distance apart, if called for by the manufacturer.

3.6.3 If bridging strips or bonding cords are fractured a new conductor should be fitted. The soldering of broken ends is prohibited.

3.6.4 High-pressure flexible pipe assemblies are usually self-bonding, but a bonding test should be made between the assembly end-couplings to prove the integrity of the bonding.

NOTE: The provisions of paragraph (3.6.2) above also apply to any long electrically-conducting parts (including metallic conduits and metal braiding) which are not insulated from earth.

3.6.5 When any bonding or earth connection is made to the structure or equipment, the specified standard of protection against corrosion should be provided.

3.6.6 After a non-conducting protective coating has been removed from the connecting area, the preferred sealing and anti-oxidant treatment as specified on the relevant drawing and specification should be carried out.

NOTE: Non-conducting protective treatments include all generally used priming and finishing paints, varnishes and temporary protectives, chromic, anodic and phosphate coatings. Metallic coatings, such as cadmium and tin, are satisfactory conductors and should not be removed. If a polysulphide compound is used for sealing the earth or bonding point, it must be ensured that the anti-oxidant to be subsequently applied will not have a detrimental effect on the sealing; e.g. DTD 5503 should not be used.

3.6.7 When the connection has been made any excess compound should be wiped off, using a rag damped in methyl ethyl ketone (MEK), and the connection and adjacent area re-protected by the specified method, this depending on the materials concerned and the position of the connection.

3.6.8 When a 'corrosion washer' forms part of the connecting assembly, it should be correctly fitted and be of the correct material for the type of connection concerned.

NOTE: A corrosion washer is plated, or manufactured of a material having a potential such that when placed between materials of widely differing potentials it reduces the risk of corrosion caused by electrolytic action.

### 3.7 Earth Terminals

3.7.1 When earth-return terminal assemblies are fitted or replaced, the correct method of fitting to the structure, the corrosion protection required and the exact location on the structure should be carefully checked. The procedure for fitting and the number of terminations to be attached will vary with the design of the terminal assembly and the type of structure, therefore reference should be made to the relevant drawings and instructions to ensure both electrical and structural integrity.

3.7.2 All earth terminal assemblies should be checked for resistance between the lug attachment point(s) and the surrounding structure and this must not exceed the figure specified for the aircraft concerned (e.g. 0·025 ohm). When earth terminal assemblies are also used to carry electrical supplies, a millivolt drop test, as outlined in paragraph 4.3 must be carried out.

3.7.3 If the resistance in either case is unsatisfactory, the terminal assembly should be removed, the contacting faces cleaned with a fine abrasive (e.g. aluminium wool), and reassembled using, where applicable, new corrosion washers. The connecting area should be sealed and treated with anti-oxidant compound as specified in the relevant drawing and specification.

NOTE: Leads connected to earth terminal assemblies should be of insulated cable with terminal tags fitted by the crimping method. It is important that the cable is of the specified gauge for the service concerned and is kept as short as possible.

3.8 **Resistance Values.** The CAA's Requirements with regard to the maximum resistance values for the various conditions of bonding are summarised in Table 1.

TABLE 1

| *Bonding Classification* | *Test Condition* | *Maximum Resistance* |
|---|---|---|
| Primary | Between extremities of the fixed portions of aircraft of non-metallic or composite construction. | Estimated and declared by manufacturer. |
| | Between extremities of the fixed portions of metallic aircraft. | 0·05 ohm |
| | Between bonded components and portions of main earth system to which they are connected. | |
| Secondary | Between metallic parts normally in contact with flammable fluids and main earth system, and also between the parts themselves. | 1 ohm (See Note 1) |
| | Between all isolated conducting parts which may be subject to appreciable electrostatic charging and the main earth system. (See Note 2.) | 0·5 megohm or 100 000 ohms per sq ft of surface area whichever is the less |
| | Between equipment supplied from an unearthed system, of any voltage, and the main earth system. | 1 ohm (See Note 1) |
| | Between equipment containing circuits carrying 50 volts (rms or dc) or more, and the main earth system. | |

NOTES: (1) The value of 1 ohm is chosen to allow for the inclusion of the resistance of any cable that may be employed for this bonding case, but no one contact resistance should exceed 0·05 ohm.

(2) The parts concerned are those situated inside and outside an aircraft and having an area greater than 3 sq in and a linear dimension greater than 3 inch.

### 3.9 Bonding Carrying the Main Electrical Supply

3.9.1 The cross-sectional area of the main earth system, or any connection to it, must be such that without over-heating or causing excessive voltage drop, it will carry any electrical currents which may pass through it normally or under fault conditions.

3.9.2 If, under fault conditions, it should form part of a short-circuit, not provided against by a protective device, it should be capable of carrying the full short-circuit current which can pass, without risk of fire or damage to the bonding system.

NOTE: For example, paragraph 3.9.2 may apply to bonding which under fault conditions becomes part of a starter or other heavy current circuit. Particular attention should be given to non-metallic aircraft fitted with a double-pole wiring system to which single-pole equipment has subsequently been added.

### 3.10 Bond Testing

3.10.1 Special test equipment, comprising a meter and two cables each of specific length, is required for checking the resistance of bonding. A meter widely used, consists of an ohmmeter operating on the current ratio principle, and a single 1·2 volt nickel-alkaline cell housed in a wooden carrying case. The associated cables are 60 feet and 6 feet in length, and are fitted with a single-spike probe and a double-spike probe respectively. Plug and socket connectors provide for quick-action connection of the cables to the instrument.

3.10.2 Prior to carrying out a bonding test, a check should be made on the state of the nickel-alkaline cell of the tester by observing;

(a) that a full-scale deflection of the meter is obtained when the two spikes of the 6-foot cable probe are shorted by a suitable conductor; and

(b) that the meter reads zero when the two spikes of the 6-foot probe are shorted by the single spike of the 60-foot probe.

3.10.3 The 60-foot lead of the test equipment should be connected to the main earth (also known as the bond datum point) at the terminal points which are usually shown diagrammatically in the relevant Aircraft Maintenance Manual. Since the length of a standard bonding tester lead is 60 feet, the measurement between the extremities of the larger types of aircraft may have to be done by selecting one or more main earth points successively, in which event the resistance value between the main earth points chosen should be checked before proceeding to check the remote point.

NOTE: When connecting the 60-feet lead to an earthing point, any protective treatment (e.g. strippable lacquer) should be removed at the point of contact.

3.10.4 The 6-foot test lead should be used to check the resistance between selected points; these are usually specified in the bonding test schedule or the Maintenance Manual for the aircraft concerned. When the two spikes of the test lead probe are brought into contact with the aircraft part, the test-meter will indicate, in ohms, the resistance of the bond.

3.10.5 As an alternative to the above, the four terminal method of resistance measurement may be adopted with the appropriate miliohmmeter (see Figure 1). With this type of instrument, a test current (approximately 2 amps) is supplied by the internal batteries and passed through the resistance via cables C1 and C2. The voltage drop across the resistance is measured (P1 and P2) and compared with the current flowing. The resultant value is then displayed (normally digitally) on the meter. The test leads may be in the form of duplex spikes (see Figure 2) or when used in association with crocodile type test leads, single spikes. In order to check that the instrument is functioning correctly, the two hand spikes should be placed on a low resistance conductor with the potential spikes (P1 and P2) closely together (see Figure 3). The result of this test should be a zero reading on the meter.

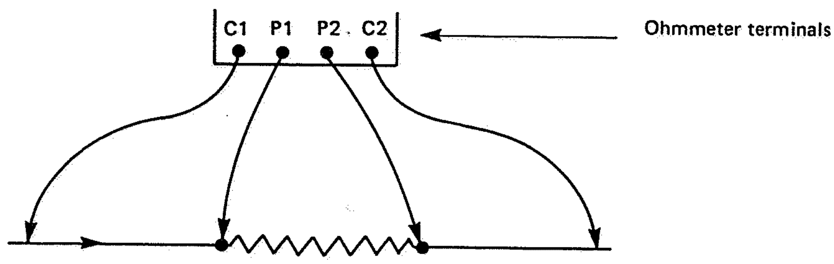



*Figure* 1 FOUR TERMINAL RESISTANCE MEASUREMENT

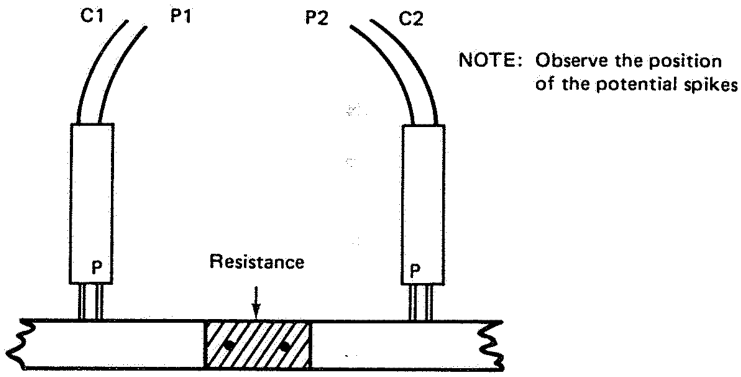



*Figure* 2 DUPLEX HAND SPIKES

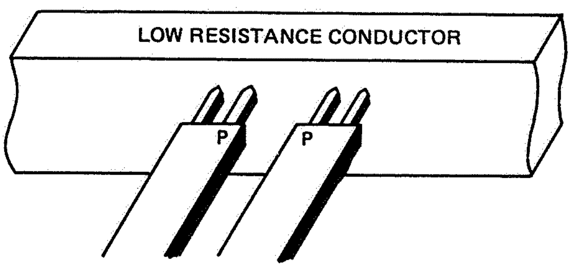



*Figure* 3 TEST POSITION OF HAND SPIKES

3.10.6 To ensure good electrical contact at the probe spikes, it may be necessary to penetrate or remove a small area of a non-conducting protective coating. Therefore, after test, any damage to the protective coating must be restored.

3.10.7 If the resistance at a bond connection is excessive, rectification action will depend on the type of connection. The following action should be taken for the more common types of connections:—

(a) In the case of bonding jumpers, the connecting tag or lug should be removed and the contacting faces thoroughly cleaned, using a slight abrasive if necessary. The bare metal thus exposed should be only just large enough to accept the palm of the tag or lug. The connecting area should be sealed and treated with anti-oxidant as specified in the relevant drawing and specification.

NOTE: When an abrasive has been used it is important to ensure that all traces of it are removed.

(b) Where equipment is bonded through a holding bolt, the bolt should be removed and the area under the bolt-head, or nut, thoroughly cleaned and protected as recommended in paragraph 3.10.7 (a). The correct washer (both with regard to size and material) should be fitted before the bolt is replaced and tightened.

(c) Where the required bond value cannot be obtained at a structural joint the advice of the manufacturer should be sought.

NOTE: Corrosion tends to form at a bonding or earth connection and is often the cause of excessive resistance.

3.10.8 The resistance between the main earth system and a metal plate on which the earthing device (e.g. tyre) is resting should be measured and should not exceed 10 megohms when measured with a 250-volt or 500-volt resistance tester, as specified in the test schedule.

NOTE: After carrying out tests, all areas where the protective coating has been removed should be re-protected using the appropriate scheme.

### 3.11 Bonding Tester Servicing

3.11.1 A tester requires little in the way of servicing, apart from periodic attention to the alkaline cell, which should be removed at prescribed intervals for routine servicing. When replacing the cell, it is most important that the polarity of connection is correct. The ohmmeter is normally sealed in its case and no attempt should be made to open it; if a fault should develop, then the complete instrument should be withdrawn from use and overhauled.

3.11.2 The leads are an integral part of the tester, and being carefully matched to the meter unit must not be modified or altered in any way. All contact surfaces of plug pins and probes must be kept scrupulously clean, and the points of the probe spikes should be reasonably sharp to give effective penetration of protective finishes, etc., on metal surfaces.

3.11.3 The accuracy of the tester should be checked periodically by using it to measure the resistance of standard test resistors. Normally, three such resistors are supplied for testing purposes and the readings obtained should be within 10% of the standard ohmic values.

## 4 INSPECTION AND TESTING OF CIRCUITS

### 4.1 Inspection of Wiring System

4.1.1 Before carrying out tests, or when inspection is specified in the Approved Maintenance Schedule, all aircraft circuits, together with plugs, sockets, terminal blocks and equipment terminals, should be examined, as appropriate, for signs of damage, deterioration, chafing, poor workmanship and security of attachments and connections. It is not intended, for the purpose of this examination, that electrical apparatus should be removed from its mountings or that cables should be unduly disturbed, but if modifications or repairs, for example, have been carried out in the vicinity, looms should be closely inspected for ingress of metallic swarf between cables. Whenever a structure is opened over wiring which is not normally visible through available inspection panels, circuits so exposed should be thoroughly inspected.

4.1.2 The primary purpose of the inspection is to determine the physical state of the wiring system, especially at bends, points of support, duct entries, etc., or where high temperature or contamination could cause local deterioration. Where cables are grouped together, the state of the outer cables is generally indicative of the condition of the remainder.

4.1.3 Cables completely enclosed in ducts obviously cannot be examined along their length, but should be checked for continuity and insulation, especially if oil or water ingress is suspected. Where there is evidence of damage to the ducts, the cables should be exposed to ascertain their condition.

4.1.4 Terminations must be secure and good electrical contact obtained without strain on the threads of terminal pillars or studs. Torque loadings, where appropriate, should be within the limits specified.

**4.2 Continuity Testing**

4.2.1 A concealed break in a cable core or at a connection may be found by using a continuity tester which normally consists of a low voltage battery (2·5 volts is satisfactory) and a test lamp or low reading voltmeter.

NOTE: In some testers incorporating a test lamp, semiconductors are included in the test lamp circuit and, to prevent damage, the currents should be limited to 120 milliamps.

4.2.2 Before testing, the main electrical supply should be switched off or disconnected. A check should be made that all fuses are intact and that the circuit to be tested is not disconnected at any intermediate point. All switches and circuit breakers, as appropriate, should be closed to completed the circuit.

4.2.3 When carrying out a low voltage continuity check, it is essential to work progressively through the circuit, commencing from the relevant fuse or circuit breaker and terminating at the equipment. Large circuits will probably have several parallel paths and these should be progressed systematically, breaking down as little as possible at plug and socket or terminal block connections. In testing of this nature, it is valueless to check several low resistance paths in parallel.

4.3 **Millivolt Drop Test.** Excessive resistance in high-current carrying circuits can be caused by loose terminal connections, poorly swaged lead ends, etc. Faults of this kind are indicated by low terminal voltage at the connections to the service load and by heating at a conductor joint. If such faults are suspected, a millivolt drop test as described below is recommended, but it is also acceptable to check along progressive sections of the system with an accurately calibrated voltmeter:—

(a) For continuously-rated circuits, the test should, whenever possible, be made with the normal operating current flowing, the power being derived from an external source. For short-rated circuits, a suitable resistance or other dummy load should be used in lieu of the normal load and the current should be scaled down to avoid overheating.

NOTE: The test voltage may be reduced for safety reasons.

(b) The millivolt-meter should be connected to each side of the suspected joint and a note made of the volt drop indicated. The indicated reading should be compared with the figures quoted in the relevant publication (an approximate guide is 5 mV/10 amps flowing).

**4.4 Insulation Resistance Testing**

4.4.1 In the following paragraphs general test procedures are outlined; however, as a result of the wide variation in electrical installation and equipment which exists with different aircraft, the routing charts and Approved Test Schedule for the aircraft concerned must be consulted. All ancillary equipment should be tested separately in accordance with the appropriate manufacturers' publications.

4.4.2 After installation and where specified in the Approved Maintenance Schedule or Test Schedule, aircraft circuits should be tested by means of a 250-volt insulation tester which should have its output controlled so that the testing voltage cannot exceed 300 volts. In all systems having nominal voltages over 30 volts, cables forming circuits essential to the safety of the aircraft should be tested individually. Other circuits may be connected in groups for test. However, the numbers of circuits which may be grouped for test is governed by the test results; where the insulation resistance so measured is found to be less than the appropriate minimum value stated in paragraph 4.5.4, the number of circuits grouped together should be reduced.

NOTE: Information on the testing of magneto earthing circuits is given in Leaflet EL/3-9.

4.4.3 Immediately after an insulation test, functioning checks should be made on all the services subjected to the test. If the insulation test or subsequent functioning tests should reveal a fault, the fault should be rectified and the insulation and functioning tests should be repeated in that sequence on the affected circuits.

4.4.4 **Preparations Prior to Test.** Before beginning an insulation test on a system, the following preparations should be made, details of which will depend on the installation concerned:—

(a) The aircraft battery and any external supply should be disconnected.

(b) Where applicable, circuit breakers should be closed.

(c) The power selector switch should be switched to the position appropriate to that required for normal in-flight operation.

(d) All switches in the circuit concerned should be 'ON', dimmer-switches should be set at the minimum resistance position and micro-switches operated to the 'ON' position.

(e) All items of ancillary equipment which are supplied by the system concerned should be disconnected. This includes all rotary equipment (e.g. generators, motors, actuator units, etc.), radio equipment, capacitors, semiconductors, voltage regulator coils, electrical instruments, fire extinguishers, etc.

(f) In cases where the insulation resistance with the items connected is not less than 2 megohms, the disconnection may be made by the earth lead, leaving the item connected to the circuit.

NOTE: Bonded earth connections to the airframe structure should, if possible, remain undisturbed for the purpose of these tests.

(g) Components such as cut-outs and relays which are normally open should have their terminals bridged to ensure continuity of the circuit, and disconnected leads from suppressors should also be bridged for similar reasons. Where a suppressor cannot be bridged, and plug and socket connections are used, the capacitors should be discharged before the circuit is re-connected, otherwise arcing and burning of the pins may occur. Items in series which are disconnected should also be bridged so that part of the circuit is not omitted.

## 4.5 Testing the System

4.5.1 Double-pole systems on some older types of aircraft can be tested by connecting the leads of the insulation tester to each of the battery leads and measuring the resistance between them and, afterwards, checking the resistance between each battery lead and earth; fuses should be left in position for this test. On some large aircraft with double-pole systems, cables may be grouped as for single-pole systems, the earthing checks being made between bunched positive and earth and bunched negative and earth.

4.5.2 To test single-pole systems, one lead of the tester should be connected to earth and the other to the cable or bunch of cables to be tested. When cables are bunched together, it is advisable to limit the number to the smallest convenient figure. If the insulation resistance is less than the appropriate value quoted in paragraph 4.5.4, the number of circuits should be reduced. Testing should continue until, by process of elimination, any defective cables have been identified.

4.5.3 **Test Results.** The results of insulation tests are of little significance unless they are related to test results obtained on other occasions. The insulation resistance values are likely to vary with changes in the temperature and humidity of the local atmosphere, e.g. if the aircraft has been in damp conditions for some time before the test, low readings can be expected. Results of tests and the temperature and humidity conditions at the time of the test should be recorded, so that any pronounced drop in resistance found on subsequent tests can be checked and rectified as necessary.

4.5.4 Section J of British Civil Airworthiness Requirements does not specify minimum values of insulation resistance, but gives guidance on values that may be expected during maintenance testing. These values can be, and frequently are, exceeded considerably on new installations. The values given are as follows:—

(a) Wiring (including accessories for jointing and terminating):—

In engine nacelles, undercarriage wheel wells and other situations exposed to weather or extremes of temperature .. 2 megohms

Galley and other non-essential services, lighting, signalling and indication services .. .. .. .. .. .. .. .. .. 5 megohms

Other services .. .. .. .. .. .. .. .. .. 10 megohms

NOTE: The above values relate to single circuits or small groups of circuits.

(b) Wiring accessories alone (e.g. terminal blocks, connectors, plugs and sockets, etc.):—

Between terminals .. .. .. .. .. .. .. .. 100 megohms

Between terminals bunched together and earth $\frac{200}{\text{number of terminals}}$ megohms

(c) Rotating machinery whichever is the greater of $\frac{\text{rated voltage}}{150}$ or 0·5 megohms

(d) All other equipment (including indicating instruments) .. .. 5 megohms

## 4.6 Functioning Tests

4.6.1 Before conducting any tests, all precautions for aircraft and personnel safety should be taken. Whenever possible, functioning tests should be carried out using an external supply coupled to the ground supply connector. Tests must ensure proper functioning of individual and integrated sections of circuits, and should be in accordance with schedules established by reference to details in the relevant Maintenance Manual, Wiring Diagram Manual or, where appropriate, instructions relating to the incorporation of a modification or any substantial rewiring.

NOTE: Where applicable, when one or more engines are running, the power supply can be obtained from the associated generators, due reference being made to the functioning of any isolating relays.

4.6.2 For certain circuits (e.g. standby lighting), functioning tests can only be carried out using the aircraft battery system, but this battery should be used as little as possible.

4.6.3 After the normal functioning test of an individual circuit has been completed and the circuit switched off, the fuse should be removed or the circuit breaker tripped and the circuit again switched on to check the isolation of the circuit concerned.

4.6.4 When the operation of a circuit (e.g. generator equaliser circuit) depends on the inherent resistance value of the circuit, the resistance should be measured with a low reading ohm-meter (such as that used in a bonding tester) to determine that the resistance is within the specified limits.

EEL/1-7

*Issue 2*

*September, 1988*

# ELECTRICAL EQUIPMENT

## FIRE DETECTION AND EXTINGUISHING SYSTEMS

## ELECTRICAL TESTS ON SYSTEMS

### 1 INTRODUCTION

1.1 The purpose of this Leaflet is to provide guidance and advice on the electrical tests applicable to the circuits and components of fire, overheat and smoke detection systems and also of fire extinguishing systems. It should be read in conjunction with the Maintenance Manuals for both the equipment and the aircraft in which it is installed, Wiring Diagram Manuals, approved drawings, test schedules and Approved Maintenance Schedules.

1.2 Subject headings are as follows:—



1.3 Related CAIP Leaflets:—

| | |
|---|---|
| **AL/3-8** | Fire — General Precautions |
| **AL/3-9** | Fire Detection Equipment |
| **AL/3-10** | Fire Extinguishing Equipment |
| **EEL/1-6** | Bonding and Circuit Testing |

1.4 The conditions under which detection and extinguishing systems should be fitted to aircraft are prescribed in British Civil Airworthiness Requirements.

### 2 DETECTION SYSTEMS

2.1 Detection systems are designed to give indications of fire, smoke or hydraulic mist at various locations in an aircraft by the illumination of warning lamps and, in the event of fire, by audible warning devices. Engine and auxiliary power unit (APU) compartments, where there is likelihood of fire, are protected by fire detection and extinguishing systems, while other areas, such as equipment bays, cargo and baggage compartments, are fitted with smoke detection systems but not necessarily extinguishing systems. On some turbine powered aircraft, detection systems are also used to indicate potentially dangerous overheat situations in critical parts of the structure, e.g. landing gear wheel bays and structure adjacent to hot air ducting supplying air for cabin pressurisation and de-icing systems. Test facilities, for completely testing the continuity and operation of the circuit, are generally provided in detection systems. Alternatively, some circuits may be fitted with warning lamps which incorporate a press-to-test facility.

## 2.2 Types of Detectors

2.2.1 For fire warning and overheat warning purposes, the detectors in use are of, 'unit', 'continuous' or, 'sensor/responder' type. Detectors may be used separately, or together in a combined fire warning and engine overheat system. For detecting the presence of smoke and hydraulic mist, special detectors are used particularly in compartments which are not accessible in flight.

2.2.2 **Unit Type Detectors.** These detectors are normally situated at points most likely to be affected by fire, e.g. an engine breather outlet or hot air ducting. The type most commonly employed is a switch, the contacts of which are actuated by the differential expansion of dissimilar metals.

2.2.3 **Continuous Type Detectors.** These detectors are designed to provide maximum coverage in the particular fire zone and are employed principally for engine and APU installations and, in some instances, are also installed in landing gear wheel bays. A system in most common use, consists of a number of lengths of sensing elements containing a special temperature-sensing material, and a control unit. The elements are joined together to form a continuous loop round the installation, and depending on the type of control unit, variations in either the resistance or the capacitance of the elements with changes in temperature, are detected and used for controlling visual and/or audible warning devices.

2.2.4 **Sensor/Responder Type Detectors.** Sensor/Responder type detectors operate on gas law principles when exposed to temperatures outside of the calibrated range. The detector, which has dual sensing functions, comprises a responder and a pneumatic sensor (see figure 1).

(a) **Responder** — The responder comprises an electrical interface, responder diaphragm, and two switches; the Alarm Switch (normally open), and the Integrity Switch (normally closed), both of which 'respond' to gas pressure changes.

(b) **Pneumatic Sensor** — The pneumatic sensor is a hermetically sealed corrosion resistant steel tube filled with an inert 'averaging' gas (normally Helium), and, a central core element made of a metal hydride which is enclosed in an inert metallic material with absorption and discharge properties.

(c) **Operation** — In the case of a general overheat (approx 177° C), the averaging gas will expand, and, via the responder diaphragm, close the Alarm Switch. However, under the circumstances of a direct fire, any impinging flame on the detector causes the core element to gas (normally Hydrogen). This gassing will increase line pressure within the detector and close the alarm switch. Both of the above functions are reversible. That is to say, as the sensor cools, the averaging gas pressure is lowered, and where appropriate, the gas from the core material returns to the core element.

(d) **Integrity Monitoring** — The Integrity Switch is kept closed by gas pressure. Should a leak develop, the contacts will open and signal a lack of detector integrity. A test selector switch is also normally incorporated to monitor the integrity of the contacts and associated circuitry.

2.2.5 **Smoke Detectors.** These units vary in construction and the application of any one version depends largely on the type of aircraft and its particular operating configuration, i.e. passenger with separate baggage and cargo compartments, or all-cargo, all require electrical power for their operation, and normally operate on photo-electric, visual or ionisation principles.

(a) **Photo-electric** — Air from the appropriate compartment is arranged to flow through a detecting chamber containing a projector lamp. In the event that smoke is present, it causes a change in the amount of light transmitted from the lamp. In some commonly used detectors the changing light transmission is detected by a photo-electric cell, the output of which varies to energise a warning light system. In addition to the detecting cell, certain detectors also employ a balancing cell against which the detecting cell output is continually compared. Both cells are connected in a bridge circuit coupled to the warning light system.

(b) **Visual** — For those types known as visual smoke indicators, any smoke present within the detecting chamber is illuminated by the projector lamp and is visible through an observation window. When clear air is present in the chamber the observation window appears dark and, in order to check that the lamp is illuminated, a small tell-tale window is provided adjacent to the observation window and directly in front of the lamp.

(c) **Ionisation** — This type of detector analyses the chemical properties of the air being monitored and reacts to combustion gases whether visible or not. When the air/combustion gases enter the detector, they modify the balance between the two ionisation chambers. Ionisation of the monitored air, is effected by a small particle of radioactive material which bombards the oxygen and nitrogen molecules in the ionisation chamber. This action permits a small current flow except where there is smoke which reduces current flow. A field effect transistor then evaluates this change and transmits a warning.

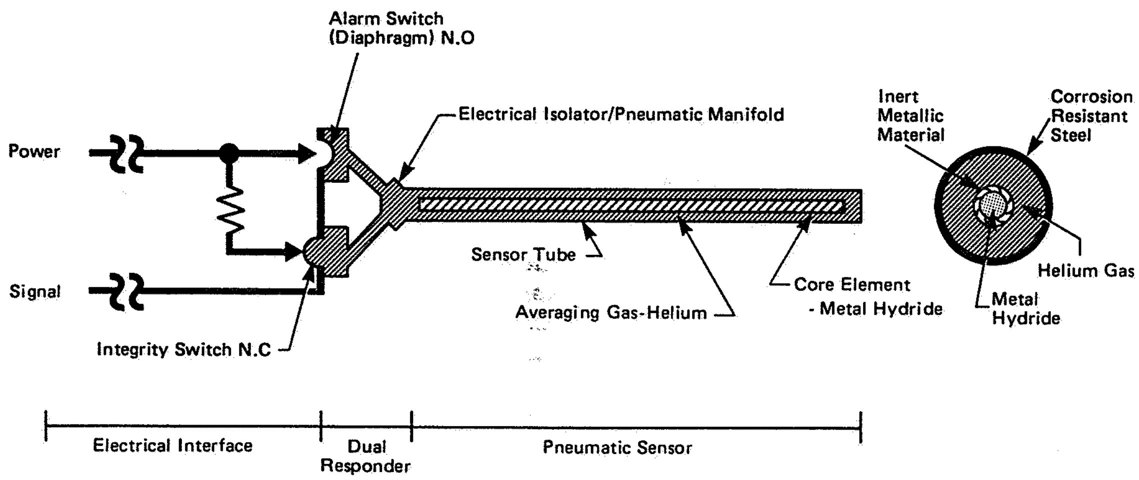



*Figure 1* SENSOR/RESPONDER TYPE DETECTOR (SCHEMATIC)

## 2.3 Tests

2.3.1 **General.** The procedures for performing electrical tests on fire detection systems and components, and the amount of test equipment required, vary between installations and reference should be made to the relevant Maintenance Manual, Wiring Diagram Manual and test schedule for appropriate details. The details given in the following paragraphs are intended to serve only as a general guide to the tests which are normally concerned with the checking of insulation resistance, circuit resistance and overall system functioning.

### 2.3.2 Test Precautions

(a) Fire detection equipment is located in areas where maintenance operations are comparatively frequent, e.g. engine nacelles and wheel bays, and it is, therefore, susceptible to damage from actions unconcerned with the testing of the fire detection system. When work is being carried out in these areas extreme care is therefore necessary to prevent damage or contamination of the system, since a spurious fire warning or failure to detect an actual fire could result.

(b) Before using high voltage equipment for testing circuits in any area where explosive vapours or gases from fuel, cleaning or sealing compounds, cements and similar materials may be present, it must be ensured that the area concerned is completely cleared of such vapours by forced air circulation.

(c) It should be ensured that personnel working on, or in the vicinity of, an aircraft during the testing of fire detection systems, are fully aware of such tests and do not misinterpret the indications of associated warning lights and operation of a fire warning bell. Warning placards should also be placed in the Flight Crew compartment, and the associated work areas.

### 2.3.3 Insulation Resistance Tests

(a) **Unit Type Detectors.** The method of testing differential expansion type detectors is straightforward, consisting only of resistance measurement between each terminal and the outer casing, by means of a 250 volts insulation resistance tester.

(b) **Continuous Type Detector.** Before carrying out tests on continuous type detector systems, the appropriate circuit breakers should be tripped, and the ends of the complete loop must be disconnected from the system junction boxes or bulkhead fittings. If possible, this should be done by disconnecting cables at terminals rather than disconnecting the element connectors, thus avoiding disturbance of torque loaded unions and sealing washers. The tester should be of the 250 volt type, and open-ended test leads should be used to avoid damaging the centre electrodes of elements and the sockets of interconnectors.

(i) Resistance should be measured between the centre electrode and element sheath and the reading obtained should not be less than that specified (a typical value is 1 megohm). If this minimum resistance is not achieved, systematic checks should be made at intermediate elements and inter-connectors to isolate the cause; this could be metallic chips, dirt or moisture in the connections or a fractured element into which water has penetrated.

(ii) The resistance between the centre electrode and sheath of single elements disconnected at both ends, and between the socket and body of each individual connector should also be measured to ensure that it is not less than the specified value (a typical minimum value is 20 megohms).

NOTE: An insulation resistance test should not be performed on any single element whose temperature at the time of test exceeds that of prevailing ambient conditions, and under no circumstances should be prolonged.

(iii) On satisfactory completion of the foregoing tests, sensing elements and cables should be re-connected, circuit breakers reset and a functioning test of the complete detection system carried out. (See paragraph 2.3.5(b).)

2.3.4 **Circuit Resistance Tests.** The resistance of the centre electrode of the complete sensing element loop should be measured by means of a safety ohmmeter or universal type test meter connected at the system junction boxes or bulkhead fittings. A similar check should be carried out on individual sensing elements prior to installation. The readings obtained in both cases should be within the ranges specified in the relevant aircraft Maintenance Manual. On completion of resistance tests a functioning test of the complete detection system should be carried out. (See paragraph 2.3.5(b).)

2.3.5 **Functioning Tests.** Functioning tests must be carried out at the check periods specified in Approved Maintenance Schedules, when a system malfunction has occurred or a major component (e.g. a control unit or a sensing element) has been replaced. The method of testing depends mainly on the fire detection system equipment specified for the particular type of aircraft. Reference should therefore be made to relevant manuals and test schedules for precise details of testing, specific test equipment required and also for any precautions to be observed. There are, however, aspects of testing which are of a standard nature and these are given in the following paragraphs for general guidance.

(a) **Unit Type Detectors.** Differential expansion switch type detectors and their associated circuits, may be checked for functioning by heating the switch with a shroud type of heater element clamped round the outer casing of the switch. Under no circumstances should a naked flame be used. The detectors will re-set automatically when the source of heat is removed. In some types of aircraft employing a large number of detectors, test switches are provided to check the continuity of the wiring between the detector and associated warning lights. Whenever it becomes necessary to change a detector, it is important that the replacement has the correct temperature setting, since warning temperatures vary between locations.

(b) **Continuous Type Detectors.** The operation of continuous type detection systems is checked by the use of 'in-situ' test circuits arranged to simulate fire conditions. Each circuit is controlled by an independent switch normally located on the fire-warning and extinguishing control panel.

(i) With all relevant circuit breakers closed and electrical power switched on, a check should be made that fire warning lights illuminate and the alarm bell rings as each test circuit switch is placed in the 'TEST' position. At the same time, checks should be made to ensure that the alarm bell ceases to ring when the isolation or cut-out switch is operated.

(ii) In some types of aircraft, one test switch only is provided and is common to all detection systems. In such cases, it must, therefore, be checked that when the switch is closed (a position normally placarded 'FIRE'), all fire-warning lights illuminate simultaneously with ringing of the alarm bell. Independent checks on each system should be done by opening and closing the relevant circuit breakers.

(iii) At the periods specified in the Approved Maintenance Schedule, it is also necessary to disconnect the aircraft wiring from the control units of continuous type detector systems and to substitute a test circuit in order to check that the resistance levels at which the units will operate and reset their associated warning circuits, are within the limits permissible for the type of unit and system. The test equipment required and the test procedures may vary slightly between systems, and detailed information should always be obtained from relevant manuals. In general, a test circuit consists of an accurately calibrated potentiometer connected to the control unit in lieu of the sensing element loop, a test lamp connected to represent the system warning lamp, and a test switch. With power applied to the circuit, the potentiometer resistance should be adjusted and measured at the points at which the test lamp is illuminated and extinguished, i.e. simulating the operating and resetting resistances respectively of a complete sensing element loop. If the resistance values obtained are outside the permissible limits or the test lamp fails to respond in the manner described, a control unit must be withdrawn from service. On satisfactory completion of the tests, the aircraft wiring should be reconnected to the control unit, checking that the coincidence and identification of the terminal end is in accordance with the relevant wiring diagram. A functioning test of the complete detection system should also be carried out.

(iv) In addition to the fire warning lights and test circuits, certain detector systems also use a short-circuit warning light system which can discriminate between a sensing element loop resistance drop caused by short-circuits or by rise in temperature. This system must, therefore, also be tested and a common single-pole, double-throw switch is provided for the testing of each warning circuit. When the switch is placed at the 'DISCRIMINATOR' position, the detector system control unit responds to a rapid drop in sensing element loop resistance, and it should be checked that the appropriate warning lights illuminate, thereby indicating the simulated short-circuit condition. Illumination of the warning lights should also be checked by disconnecting each sensing element loop at a convenient point and shorting the centre electrode to ground.

NOTE: At no time during these tests should both the fire warning and short-circuit indicating lights be on simultaneously.

(c) **Sensor/Responder Type Detectors.** The testing of Sensor/Responder type fire/overheat detection systems is normally limited to checking the Sensor and, the integrity of the associated circuits.

(i) **Sensor Test** — Testing the Sensor section of the detector requires specialised equipment which, for the purpose of activating the alarm circuit, simulates a fire/overheat condition. This is accomplished with a resistive type heater which encases and heats up a small section of the sensor element, a test procedure which must be carried out in accordance with the manufacturers instructions.

(ii) **Responder Test** — For most modern aircraft, the integrity of responder circuitry, is checked by the self test facility, whereby each detection sensor loop is constantly monitored by an electronic logic circuit board or control card. Further test facility is provided for in the flight crew compartment in the form of a fire/overheat test panel. This panel allows the flight crew to check the fire/overheat sensor systems on the engines, auxiliary power unit (APU), and smoke detection systems.

(d) **Smoke Detectors.** The method of testing smoke detectors varies because of the differences between types of unit and the procedures detailed in relevant manuals and test schedules must, therefore, be strictly observed. The checks described in the following paragraphs, although based on the requirements for some currently used detector units, are intended to serve only as a general guide.

(i) Test switches are provided in detector units and when operated it should be checked that the appropriate smoke indicator lights, and fire indicator lights where fitted, are illuminated thereby simulating a smoke condition.

(ii) Where appropriate to the type of detector, the established signalling voltage should be checked against the value which is inscribed on the unit. In addition to this, a second value is also inscribed to denote the percentage observation density of smoke to give a one volt increase in calibrated voltage. A voltmeter test socket is provided for the purpose and the readings obtained determine the smoke sensitivity of the unit. For example, the inscription '8·6/15' indicates the calibrated voltage and percentage obscuration density respectively, and if a reading of 8 volts is obtained during a check, then the sensitivity is equal to 15 (8·6 — 8) = 15 x 0·6 = 9% obscuration. If, therefore, this detector is subsequently subjected to smoke of a density which obscures its light beam by 9%, the associated warning system will be operated. A typical sensitivity limit for a new detector is between 8% and 14% while for used detectors a limit between 8% and 30% smoke obscuration is acceptable.

(iii) The **photo-electric** cells of twin-cell detector units must be checked to ensure that the current output balances at the required operating levels and a 'zero' switch, shutter adjusting screw and sensitive relay pointer are normally provided for this purpose. The 'zero' switch cuts out a resistor in the projection lamp circuit so that the voltage is raised for testing purposes to make the lumen output of the lamp comparable to that produced with engines running. When the switch is raised and held 'on' it should be checked that the sensitive relay pointer indicates zero. If necessary, the pointer should be set to zero by means of the shutter adjusting screw. If, during this check, excessive adjustment is required, i.e. more than two turns of the screw per micro-amp, a defective balancing cell or detecting cell is indicated and the smoke detector unit should be changed.

(iv) Functional testing of **visual** smoke indicators is straightforward and, in general, is confined to checking that with electrical power applied to the unit, serviceability of the projector lamp is indicated by illumination of the tell-tale window. At periods specified in the Approved Maintenance Schedule a leak test and a smoke test should be carried out, in the manner appropriate to the type of indicator, to check that air flow through the detecting chamber is not obstructed.

(v) The test procedures for **ionisation** type smoke detectors, are normally confined to self test, or circuit integrity checks carried out by on-board computers. However, for those smoke detectors located in cargo compartments or ventilation ducts, test procedures may require removal of the detector or in-situ tests. For those smoke detectors installed in toilet compartments, testing will normally include verification of the visual and aural warnings.

## 3 EXTINGUISHING SYSTEMS

3.1 These systems are provided for power plants, APUs, and in some types of aircraft, for landing gear wheel bays, baggage compartments and combustion heater installations. A system generally consists of a number of metal containers or bottles, containing an extinguishant e.g. methylbromide, bromotrifluoromethane or bromochlorodifluoromethane (B.C.F.) which is pressurised with an inert gas and sealed by means of a discharge or operating head. When operated, either by selector switches in the cockpit or crash switches, an electrically fired cartridge ruptures a metal diaphragm within the discharge head and the extinguishant is released to flow through spray pipes, spray rings or discharge nozzles into the appropriate fire zone. Electrical power is 28 volts d.c. and is supplied from an essential services busbar.

3.2 Two extinguishing methods are used for power plants. In the first method, which is employed in the majority of older types of aircraft, an individual system is provided for each power plant. The second method, known generally as the 'two-shot system', is the one most widely used and comprises connections between the individual power plant systems, so permitting two separate discharges of extinguishant into any one power plant.

3.3 In several types of aircraft, indication that a fire extinguishing circuit has been operated, is provided either by, warning lights or, indicating fuses connected in the circuit. The fuses contain a small charge and are enclosed within a domed cover which is normally transparent. When current flows in the relevant extinguishing circuit the charge is fired, and this causes a red powder to be spattered on the inside of the domed cover, thus furnishing a clear and lasting indication of the operation of an extinguisher.

3.4 In some installations special switches are incorporated to automatically operate the extinguishers in the event of a crash. These switches also connect cabin emergency lights to the aircraft battery power supply. Two types of crash switch are in common use: the inertia control type and the frangible type. An inertia controlled switch generally consists of a heavy piston supported on its own spring and so arranged that at the required degree of deceleration (a typical value is 3g), it compresses the spring and causes a bow spring to snap over thereby bridging contacts connected in the extinguishing system circuit. To allow resetting of the switch after operation or rough handling during transit, a reset plunger is incorporated.

3.5 Frangible switches consist of two electrical contacts mounted in a hermetically sealed glass envelope. The contacts are prevented from closing by a spring, but in the event of the glass envelope being shattered, the contacts will close and complete the circuit to the extinguishing system. The switches are located in positions such as the wing tips, the underside of engine nacelles, at various points on the underside of the fuselage, etc., so that in the event of a crash, at least one of the switches will be shattered.

### 3.6 Tests

3.6.1 The testing of fire extinguishing control circuits must be carried out at the check periods specified in Approved Maintenance Schedules, or when a system malfunction has occurred or a major component has been replaced. As in the case of fire detection systems, the procedures for testing the circuits can vary, particularly in installations which are interconnected with other circuits. For example, in one type of aircraft, the operation of a control switch in addition to arming the relevant engine fire extinguishers, automatically closes the fuel shut-off valve, trips the generator field circuit and shuts off the supply of fluid from the engine-driven hydraulic pump. Therefore, in carrying out the test procedures appropriate to the extinguisher discharge circuits, it must also be established that the other circuits function correctly. Test procedures are detailed in the manuals and test schedules for the relevant aircraft type, reference should therefore be made to these documents and also to the associated wiring diagrams. The testing of extinguisher discharge circuits, however, follows the same broad pattern, their purpose being to check the continuity between control switches and cartridge unit connections. The details given in the following paragraphs are based on some typical systems and are intended to serve only as a general guide.

3.6.2 **Discharge Circuit Functioning Tests.** Before commencing the tests, the system circuit breakers should be tripped and the cables disconnected from the cartridge units at the extinguisher discharge heads.

(a) A 28 volt indicator test lamps should be connected to the cable plugs and, where appropriate, lamps should also be connected to the holders of indicating fuses after having first removed the fuses.

(b) Circuit breakers should then be reset and with electrical power applied, the lamps should not light.

(c) Each system control switch or fire control handle, as appropriate, should be operated in turn noting that the relevant lamps are illuminated to simulate 'firing' of the extinguishers.

(d) The operation of systems incorporating crash switches should also be similarly checked to ensure continuity between the switches, extinguisher cartridge units and cabin emergency lights. Before switching on the electrical power, it is necessary to bridge the terminals of certain types of inertia controlled switches and for all frangible type switches, by means of shorting links. With electrical power applied it should be noted that the test lamps at the extinguisher cable plugs and the emergency lights are illuminated.

(e) In some types of inertia controlled switches, a plunger is provided at the top of the casing, and may be turned to either a 'SET' position, its normal functional position, or a 'TRIP' position. In order to test the switch circuit for continuity, the plunger must be turned to the 'TRIP' position and then pressed down firmly. This releases the inertia unit, thereby simulating a rapid deceleration condition, and with electrical power applied it should be noted that all relevant lamps are illuminated. A switch should be reset by turning the plunger to the 'SET' position, depressing a lever at the side of the switch casing to its full extent, and whilst the lever is held, depressing the plunger. The side lever should then be released before releasing the plunger. When the switch is set the side lever must be level with the top of its guard.

3.6.3 **Cartridge Unit Tests.** The tests on cartridge units are normally concerned with the checking of insulation resistance and the continuity and resistance of the fuse element within the cartridge. Before commencing the tests, the date of manufacture stamped on the unit body should be checked to ensure the cartridge life has not exceeded that specified in the appropriate Maintenance Manual. The units should be removed from extinguisher discharge heads for testing and as an additional safeguard they should be mounted on a fixture in such a way that the charge end is shielded, but unrestricted, in case of accidental firing.

NOTES: (1) Cartridge units contain gunpowder and should therefore be handled with extreme care at all times. They should be kept dry and if a unit is not to be refitted immediately following the tests it should be stored in a polythene bag.

(2) Where a power supply cable is connected to a cartridge unit through a Breeze type plug and socket, it must be disconnected or mated only after slackening off its outlet gland nut. If this is not done, or if the necessary internal movement is otherwise prevented, e.g. by corrosion, the two wires of the cable become severely twisted together inside the socket and may be broken or short-circuited.

3.6.4 **Insulation Resistance.** The resistance should be measured to ensure that it is not less than the value specified for the cartridge unit (a typical minimum value is 20 megohms). The check should be carried out, firstly, by shorting together the appropriate pair of connector pins, and then connecting a 250 volt insulation resistance tester between the shorted pins and cartridge unit body.

3.6.5 **Continuity and Resistance.** The continuity and resistance of a fuse element should be checked by connecting a safety ohmmeter across both pins of the connector. The reading obtained should be between the limits specified for the cartridge unit (the limits for a typical unit are between 5 and 6 ohms and between 7 and 11 ohms).

NOTE: Care must be taken to ensure that the correct type of safety ohmmeter is used for the tests and that its current output does not exceed the level required to detonate the charge.

3.6.6 **Tests on Indicating Fuses.** The testing of indicating fuses is normally concerned with checking their continuity and resistance, and should be carried out at the regular intervals specified in the Approved Maintenance Schedule; every three months is generally recommended. Before commencing such tests, a fuse should be removed from its holder and a check made on the date recorded on the side of its body, to ensure that the specified life of the fuse (normally three years) has not been exceeded. A fuse should be properly located within its holder for testing and the resistance should be measured by means of a safety ohmmeter connected to the fuse holder. The reading obtained should be between the limits specified in the relevant manual (the limits for typical fuses are between 10 and 16 ohms and between 31 and 39 ohms).

NOTE: As in the case of extinguisher cartridge units, fuses contain an explosive charge and, although not having as great an effect, they should always be handled with extreme care. It is also necessary to ensure that the correct type of safety ohmmeter is used for the test, and that its current output does not exceed the level required to detonate the fuse. The maximum test current for a typical fuse is 13 mA.

3.6.7 **Final Inspection.** At the conclusion of the functioning tests on the discharge circuits of extinguishers and associated circuits, the electrical power source should be disconnected and a careful inspection of complete systems should be carried out to verify that:—

(a) All test lamps have been removed.

(b) Plugs, sockets and cables disconnected for test purposes have been reconnected to their respective items of equipment and locked as necessary, in accordance with the approved wiring diagram. In order to prevent cross connection of the cartridge units, particular attention should be paid to the cables connecting the discharge heads of extinguishers mounted in adjacent positions. The cables are normally of different lengths.

(c) Damage has not been caused to cartridge unit cables fitted with Breeze type sockets as a result of removal and replacement. (See NOTE (2) paragraph 3.6.3.)

(d) Switches have been reset and locked where applicable.

(e) System components disturbed for the tests have been returned to their previous condition and locked as necessary.

(f) All relevant fuses and circuit breakers have, as appropriate, been replaced and reset.

(g) Shorting links have been removed from frangible type crash switches and that inertia controlled switches are in their 'SET' positions.

**EEL/1-9**

*Issue* 1.

*January*, 1981.

# AIRCRAFT

## ELECTRICAL EQUIPMENT

## CIRCUIT PROTECTION DEVICES

1 INTRODUCTION This Leaflet gives information of a general nature on the types of circuit protection devices used in typical aircraft installations. There are wide variations in the application of these devices, and no attempt is made in this Leaflet to describe any particular aircraft installation. It is important, therefore, that this Leaflet should be read in conjunction with the relevant aircraft constructors' and equipment manufacturers' manuals.

1.1 The following Leaflets contain information associated with the subject covered by this Leaflet and reference should be made to these as appropriate:

**EEL/1-2** Voltage Regulation

**EEL/1-4** D.C. Generators

**EEL/1-5** Power Supply—A.C. Generators

**EEL/1-6** Bonding and Circuit Testing

**EEL/1-8*** Power Supply Systems

**EEL/3-1** Cables—Installation and Maintenance

1.2 For those not familiar with the basic principles of circuit protection devices, brief details of construction and operating principles are given in the introductory paragraphs associated with each group of devices.

2 GENERAL Fault conditions such as a short circuit or an overload will cause excessive current to flow in that circuit which, if left unchecked, would produce sufficient heat to cause considerable damage to the cables. Damage would not necessarily be confined to a single circuit as the heat generated by the first failure could also burn the covering and insulation of adjacent cables causing further short circuits. It is essential, therefore, that a means of protection is integrated into electrical circuits. Devices normally used for this purpose are fuses, current limiters, limiting resistors and circuit breakers. Other fault conditions such as reverse current flow, over and under voltage and frequency, and phase imbalance are protected against by the incorporation of other devices and circuit arrangements within the generator control units of the main power supply system.

3 SHORT CIRCUIT AND OVERLOAD

3.1 **Fuses.** A fuse is made up of a fusible element or link manufactured from such materials as tin, lead, alloys of tin and bismuth, silver, or copper, and having a predetermined low melting point. Construction and current ratings are varied in order to provide a suitable selection of protection for specific electiical installations and individual circuit requirements.

* Leaflet EEL/1-8 will be published in a later batch of Leaflets.

3.1.1 **Light Duty Fuses.** Light duty fuses normally have the fusible element encased in a protective glass or ceramic tube, which also localises any flash which may occur when the element is ruptured. Metal end caps are fitted to enable the element to be connected to the circuit. The fuse is normally held in its holder by means of a screw or bayonet cap which may have a small hole drilled through the centre to allow the insertion of a fuse tester probe. The assembly is secured to the fuse panel by a clamp nut and circuit connections are made via terminals located on the fuse holder.

3.1.2 **Heavy Duty Fuses.** Heavy duty fuses, used normally for such circuits as main electrical distribution, consist of a ceramic tube in which a number of identical fusible elements are connected in parallel to end contacts. The tube is filled with a packing medium of granular quartz, magnesite (magnesium oxide), kieselguhr or chalk (calcium carbonate) to damp down the explosive effect of the resulting arc when rupturing takes place. The pack tube is sealed at each end with metal end caps, formed into mounting lugs, and fireclay cement. When an excessive current is flowing each element will be heated close to its melting point until one element fails, and being connected in parallel, will transfer its share of the load to the remaining elements causing further failures in quick succession.

3.2 **Current Limiters.** Current limiters are used mainly for the protection of heavy duty power distribution circuits and consist of a high melting point single strip of tinned copper shaped at each end to form mounting lugs. The central portion of the strip is, in some cases, "waisted" to form the fusible area, and is encased in a ceramic housing which also has a window, of glass or mica, set in one side to allow for a visual inspection of the device. The time/current characteristic of the device will allow a considerable overload current in the circuit before rupturing occurs.

3.3 **Limiting Resistors.** Limiting resistors provide another form of circuit protection for circuits which normally have high initial starting current, e.g. engine starter motor, invertor circuits and circuits containing high capacitive loads. In order, therefore, to keep the initial current surges within a reasonable limit the starting section of the appropriate circuit incorporates a limiting resistor which is shorted out when the current has fallen to a safe level. Figure 1 shows a limiting resistor in a typical turbine engine starter circuit utilising a time switch for the control of the limiting resistor.

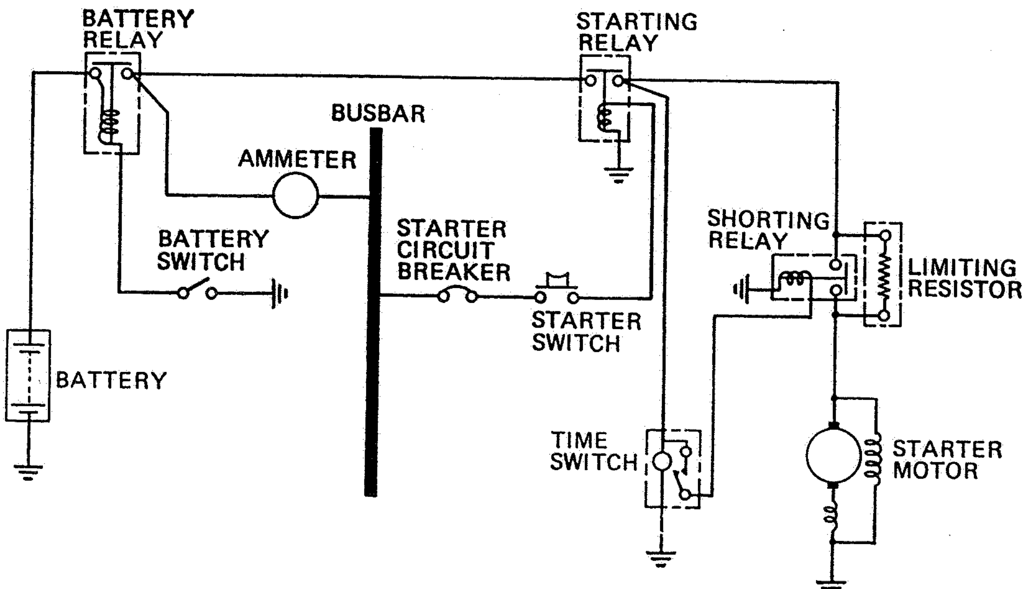



*Figure* 1 APPLICATION OF A LIMITING RESISTOR

3.3.1 The limiting resistor is connected in parallel to the contacts of a shorting relay which is controlled by the operation of a time switch. When the starter push switch is operated, current will flow from the busbar to energise the main starting relay and close its contacts, which in turn causes the time switch to operate, and supplies current through to the starter motor via the limiting resistor so reducing the peak current and the initial torque of the starter motor. After a pre-determined period of time, which allows for a build up of the speed at which the engine shaft is being rotated, the torque load of the starter motor reduces and the time switch causes a set of contacts to close to energise the shorting relay. With the relay energised the current from the busbar passes direct to the starter motor. When engine ignition takes place and the engine reaches 'self sustaining speed', the power supply to the starter motor circuit is then switched off.

3.4 **Circuit Breakers.** The range of circuit breakers designed for use in aircraft is extensive, and a full description of each specific type is outside the scope of this Leaflet; therefore, the following information is only of a general nature and limited to typical examples of the principal classes: Manually operated thermal trip, electromagnetically operated thermal trip, and reverse current trip circuit breakers. For precise details of any particular type fitted to an aircraft, reference should be made to the Maintenance Manual or Wiring Diagram Manual for the relevant aircraft or to the manufacturers' Technical Publication.

3.4.1 **Manually Operated Circuit Breakers.** Manually operated circuit breakers are of the trip free type to ensure that the circuit breaker cannot be maintained closed, or held against a fault current when any part of a circuit is carrying overload current. The circuit breaker is tripped by the operation of a thermal overload device if an overload current should flow in all, or any part of, the circuit. Compensation is normally provided to reduce variation in tripping time with change in ambient temperature. The contacts remain open after tripping on overload, and the operating button or lever is automatically returned to the fully open position.

(a) Manual operation of a circuit breaker is usually by means of a single push-pull button, or lever, by pushing the button to close the contacts and pulling the button to open. The portion of the button visible when the breaker is closed is normally black, while a white band on the button is exposed when the breaker is open. The current rating is marked in white in the centre of the end of the button. The mechanism is so constructed that it provides a positive snap action make and break of the contacts, so reducing the risk of the contacts becoming burnt. Circuit breakers are normally constructed in such a manner that the calibration cannot be interfered with without dismantling the device or breaking a seal.

(b) Three pole circuit breakers are so constructed that the three sets of contacts open and close together when operated manually and open on overload current in one or more lines. The difference in time between the making or breaking of the three sets of contacts should not normally exceed 5·0 ms.

(c) Any form of thermal trip mechanism requires a certain period of time to operate under overload conditions, the length of the 'waiting time' depending on the severity of the overload, hence a circuit that is protected by a simple thermal trip unit may possibly suffer damage if a really severe overload should occur. Protection against sudden severe overloads is given in other types of manually operated circuit breakers by a magnetic trip which operates almost instantaneously when the current through the main contact assembly exceeds the normal (continuous maximum) rated current by several times. Normal protection against sustained, but less severe, overloads of more than the rated current is given by the usual thermal trip mechanism. The theoretical circuit and principle of latching control in this form of circuit breaker is illustrated in Figure 2.

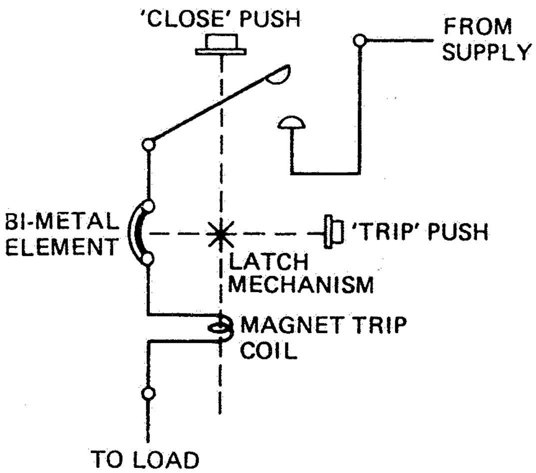



*Figure* 2 PRINCIPLE OF A THERMAL/MAGNETIC CIRCUIT BREAKER

(d) The magnetic trip element is simply an electromagnet and an attracted armature which, when attracted to the pole faces of the electromagnet, operates the contact assembly trip latch. The magnet coil is connected in series with the thermal element and the main contacts, and the spring loading of the armature is such that the armature cannot be attracted until the current through the coil (and also through the contacts) exceeds the danger level already quoted.

3.4.2 **Electrically-Operated Circuit Breakers.** The theoretical circuit of a typical circuit breaker used to link a d.c. generator to the busbar of an installation is shown in Figure 3. This type of circuit breaker consists of a stationary electromagnet, a pivoted soft iron armature which is attracted to the pole faces of the electromagnet when the winding is adequately energised, a pivoted contact bridge carrier which is latched to the pivoted armature, a contact bridge which incorporates a bimetal plate and is permanently secured to the carrier, and two groups of fixed contacts which are bridged by the contact bridge when the armature, if latched to the contact carrier, is held against the pole faces of the electromagnet. The circuit breaker is normally biased to the open condition by the action of an accelerating spring (attached to the thermal element) and two throw-off springs (located in recesses in the pole pieces). With the thermal element at ambient temperature, the latch of the carrier is engaged with a roller on the armature, hence when the circuit breaker is open with the magnet system de-energised both auxiliary switches are closed. The sequence of operation for closing action by remote control, tripping by overload, and resetting after tripping on overload are given in the following paragraphs.

(a) **Closing Action.** On applying a positive supply to terminal 7, with terminal 4 already connected to the supply return, current flows through the low resistance 'closing' coils only and immediately attracts the hinged armature to the pole faces, compressing the two throw-off springs. Since armature and contact-bridge carrier are effectively linked by the latching device, the armature takes the carrier with it and thus extends the accelerating spring. Just before the armature reaches the limit of its travel, contact is made between the two sets of stationary contacts by the contact bridge, completing the main circuit to the controlled unit. Further movement of the armature towards the pole faces increases the loading on the main contacts, and the ultimate stage in armature travel causes both auxiliary switches to open. At the same time the indicator lamp contacts, which are operated by a plunger attached to the contact bridge carrier, open to interrupt the indicating circuit to signify that the main contacts of the circuit breaker are, in fact, effectively closed.

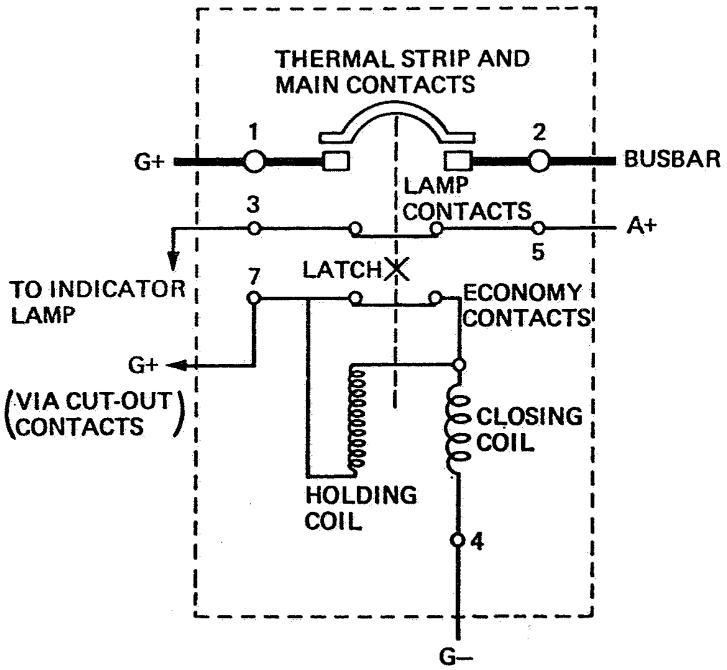



*Figure* 3 INTERNAL CIRCUIT OF A TYPICAL HEAVY DUTY CIRCUIT BREAKER

(b) **Trip Action.** With maximum continuous-rated current flowing through the main stationary contacts of the circuit breaker, the heating effect of the current in the bimetal plate is insufficient to cause distortion of the bimetal plate and the circuit breaker remains closed. Increases in current beyond this value, if sustained, will increase the heating of the bimetal plate and, because of the differing coefficients of expansion of the two metals, cause distortion; as a result the trip bolt is forced down against the latch, and the latch is disengaged from the roller on the armature. With the mechanical connection between the armature and contact bridge carrier being broken the carrier is pulled away from the armature by the accelerating spring, breaking the main contacts and interrupting the main circuit. The indicator lamp contacts, which are operated by a plunger on the contact bridge carrier, close to give indication that the circuit breaker has tripped. Only the contact bridge carrier, acting under the applied force of the accelerating spring, is released from the magnet pole faces; the armature remains in its energised state since the economy contacts (which are operated by a plunger on the armature) remain open, and current through the magnet winding remains at the normal level.

(c) **Resetting Action.** After tripping action has occurred, the main contact assembly is in the open position but the armature remains attracted to the pole faces of the magnet core. In this condition the bimetal thermal element no longer carries current and begins to cool down; the distortion of the element is reduced as cooling proceeds and eventually resumes its original position. On interrupting the supply to terminal 7 (by means of the reset push switch which is normally closed), the magnet winding is de-energised, and the throw-off springs push the armature away from the pole faces until the armature roller re-engages with the latch on the carrier. On restoring the supply to terminal 7 (by releasing the reset push) the closing section of the winding is again energised through the now closed economy contacts to close the circuit breaker in the normal manner.

3.4.3 **Short-Rated and Continuous-Rated Circuit Breakers.** Typical circuit diagrams for short-rated and continuous-rated circuit breakers are shown in Figure 4. The operating mechanism comprises a two-core electromagnet and thermal trip system substantially similar to that of the circuit breaker described in paragraph 3.4.2, but in this type the magnet winding consists of a single low-resistance coil wound on each of two cores, the two coils being connected in series; in the continuously-rated version an economy resistor is placed in series with the winding (as the contact assembly closes) to reduce coil current and prevent undue temperature rise in the magnet assembly.

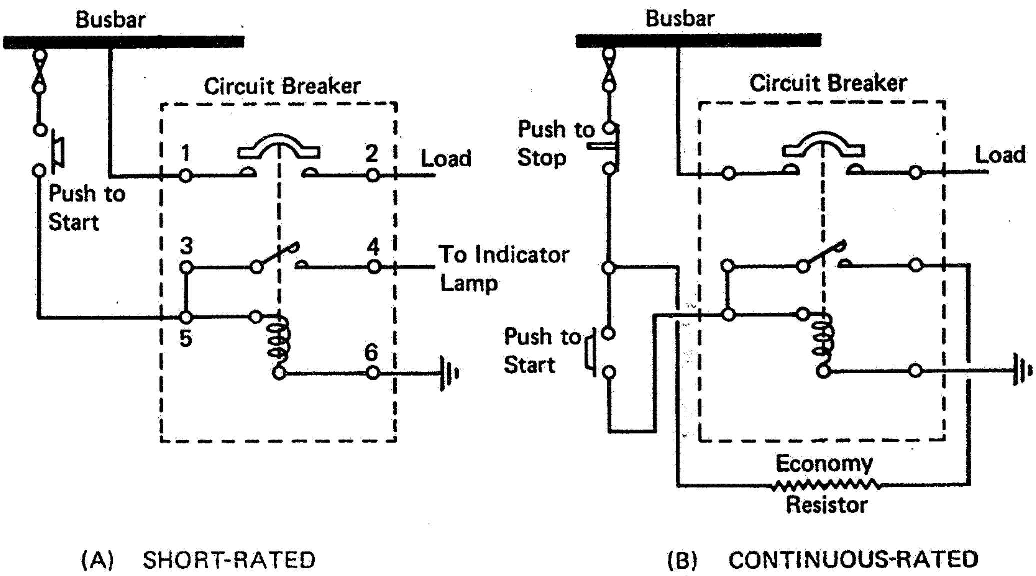



*Figure* 4 TYPICAL CIRCUIT DIAGRAMS FOR SHORT-RATED AND CONTINUOUS-RATED CIRCUIT BREAKERS

(a) **Example B.** In this type of electrically-operated thermal trip circuit breaker the remote control of closure and tripping of the contacts assembly is provided by an electromagnet system similar in form to that of a cylindrical type of heavy duty relay. The contact assembly is operated by the axial movement of a cylindrical plunger which is drawn, against spring control, into the interior of a solenoid when the solenoid is energised. The solenoid winding is in two sections, one of which is normally short circuited by auxiliary armature operated contacts; these contacts open, thereby placing the two sections of the solenoid winding in series, as the armature moves into the operated position, provides an adequate 'hold-on' magnetic field with a relatively small current in the winding circuit. Protection against sustained overload is given by a bimetal thermal trip system, and provision is made for manual (local) tripping by a push-button on the circuit breaker casing. The breaker is reset, after having been tripped thermally or manually, by de-energising the magnet winding; on releasing the armature from the operated position the latching system reverts to normal, and the circuit breaker resets itself for further operations.

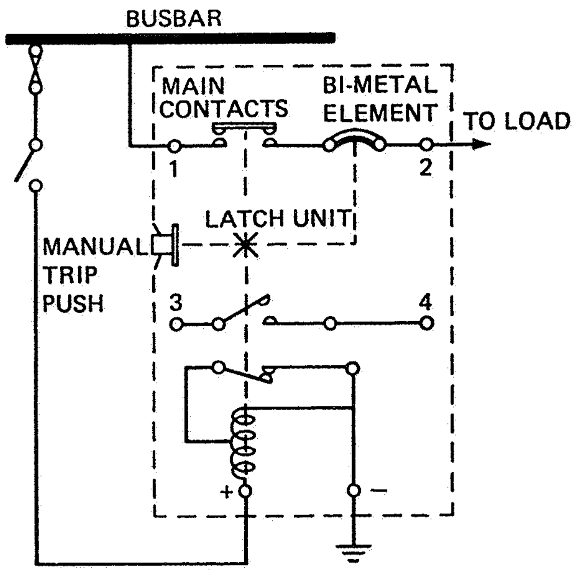



*Figure* 5 EXAMPLE B

(b) **Example C.** A further example in this range of circuit breakers for remote control (electromagnetic) closure and tripping, thermal tripping for circuit protection against sustained overload, and manual (local) tripping for emergency use which differs from others previously described in that the main contacts assembly, which is closed by an electromagnet system, is subsequently retained in the closed condition by a mechanical latching system; the operating coil of the circuit breaker is in use only during the actual closing operation, and is automatically disconnected from its supply as the main contacts are latched on. The internal circuit and latching connections are illustrated in Figure 6. The latch mechanism is subsequently freed, allowing the spring loaded main contact assembly to open, by the movement of a trip which, in turn, is operated either by pressing on a manual trip button (on the circuit breaker casing), energising a second magnet system (the remote trip system) or by distortion of the bimetal element of a thermal trip system (in series with the main contacts) as a result of an overload condition in the protected circuit. After tripping by any one of the three methods, the circuit breaker is reset by completing the remote control operating circuit.

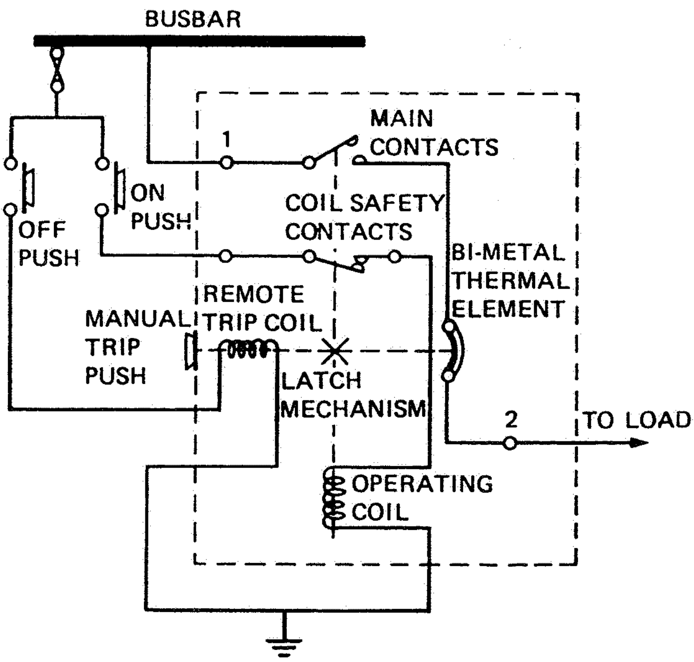



*Figure* 6 EXAMPLE C

## 4 REVERSE CURRENT FLOW

### 4.1 Reverse Current Trip Circuit Breaker

#### 4.1.1 General

(a) A further category of circuit breaker designed for the control and protection of circuits in which the current flow is normally in one direction only, which trip automatically if the current in the controlled circuit should undergo a reversal of direction is illustrated in Figure 7. Circuit breakers of this specialised form are normally incorporated in certain aircraft d.c. power supply systems, where their primary function is the isolation of any generator which, for any reason, takes current from the main busbar for unduly protracted periods. This type of circuit breaker is not affected by the momentary reversals of current in the generator output circuit which take place when the generator, with falling output, cuts out under its normal automatic control system. Such a circuit breaker is normally closed and takes no active part in the general functioning of the power supply system, opening only if the normal generator controls fail to cut out a negative output generator.

(b) The circuit breaker embodies a spring loaded contact assembly which is closed manually by a setting handle and is then held in this condition by a latch assembly. The controlled generator is then connected to the busbar through a series connection consisting of the main contacts and a single turn coil. The main contacts open to disconnect the generator from the busbar when the latch assembly is released; this action is performed by the displacement of a trip lever, which in turn is operated either manually (by pressing the trip button), by remote control through the attracted armature electromagnet system, or automatically when a reverse current condition, of sufficient magnitude and duration, develops in the single turn coil. After tripping by any of these methods, the circuit breaker must be reset by operating the setting handle.

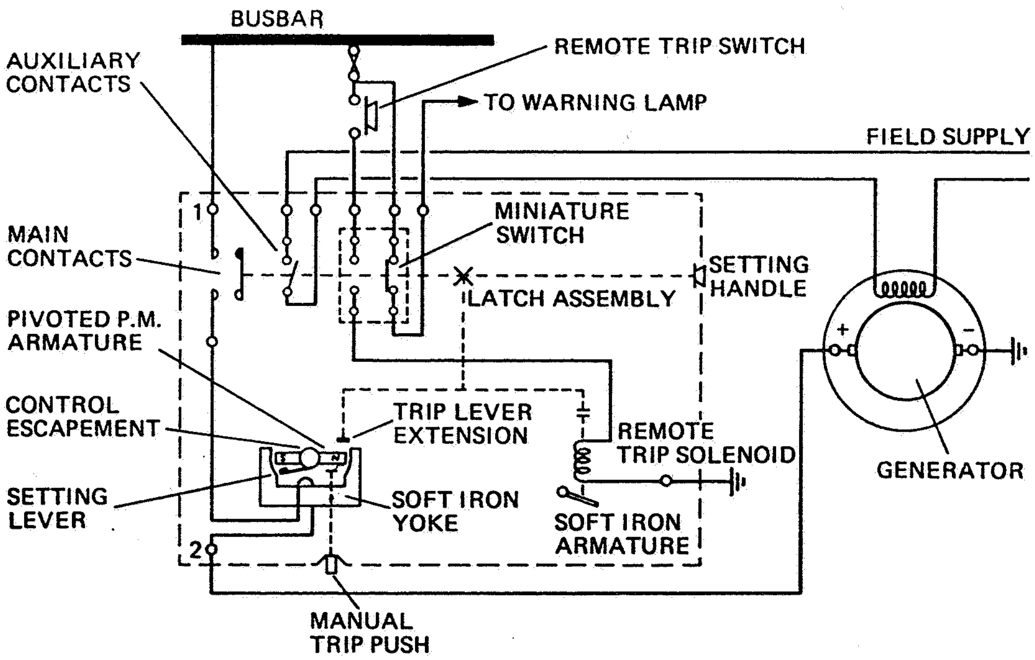



*Figure* 7 REVERSE CURRENT CIRCUIT BREAKER OPERATION

4.1.2 **Reverse Current Trip System**

(a) The single turn coil shown in Figure 7 is located over a soft iron yoke provided with pole faces between which is pivoted a permanent magnet armature. With current passing through the single turn coil a magnetic field is established between the pole faces of the soft iron yoke; polarity of this field (and hence the direction in which it tends to displace the pivoted permanent magnet armature) is dependent on the direction of current through the coil.

(b) The polarity of the yoke field, with current passing through the single turn coil in the normal direction, is such that the armature takes up a position in which one of its arms is poised above an extension of the trip lever, while the other end lies immediately below, and just clear of, a setting lever. The same position is maintained by the armature when there is no current through the single turn coil.

(c) With a reversal of current in the coil the polarity of the yoke field is also reversed, and a force tending to deflect the ends of the pivoted armature towards the trip lever extension and the setting lever is established. The setting lever, which is contacted almost immediately by the armature on the initial movement of the latter in the reverse current direction, controls an escapement mechanism; this mechanism in turn controls the rate at which all further rotary movement of the armature (after the setting lever has been contacted) is made, and the design is such that the rate of armature movement is approximately proportional to the force applied to the setting lever by the permanent magnet armature.

(d) The force exerted on the setting lever by the end of the armature under reverse current conditions is determined by the intensity of the yoke field and thus varies with the magnitude of reverse current in the single turn coil.

(i) Sustained reverse current, if slightly above the designed minimum value, results in a small but constant force being applied to the setting lever, and the escapement allows the armature to turn quite slowly until, after an appreciable delay, it displaces the trip lever to unlock the latching assembly and so permit the spring-loaded contact assembly to open.

(ii) Large reverse current, if sustained, will result in the circuit breaker tripping after a shorter delay, while an extremely severe reverse current will cause almost instantaneous tripping.

(iii) If the reverse current is not sustained and falls to less than the designed minimum trip value before the permanent magnet armature, restrained in its movement by the escapement, has been able to operate the trip lever, the armature is returned to its original position and no trip action takes place.

### 4.1.3 Remote Tripping

(a) Remote tripping of the circuit breaker is effected by means of a tripping solenoid which, when energised, attracts a hinged soft iron armature to displace the trip lever and so release the mechanical latch assembly. The supply to the tripping solenoid is controlled by a push-switch, and the remote trip operating circuit is interrupted, when the circuit breaker is open, by the normally open contacts of the miniature switch shown in Figure 7. The normally closed contacts of this switch, which open as the main contacts close, control a warning light or indicator.

(b) The contact assembly also incorporates a set of auxiliary contacts which open and close with the main contacts; these auxiliary contacts complete the circuit to the field winding of the generator when the circuit breaker is closed. A mechanical indicator, visible through an inspection window in the breaker casing, provides a visual check on the breaker state, i.e. set or tripped. The manual trip push is formed at the end of a spring-loaded plunger which, when pressed, swings the permanent magnet armature on its pivot until it displaces the trip lever and trips the circuit breaker.

## 4.2 Reverse Current Cut-out Relays

4.2.1 **General.** The generator of an aircraft electrical power supply system has to be protected from the battery voltage when the engine is shut down or when a failure of its output occurs. This is normally achieved by the action of a reverse current cut-out relay, fitted either as a separate unit or as an integral part of the voltage regulator. The circuit arrangement for such a relay as an integral part of a voltage regulator, typical of many light aircraft systems, is illustrated in Figure 8.

4.2.2 **Sequence of Operation**

(a) When the generator output voltage rises above that of the battery, the magnetic field of the voltage coil will cause the armature to move against spring tension and close the contacts of the reverse current cut-out relay placing the generator output on the busbar. Load current will now flow through the current coil and produce a magnetic field, which aids that already produced by the voltage coil, and maintains the contacts of the relay tightly closed.

(b) As the generator is being shut down or if a failure of its output occurs, the generator voltage decays to a level which is below that of the battery, resulting in a current being drawn from the battery through the busbar, circuit breaker, and the current coil of the relay. The current flow is now in the reverse direction to the previous current flow, causing an opposite magnetic field to that being produced by the voltage coil. When these two fields cancel each other out, spring tension will open the contacts, automatically disconnecting the generator from the busbar.

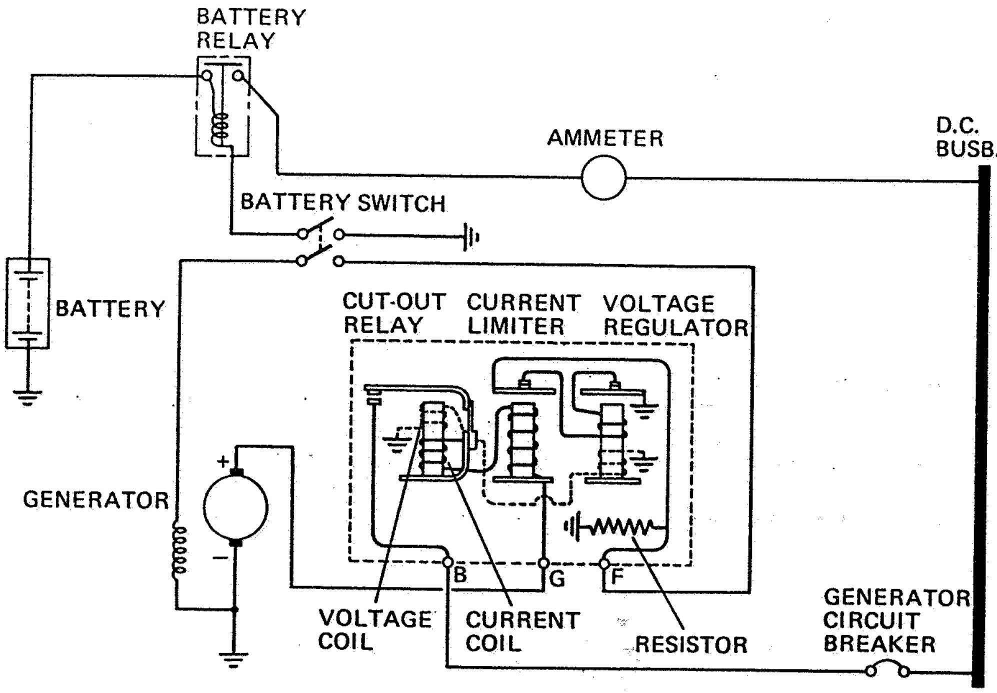



*Figure* 8 REVERSE CURRENT CUT-OUT RELAY OPERATION

## 5 OVERVOLTAGE

5.1 **General.** Overvoltage is a condition which could arise in a power supply system in the event of a fault in the generator field excitation circuit, such as internal grounding of the field windings, or an open circuit in the voltage regulator sensing lines. It is, therefore, necessary to protect consumer equipment against voltages higher than those at which they are normally designed to operate. The methods used vary between aircraft; therefore, reference should be made to the relevant Maintenance Manual for the aircraft concerned. Figure 9 illustrates an example of a typical overvoltage protection circuit for a light aircraft.

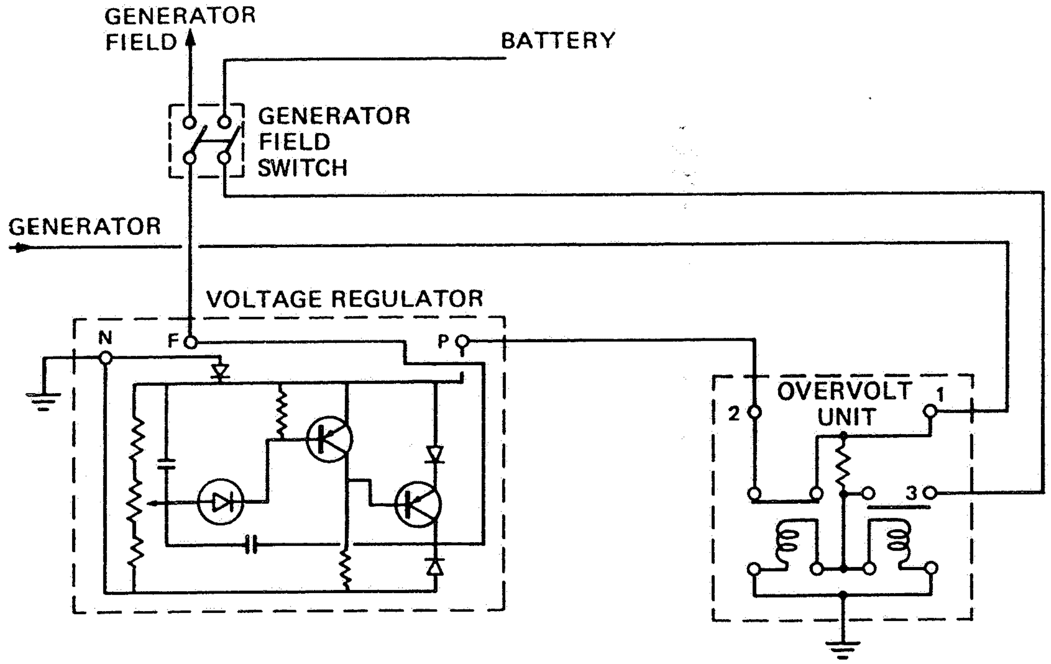



*Figure* 9 OVERVOLTAGE PROTECTION (D.C.)

5.1.1 The overvolt unit comprises two relay coils, one having a pair of normally closed contacts and the other, a pair of normally open contacts. The generator field supply passes via the normally closed contacts to the voltage regulator. Should the generator output voltage rise to a pre-determined value both relay coils become energised via the resistor; opening the generator field circuit causing the generator output to fall to zero, while a permanently connected battery supply will hold on the overvolt relays via the now closed set of contacts.

5.1.2 To reset the system, the generator field switch should first be selected to the OFF position which will reset the generator field circuit so that the generator may be brought on line by returning the field switch to the ON position. If the cause of the overvoltage condition still exists the generator will automatically be tripped off again and no further attempt at resetting should be made until the cause has been established and rectified.

5.2 **A.C. Supply Systems.** A typical method of overvoltage protection, as used in an a.c. power supply system utilising magnetic amplifiers for the control and protection, is illustrated in Figure 10. The circuit is formed by the combination of a single-phase magnetic amplifier and a rectifier bridge, the output of which is applied to the operating coil of a protection relay. The a.c. windings of the magnetic amplifier are normally supplied from a supply and reference transformer, while a voltage sensing network is used in conjunction with the control winding.

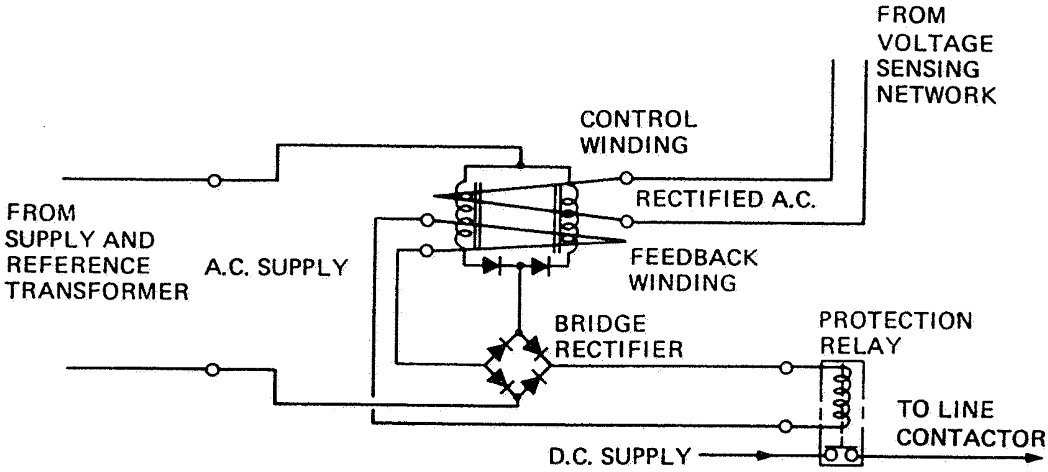



*Figure* 10 OVERVOLTAGE PROTECTION (A.C.)

5.2.1 At the nominal supply voltage the circuit is adjusted so that the protection relay is de-energised; with an increase of supply voltage, the magnetic amplifier saturates and energises the protection relay which interrupts the d.c. supply to the hold-in circuit of a line contactor which disconnects the generator from the busbar. At the same time, the main control unit interrupts the supply to the generator field, causing its output to collapse to zero.

## 6 UNDERVOLTAGE

6.1 **General.** Undervoltage occurs in the normal course of operation when a generator is being shut down, and reverse current flow from the battery to the generator is a normal indication of this condition.

6.2 **D.C. Supply Systems.** In a single d.c. generator power supply system, additional undervoltage protection is not essential since the reverse current is sensed and checked by the reverse current cut-out relay.

6.3 In a multi-generator system additional protection is required and usually takes the form of a polarised relay designed to be energised by a voltage rising to a pre-determined level and to be de-energised as the voltage falls approximately 2 volts below that level. A typical circuit, as used on a twin-engined light aircraft, is illustrated in Figure 11.

6.3.1 The undervolt relay is energised by the generator supply through the generator field switch, and a warning light is connected in series with the normally closed contacts of the unit. When the engine and generator is at rest, or the generator isolated or faulty, the undervolt unit will be de-energised and the warning light illuminated.

6.4 **A.C. Supply Systems.** In an a.c. power system an undervoltage condition results in a lagging current, or reactive power, which is the equivalent of reverse current. The protective function is, therefore, usually performed by the reactive load sharing circuit of an a.c. power supply system. Further information may be found in Leaflet **EEL/1-8**.

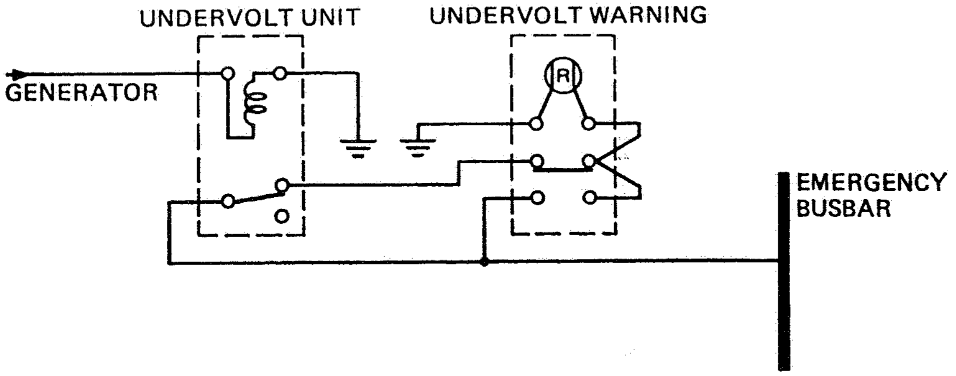



*Figure* 11 UNDERVOLTAGE PROTECTION (D.C.)

7 UNDER/OVER FREQUENCY Protection against these faults is required only in a.c. power supply systems and protection is usually effected by the real load sharing circuit of the system. Further information may be found in Leaflet **EEL/1-8**.

8 MAINTENANCE PRACTICES The method of installing the principal protection devices of aircraft electrical circuits, and the carrying out of the relevant maintenance procedures, will vary between types of aircraft. For precise details of any particular aircraft, reference should be made to the Maintenance Manual and Wiring Diagram Manual for the aircraft concerned. Certain aspects are, however, of a general nature and the information given in the following paragraphs is intended only as a general guide.

8.1 **General Precautions**

8.1.1 On aircraft which have three-phase a.c. primary power supply, the voltage potential between phases is 200 volts RMS and can be lethal. Therefore, before carrying out any maintenance on the aircraft's electrical power supply and distribution system, it should be ensured that the system is de-energised and that no external supplies are connected to the aircraft.

8.1.2 To eliminate the possibility of damage to equipment or the structure of the aircraft by the shorting of live terminals to earth, and before removing any circuit protection device, it should be ensured that all electrical power is off, by disconnecting ground power supplies and the aircraft batteries. Notices should be prominently displayed adjacent to the ground power plugs and aircraft battery connections stating that electrical power supplies are not to be connected.

8.1.3 Sufficient time must always be allowed for the thermal element to cool adequately before attempting to reset a circuit breaker which has tripped on overload. If the breaker trips again shortly after resetting, it must be assumed that a fault condition exists, so further attempts at resetting should not be made until the fault has been investigated and cleared.

8.2 **Checking of Components.** Whenever the serviceability of a protection device is suspect, or at specific inspection periods, components should be subjected to the following checks:—

(a) Check component for proper installation, security of attachment, physical damage, and for any evidence of overheating.

(b) Check that electrical connections are secure and free from contamination.

(c) Check all wiring for physical damage such as chafing, fraying or cut insulation.

8.3 **Removal/Installation.** Procedures for the less complex protection devices, such as fuse-holders and circuit breakers, will usually be provided within the relevant aircraft Wiring Diagram Manual. Procedures for the more complex units, such as reverse current cut-out relays and reverse current circuit breakers, will be in the relevant aircraft Maintenance Manual. The information given in the following paragraphs is intended only as a general guide to the safety precautions that should be observed.

8.3.1 Following removal of circuit protection devices, and where replacements are not readily available, to ensure that the aircraft remains electrically safe, all exposed terminations on cables should be covered with insulating boots or tubing. In addition, all plugs and sockets should be protected with plastic, or equivalent, dust caps to prevent damage to pins and the possible ingress of moisture or foreign matter. Electrical power supplies may then be re-connected to the aircraft power distribution system to permit operation of other services.

8.4 **Power Supplies for Testing.** Power supplies for the testing and ground operation of aircraft electrical systems should be those obtainable from either ground supply sources or the auxiliary power supply of the aircraft. Use of the aircraft battery power supply should be severely restricted. Before applying external power to an aircraft distribution system, it should be ascertained that all associated switches located in the crew compartment, on the ground power control panel and on the cabin ground service panel, as applicable, are selected to the off, normal or open position as required.

8.4.1 Damage to the equipment of the aircraft can occur if the electrical power supply circuits have been subjected to an abnormally high or abnormally low voltage, extreme frequency variations or to the application of incorrect phase rotation.

8.4.2 Prior to carrying out any functional tests or adjustment procedures, it should be ensured that all applicable fuses have been refitted and circuit breakers reset. Relevant warning notices should be removed.

# EEL/1-10

*Issue* 1.
*June*, 1981.

## AIRCRAFT
## ELECTRICAL EQUIPMENT
### LIGHTING SYSTEMS

1 INTRODUCTION This Leaflet gives information of a general nature on the different types of lighting which can make up typical aircraft lighting systems. No attempt is made in this Leaflet to describe any particular aircraft installation; it is important, therefore, that this Leaflet should be read in conjunction with the relevant manufacturers' and aircraft manuals.

1.1 The following Leaflets contain information associated with the subject covered by this Leaflet, and reference should be made to these as appropriate:

**EEL/1-6** Bonding and Circuit Testing
**EEL/1-9** Circuit Protection Devices
**EEL/3-1** Cables—Installation and Maintenance
**AL/11-6** Ice Detection Systems

2 GENERAL Lighting plays an important role in the safe operation of an aircraft and in the control of many of its systems. In the main, lighting falls into two groups—external lighting and internal lighting. The main functions of such lighting are:

(a) **External Lighting**

(i) The marking of some of the aircraft's extremities by means of navigation lights.
(ii) The attracting of attention by means of flashing lights.
(iii) Forward and lateral illumination for aircraft landing and taxying.
(iv) Illumination of parts of the aircraft, to enable visual checks for ice formation.
(v) Illumination to facilitate evacuation of passengers and crew following an emergency landing.

(b) **Internal Lighting**

(i) Illumination of flight deck instrumentation and control consoles.
(ii) Illumination of passenger compartment and passenger information signs.
(iii) Indication and warning of system condition and operational status.
(iv) Emergency lighting.

2.1 In general, white incandescent and fluorescent lamps, electro-luminescent (electrically activated phosphor) and self-illuminating signs are used to provide aircraft lighting. Coloured lighting used for warning lights, indicator lights on instrument panels, navigation and anti-collision lights is normally achieved by the use of coloured lenses. Emergency lights are used to illuminate both internal and external emergency egress paths.

2.2 Primary power supplies required for the individual lights and lighting systems described in this Leaflet will vary according to the size and complexity of the aircraft and may be either a.c. or d.c. Reference should, therefore, be made to the relevant aircraft Maintenance Manual for precise details. Individual circuit protection is normally provided by panel mounted circuit breakers whilst lighting controls are conveniently located throughout the aircraft.

2.3 Requirements for the minimum intensities, dihedral angles, effective flash frequency and colours which are applicable to the external lights provided in order to comply with the Rules of the Air and Air Traffic Control Regulations are contained in JAR-25 and BCAR Chapter **D6-7** for large aeroplanes, **G6-7** for rotorcraft and **K6-7** for light aeroplanes.

## 3 EXTERNAL LIGHTING

3.1 **Navigation Lights.** The requirements and characteristics for navigation lights have been agreed internationally, and for UK registered aircraft are set out in the statutory Rules of the Air and Air Traffic Control Regulations and the Air Navigation Order. Briefly, the requirement is that every aircraft in flight or moving on the ground during the hours of darkness shall display:

(a) A green light at or near the starboard wing tip, visible in the horizontal plane from a point directly ahead through an arc of 110° to starboard (dihedral angle R of Figure 1).

(b) A red light at or near the port wing tip, with an arc of visibility to port similar to that in (a) (dihedral angle L of Figure 1).

(c) White light visible from the rear of the aircraft in the horizontal plane through an arc of 140°. The conventional location of this light is on the tail of the aircraft, but in some cases, notably such aircraft as the wide bodied types, a white light meeting the specification is mounted on the trailing edge section of each wing tip (dihedral angle A of Figure 1).

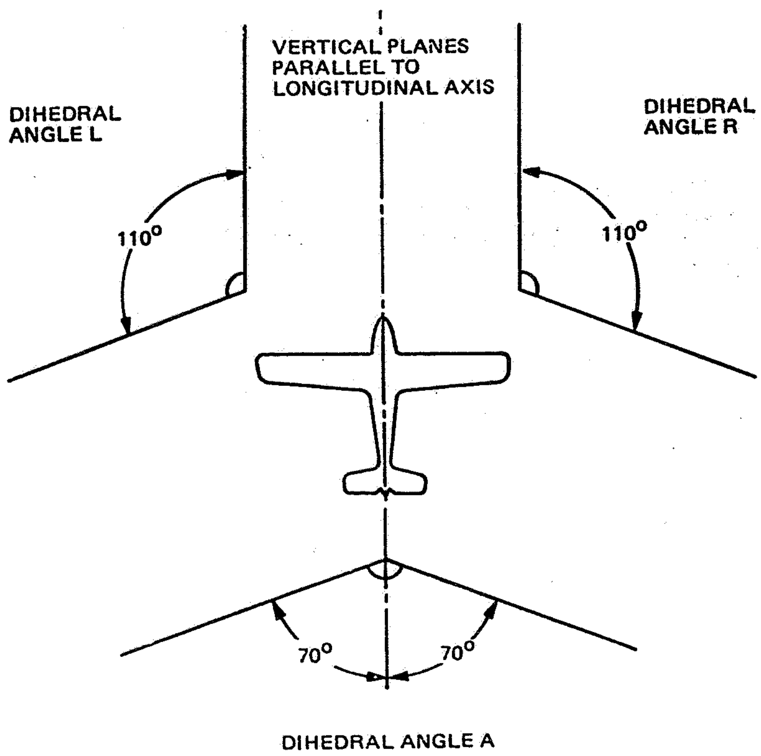



*Figure* 1 EXTERNAL LIGHTING ANGLES

3.1.1 Construction of the light fittings varies in order to meet the installation requirements for different types of aircraft. In general, however, they consist of a filament type lamp, an appropriate fitting and a transparent coloured screen or cap. To obtain a sharp cut-off of light at the required angle of visibility, the screen and the filament of the lamp are shaped and arranged accordingly.

3.1.2 Originally, navigation lights were required to emit a steady light, but in order to improve the attention attracting function, subsequent legislation required the lights to flash in a controlled sequence. However, following the introduction of flashing anti-collision beacons the requirement for flashing navigation lights was discontinued, and the steady lighting requirement was re-introduced. It is, therefore, possible for some aircraft, which are below a certain weight criterion and registered before current regulations became effective, to be still equipped with flashing navigation lights.

### 3.2 Anti-Collision Lights

3.2.1 Anti-collision lights complement the navigation lights and by emitting a flashing light attract attention and thus enable the presence of an aircraft to be more readily identified. The lights may be of the type which emits a rotating beam of light or of the strobe type, from which short-duration flashes of high intensity light are emitted. In some current types of aircraft both types are used in combination, the strobe lighting forming supplementary lighting.

3.2.2 **Rotating Beam Lights.** These lights, or beacons as they are often called, consist of a filament lamp unit and a motor. In some cases the motor drives a reflector (see (a)) and in others the actual lamp unit (see (b)). The drive transmission system is usually of the gear and pinion type and has a specific reduction ratio. All components are contained within a mounting enclosed by a red glass cover. The motor speed and gear drive ratios of beacons are such that the reflector or lamp unit, as the case may be, is operated to establish a beam of light which rotates at constant frequency. Typical speeds are 40-45 rev/min giving a flash frequency of 80-90 Hz/min (but see paragraph 2.3). There are variations of design, but the two types described in (a) and (b) usefully illustrate how the rotating reflector and rotating lamp techniques are applied.

(a) The beacon illustrated in Figure 2 employs a V-shaped reflector which is rotated at approximately 45 rev/min by a motor, over and about the axis of a sealed beam lamp. One half of the reflector is flat and emits a narrow high-intensity beam of light near the horizontal, while the other half is curved to increase the up and down spread of its emitted beam to $30^{\circ}$ above and below the horizontal, thereby effectively reducing the light intensity.

(b) The beacon illustrated in Figure 3 is one employing two filament lamps, mounted in tandem, each of which is pivoted on its own axis. One half of each lamp forms a reflector by being silvered, and the drive from the motor is so arranged that the lamps oscillate through $180^{\circ}$ and, as can be seen from the inset diagram, the light beams are $180^{\circ}$ apart at any instant.

3.2.3 **Strobe Lighting.** This type of lighting system is based on the principle of a capacitor-discharge flash tube. The light unit takes the form of a quartz or glass tube filled with xenon gas which is connected to a power supply unit made up essentially of a capacitor, and which converts an input power of either 28 V d.c. or 115 V a.c. into a high d.c. output, usually around 450 V. The capacitor is charged to that voltage and periodically discharged between two electrodes in the xenon-filled tube, the energy producing an effective high-intensity flash of light having a characteristic blue-white colour.

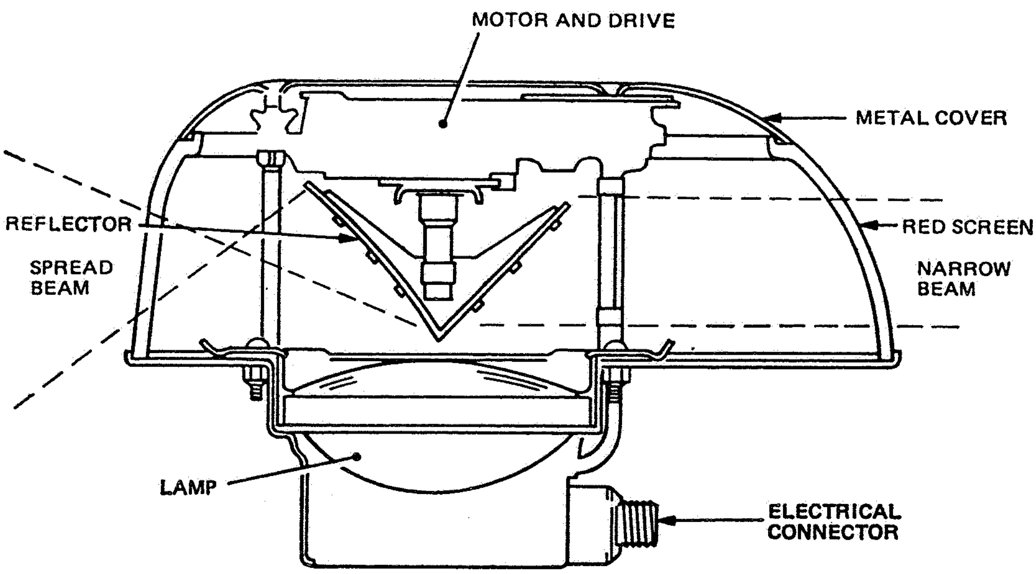



*Figure* 2 ROTATING REFLECTOR BEACON

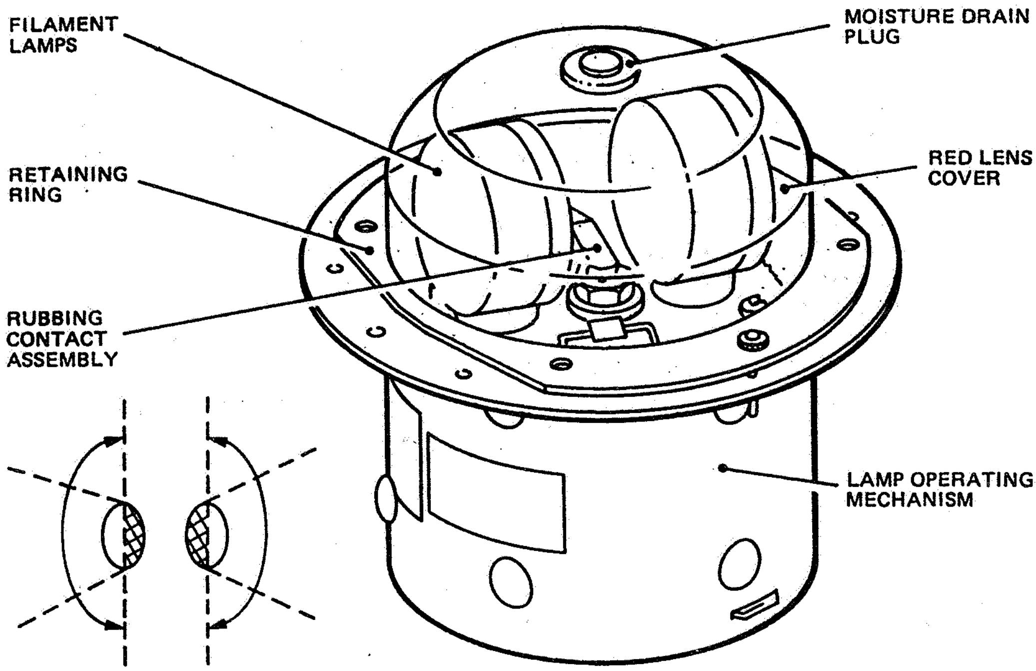



*Figure* 3 ROTATING LAMP BEACON

3.2.4 **Supplemental Lighting.** Depending on the size of the aircraft, strobe lighting may be installed in the wing tips to supplement the conventional red beacons, or may be used in combination as a complete strobe type anti-collision high-intensity lighting system controlled in a flashing sequence by controllers and flasher timing unit.

3.3 **Landing and Taxying Lamps.** Landing and taxying lamps, as the names indicate, provide the necessary illumination for the landing of an aircraft and for taxying it to and from runways and terminal areas at night and in poor visibility conditions.

3.3.1 **Landing Lamps.** Landing lamps are used to illuminate that area of the runway immediately ahead of the aircraft. These lamps are generally of the sealed beam type and are, in some aircraft, mounted in wing leading edges, front fuselage sections, or on the nose landing gear, so as to direct beams of light at pre-determined and fixed angles. In other aircraft the lamps are mounted under the wings and may be extended to pre-selected angles and then retracted. Actuator operated lamps are normally operated through a slipping clutch mechanism or shear links to ensure retraction, should they not be retracted or fail to retract, before a high air speed is achieved. The requirements for landing lamps fitted to rotorcraft differ, in respect to angles of coverage, and reference should, therefore, be made to BCAR Chapter **G6-1.**

3.3.2 **Taxying Lamps.** Taxying lamps are also generally of the sealed beam type, located, in most cases, on the nose landing gear. The power rating of such units is normally lower than that of the landing lamps, 250 W being typical, and the supply required is either d.c. or a.c. In some designs the function of a taxying lamp is combined with that of a landing lamp, the lamp unit then consisting of two filaments, one of 600 W and the other of 400 W. Typically both filaments may provide the illumination for landing, and for taxying only the 400 W filament would be used.

3.3.3 In addition to taxying lamps, some of the larger types of aircraft are equipped with lamps which are so mounted as to direct beams of light to the sides of the runway, and are known as runway turn-off lights. The primary function of these lights is to illuminate the points along the runway at which the aircraft can turn to leave the runway.

3.4 **Ice Inspection Lamps**

3.4.1 Ice inspection lamps, or wing-scan lamps as they are sometimes called, are fitted to transport aircraft to allow for the visual inspection of the wing leading edges and air intakes of turbine engines, for the formation of ice. Further information on ice inspection lamps is given in Leaflet **AL/11-6.** The lamps are generally of the sealed beam type with power ratings ranging from 60 to 250 W depending on the light intensity required for the particular aircraft type.

3.5 **Service Lighting**

3.5.1 Service lighting is fitted to some aircraft to provide general illumination for routine inspection and servicing in such areas as wheel wells, air conditioning compartments, tail cone, APU compartments, electrical/electronic equipment centres and fuelling panels. The lights are generally of the explosion-proof dome or bulkhead type with conveniently located control switches.

3.6 **Exterior Emergency Lighting**

3.6.1 Exterior emergency lighting is normally provided by white incandescent lights at each overwing emergency exit to illuminate the area where an evacuee is likely to make the first step outside the passenger cabin, along a portion of the overwing escape route to an area where first contact with the ground would be made.

3.6.2 At each non-overwing emergency exit not having an escape assist means, similar illumination is provided which is capable of lighting the ground surface where an evacuee is likely to make first contact with the ground outside the passenger compartment.

3.6.3 Where an emergency exit has an escape assist means, illumination is provided to ensure that it is visible from the relevant emergency exit and to illuminate the area of the ground with which an evacuee would first make contact. In some such installations the light units may form part of the escape assist means and are, therefore, automatically activated when the assist means is erected.

## 4 INTERNAL LIGHTING

4.1 An important requirement of internal lighting is that there should be adequate illumination of the aircraft interior for all conditions of flight. To achieve this, most passenger transport aircraft have flight deck and passenger compartment lighting divided into three groups:—

(a) **Main.** Main lighting is usually equally distributed and connected to the various busbars, so ensuring that single power failures do not result in the loss of all main lighting.

(b) **Standby.** In the event of a total electrical power failure, illumination, at a considerably lower level, would be provided by standby lighting normally powered from the aircraft batteries.

(c) **Emergency.** Emergency lighting is normally provided for the illumination of emergency exit paths and exits throughout the aircraft. Such lighting is, in some aircraft, arranged and connected in groups to the aircraft batteries, capable of being automatically transferred to emergency battery packs when the main battery voltage level has fallen to a pre-determined value. On other aircraft these are of the self-contained battery operated type.

4.2 The internal lighting can also be further divided into four categories—flight deck or operational lighting, passenger compartment lighting, service lighting (which includes galleys, toilet and cargo/baggage compartments) and emergency lighting to assist egress and survival independently of passenger compartment lighting.

### 4.3 Flight Deck Lighting

#### 4.3.1 General

(a) To ensure adequate illumination of all instruments, switches, controls, etc., and of the panels to which these items are fitted, the following types of lighting are used:

(i) Integral lighting, in which the light source is contained within the instrument.

(ii) Pillar and bridge lighting, in which a number of lights are positioned on an instrument panel to illuminate small adjacent areas, and to provide the dial lighting of individual instruments.

(iii) Trans-illuminated panels, which are used to allow engraved marks on various controls, notices and instructions to be read under night conditions.

(iv) Flood-lighting, whereby lamps are positioned around the flight deck so as to illuminate an entire instrument panel or general area.

(v) Electro-luminescent lighting for control-position indicators and passenger information signs.

(b) The choice of colour for the lighting of aircraft flight decks has been the subject of many tests and studies, and as far as the contribution to the safe and efficient operation of aircraft at night is concerned the choice has been between red and white. Red lighting was introduced during the second world war, was subsequently carried over to civil aviation, and for some time was universally adopted as the principal lighting scheme, supplemented by a certain amount of white lighting. However, from continued tests and studies of the comparative merits of red and white lighting, it was generally concluded that at the brightness levels adopted, the advantages of white light were very significant.

(c) White light is superior to red for several reasons which can be listed as follows:

- (i) The amount of electrical power required is reduced since red filters, which absorb about 80% of the light, are eliminated.
- (ii) Heat dissipation problems are reduced.
- (iii) White lighting permits colour coding of displays, use of red warning flags and other similar indications.
- (iv) Contrasts between instrument displays and readability are improved.
- (v) Eye fatigue is reduced.
- (vi) Better illumination is provided in thunderstorm conditions.

(d) There are a few disadvantages, of course, but they are so outweighed by the advantages that white lighting has become standard for instrument and panel lighting and is used in many aircraft currently in service.

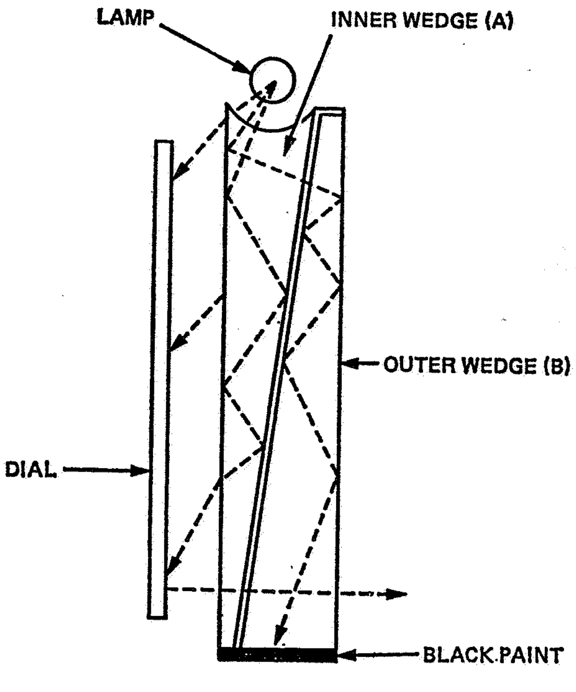



*Figure* 4 WEDGE-TYPE LIGHTING

4.3.2 **Integral Lighting**

(a) A common form of integral lighting for instruments is that known as 'wedge' or 'front' lighting; a form deriving its name from the shape of the two wedge shaped portions of glass which together make up the instrument cover. This type of lighting relies for its operation upon the physical law that the angle at which light leaves a reflecting surface equals the angle at which it strikes that surface. The two wedges, which have polished surfaces, are mounted opposite to each other with a narrow air space separating them, as illustrated in Figure 4. Light is introduced into inner wedge (A) from lamps set into recesses in its wide end. A certain amount of light passes directly through the wedge and on to the face of the dial while the remainder is reflected back into the wedge from the polished surfaces. The angle at which the light rays strike the wedge surfaces governs the amount of light reflected back; the lower the angle, the more the light is reflected back.

(b) The double wedge mechanically changes the angle at which the light rays strike one of the reflecting surfaces of each wedge, so distributing the light evenly across the dial and also limiting the amount of light given off by the dial face. Since the source of light is a radial one, the initial angle of some light rays with respect to the polished surfaces of inner wedge (A) is less than that of others. The initially low angle light rays progress further down the wedge before they leave and spread light across the entire dial. Light escaping into outer wedge (B) is confronted with constantly decreasing angles, and this has the effect of trapping light within the wedge and directing it to its wide end. Absorption of light reflected into the wide end of outer wedge (B) is ensured by painting its outer part black.

(c) A further form of integral lighting has 'festoons' of micro-miniature lamps mounted in clusters around the inside of the instrument casing, which can have a significant lamp mortality without unduly reducing the satisfactory level of illumination and the need for instrument removal for lamp replacement.

4.3.3 **Pillar and Bridge Lighting**

(a) **Pillar Lighting.** Pillar lighting, so called after the method of construction of the attachment which carries the lamp, is used to provide illumination for individual instruments and controls. A typical assembly, illustrated in Figure 5(a), consists of a miniature centre contact filament lamp (commonly known as a pea lamp) inside a housing, which is a push fit into the body of the assembly. The body is threaded externally for attachment to the instrument panel and has a hole running through its length to accommodate a cable which connects the positive supply to the centre contact. The circuit through the lamp is completed by a ground tag connected to the negative cable. Light is distributed through a filter and an aperture in the lamp housing. The shape of the aperture distributes a sector of light which extends downwards over an arc of approximately 90° to a depth slightly less than 50 mm (2 in) from the mounting point.

(b) **Bridge Lighting.** Bridge lighting, as illustrated in Figure 5(b), is a multi-lamp development of the individual pillar lamp described in (a). Two or four lamp housings are fitted to a bridge structure designed to fit over a variety of standardised instrument cases. The bridge fitting is made up of two light alloy pressings fixed together by rivets and spacers, and carrying the requisite number of centre contact assemblies above which the lamp housings are mounted.

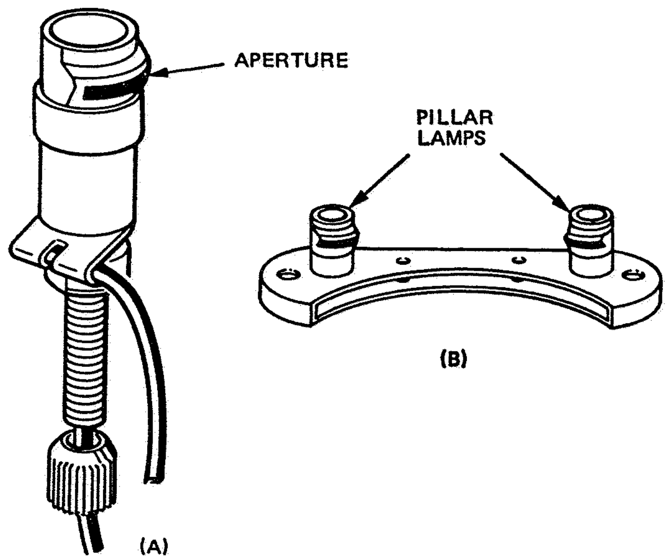



*Figure* 5 PILLAR AND BRIDGE LIGHTING

4.3.4 **Trans-illuminated Panels**

(a) Trans-illuminated panels are designed to suit the relevant metal panel on which instruments or controls are mounted and are formed from clear sheet acrylic plastics, faced on the upper and lower surfaces by a thin sheet of translucent white plastics and faced again by a sheet of black or grey plastics. The layers are then bonded together to form the panel (see Figure 6). Where necessary, numerals and inscriptions are then engraved through the outer layer to the white layer. Where components are required to be illuminated, facets are cut and angled in the surface surrounding the component. The light, transmitted by the panel clear core, originates at lamps suitably positioned in the panel. Direct emission of light is prevented by caps fitted to the lamp holders. The overall effect is to provide a clear white engraving legible during the day and illuminated by light conducted through the panel during darkness.

(b) Illumination for standard trans-illuminated panels is provided by lampholders mounted on the metal panel back plate, with the trans-illuminated panel being held in position by rubber skirted lamp caps which screw into the lamp holders.

(c) Printed circuit trans-illuminated panels use a double-faced copper laminate applied to the rear of the layered plastics panel, the lamp holders being a part of the plastics panel. Power supplies to the circuit board are introduced by a captive connector fixing screw which locates in a connector mounted on the metal panel back plate. The trans-illuminated panels are held in position by the captive connector fixing screw and captive fixing screws.

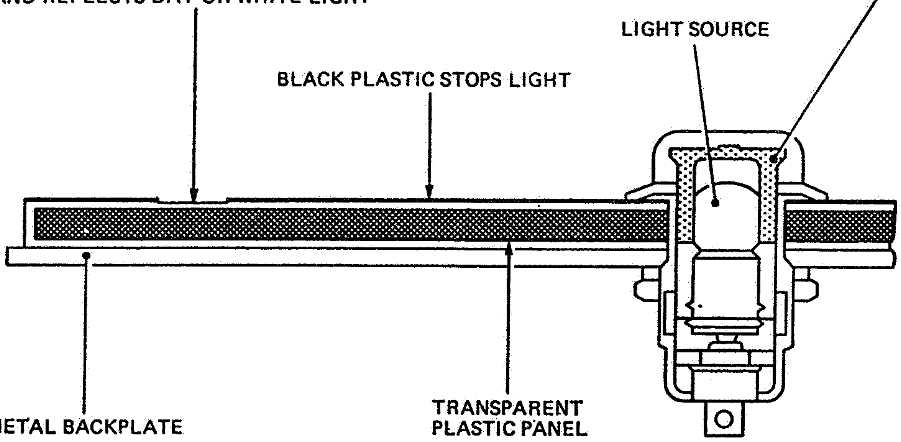



*Figure* 6 TRANS-ILLUMINATED PANEL

4.3.5 **Flood-lighting.** Flood-lighting is normally used for the general illumination of instruments, control panels, pedestals, side consoles and areas of the flight deck flooring. The lights usually take the form of incandescent lamp or fluorescent tube units, and, depending on the size and type of aircraft, both forms may be used in combination.

4.3.6 **Electro-Luminescent Lighting**

(a) Electro-luminescent lighting is employed in a number of aircraft for the illumination of passenger information signs and may also be used for the illumination of instrument dials and selective position marking of control valves and switches.

(b) An electro-luminescent light consists of a thin laminate structure in which a layer of phosphor is sandwiched between two electrodes, one of which is transparent. The lighting requires an a.c. power supply for its operation, and when this is applied to the electrodes the phosphor particles become luminescent, that is to say, visible light is emitted through the transparent electrode. The luminescent intensity is proportional to the voltage and frequency of the a.c. supply.

(c) The area of the phosphor layer which becomes luminescent when the power supply is applied is that actually sandwiched between the electrodes; consequently, if the back, non-transparent electrode is so shaped as to form a letter or figure, the pattern of the emitted light through the transparent electrode will be an image of that back electrode.

### 4.4 Central Warning System

4.4.1 A central warning system is an automatic signalling system which provides an 'attention getting' display in response to fault signals from specified systems. Urgency of crew action is normally indicated by the colour of the display, and/or audio tone, indicators for "Alert" signals (those demanding instant action) generally being coloured red, and "Caution" signals (those requiring less urgent action) being coloured amber.

4.4.2 Origination of a fault signal will cause flashing of the relevant alert or caution lamps mounted on the main instrument panels, illumination of the relevant inscription of the display unit and, in certain cases, lighting of warning lamps incorporated in, or adjacent to, control levers. Complete identification of the indicated fault will generally necessitate reference to warning indicators and instruments associated with the system at fault, as more than one fault condition can usually cause illumination of any one display unit inscription. Response to alert warnings should, however, normally be instinctive and should generally result in cessation of operation of the fault source.

4.4.3 Display signals other than major failure warning lamps, can usually be cancelled by operating a cancel switch. Integral self-test equipment is normally provided for in-flight testing of the system and may also provide an altitude inhibit control system which extinguishes and inhibits certain centralised warning captions during automatic landings, approach, and go-round procedures.

4.4.4 In addition some central warning systems are also equipped with advisory lights, normally coloured blue, that advise when a system which is operated intermittently has been activated.

### 4.5 Passenger Compartment Lighting

4.5.1 The extent to which lighting is used in a passenger compartment is dependent to some extent upon the size, but largely on the decor used for that aircraft, and can vary from a small number of roof mounted incandescent lamp fittings to a large number of fluorescent fittings located in the ceiling and hat racks so as to combine concealed, pleasing, and functional lighting effects.

4.5.2 Each fluorescent tube fitting requires a ballast unit to provide the momentary high voltage which enables the tube to strike and become fully illuminating. In all commercial passenger transport aircraft the lights are controlled from panels at the cabin attendants' stations.

4.5.3 In addition to the passenger compartment general lighting, lights are also provided at passenger service units and for the illumination of essential passenger information signs, such as "Fasten Seat Belts/No Smoking" and "Return to Cabin". The lights for these signs may be of the incandescent type or, as in a number of aircraft types, of the electro-luminescent type described in paragraph 4.3.6. Lights for signs conveying essential passenger information are usually controlled from the flight deck.

### 4.6 Cargo and Baggage Compartment Lighting

4.6.1 Dome lights are evenly distributed throughout the cargo and baggage compartments to provide the basic illumination for the handling of cargo and baggage. Lights located adjacent to the doors also provide the lighting for the entry areas.

4.6.2 Each dome light is usually provided with a protective guard both to prevent damage to the unit during cargo handling and to minimise the risk of fire by preventing the cargo or baggage from coming into direct contact with a hot lens unit.

4.7 **Internal Emergency Lighting**

4.7.1 It is essential that adequate illumination of the flight deck, and the various sections of the passenger compartment containing exits, escape hatches, chutes, etc., which must be deployed under emergency conditions, is maintained following failure or disconnection of the normal lighting systems. The lighting intensity is normally acceptable at a lower level than that provided by the standard lighting systems, since the lighting is strictly for the purpose of evacuation of the aircraft. Such lighting is normally of the white incandescent type receiving electrical power supplies as described in paragraph 4.1(c), while self-illuminating lights, as described in paragraph 4.8, are often used for emergency exit signs and hatch release handles.

4.7.2 In some aircraft the lighting is connected directly to an emergency battery (generally of the nickel-cadmium type, but sometimes of the silver-zinc type) which, under normal operating conditions of the aircraft, is maintained in a fully-charged state by a trickle charge from the aircraft main busbar system. Primary control of the emergency lights is in some aircraft by means of a control switch located on the flight deck, but in others a secondary control by means of acceleration sensitive ('g') switches is also employed for their automatic operation.

4.8 **Self-illuminating Signs.** Self-illuminating signs are entirely self-powered and require no period of daylight exposure to operate. Their brightness is such that they are instantly seen in dark areas by persons that are not dark-adapted, and present no direct radiation hazard.

4.8.1 Self-powered lights consist of a small sealed glass envelope internally coated with a layer of phosphor and containing tritium gas. Tritium is an isotope of hydrogen and emits beta-particles (electrons) of low energy which, on striking the layer of phosphor powder, cause it to emit visible light, the colour of the emitted light being controlled by the selection of the phosphor coating. Placing the light element behind a suitable silk-screened diffusing panel provides a ready means of conveying instructions or notices in darkened areas.

## 5 MAINTENANCE PRACTICES

5.1 **General.** Most light units and components can be maintained without the use of special tools. However, when special equipment or procedures are required to remove or install a light or component, detailed instructions will be found in the relevant aircraft Maintenance Manual. When defective filaments, lights or components are replaced, identical parts should always be used unless substitutes have been authorised. Identification details of the recommended filament and the acceptable substitutes are usually found in the relevant aircraft Maintenance Manuals. Particular attention should be paid to these manuals when maintenance is carried out on retractable landing or taxying lamps, so ensuring that the correct angular settings have been maintained. A spare filament storage area is often located within the flight deck for in-flight use. Operational check procedures for the lighting systems will be detailed in the relevant aircraft Maintenance Manual, to which reference should be made, and the information given in the following paragraphs thus serves only as a general guide.

5.2 **Checking of Lighting Components**

5.2.1 At the specified inspection periods, or whenever the serviceability of a light or lighting system is suspect, the checks (a) to (d) should be carried out:

(a) Check the component for proper installation, security of mounting, physical damage, and any evidence of overheating.

(b) Check that terminal connections are secure and free from foreign matter, moisture and corrosion.

(c) Check bonding connections for proper electrical contact and security, in accordance with Leaflet **EEL/1-6**.

(d) Check wiring for physical damage such as chafing, fraying, damaged insulation, or contamination by harmful fluids such as hydraulic fluids, etc.

5.3 **Removal and Installation of Lighting Components.** Should it be necessary to remove a component of a lighting system, either as a result of a check or for the purpose of bench testing, and should special tools or equipment be required, full details will normally be found in the relevant aircraft Maintenance Manual. In the absence of such information it is recommended that the procedure of 5.3.1 and 5.3.2 be adopted.

5.3.1 **Removal**

(a) Trip the applicable circuit breaker, or remove the appropriate fuse, to ensure electrical safety.

(b) Gain access to the component.

(c) Disengage from or remove the attachment parts.

NOTE: Attachment parts are sometimes removed after disconnecting electrical connections or wiring terminals.

(d) Disconnect electrical connections or wiring terminals from the component.

(e) Install dust covers on plugs and receptacles, and install identification tags and insulating boots on wiring terminals.

(f) Remove the component.

5.3.2 **Installation**

(a) Ensure that the appropriate fuse or circuit breaker is still electrically safe.

(b) Connect electrical connections or wiring terminals to component.

NOTE: Connection of electrical connections or wiring terminals is sometimes accomplished after installation of the component.

(c) Position the component on its mounting and install attachment parts.

(d) Install or secure parts that have been removed to gain access to the component.

(e) Carry out check (by operating the appropriate switch, after re-setting of the circuit breaker or replacement of the fuse) for correct electrical operation of the circuit.

5.4 **Filament Replacement.** Replacement filaments should be restricted to those recommended by the aircraft manufacturer, so as to ensure the satisfactory operation of the light and to prevent damage to the circuit and circuit components.

5.4.1 **Fluorescent Lighting.** Fluorescent lighting has three general removal/replacement methods which cover the main types of light units in use. The first method is used when a fluorescent tube is retained at each end by a butt-on type tube holder which has a movable centre tab. The second method is used when the tube is retained by a spring-loaded tube holder at one end and a stationary tube holder at the other end. The third method is used when the tube is rotated or turned in the tube holder for removal and installation. With all methods, precautions are necessary to avoid damage to the tube, tube holder, and the associated ballast unit by subsequently overheating.

(a) Butt-on type tube holders have a movable centre tube which retains the tube base pins against spring contacts. When the top of the centre tab is pressed outwards, the pins can be removed from the tube holders (see Figure 7). The tube should not be rotated as this may cause damage to the pins, tube holders, and, subsequently, the ballast unit. To replace the tube, firstly check that the spring contacts are in position and then press the pins at each end of the tube into the tube holders until they are secure in the contact detents.

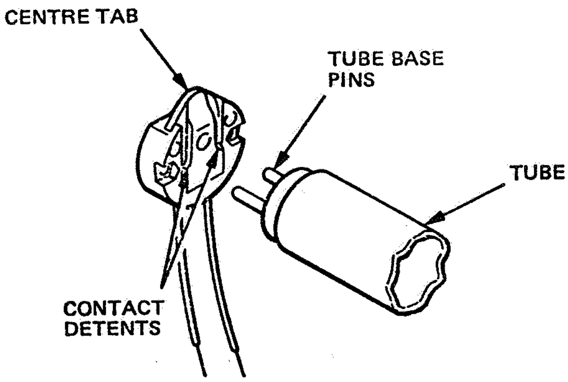



*Figure* 7 BUTT-ON TYPE TUBE HOLDER

(b) To withdraw the tube from a spring-loaded tube holder opposing a stationary tube holder, apply gentle pressure with the tube towards the spring-loaded tube holder until the tube base pins on the opposite end of the tube are released from the stationary tube holder, and can be withdrawn. The tube should not be rotated during this operation, or damage may result in the same way as for the butt-on type of tube holder. To replace the tube, position the base pins in the spring-loaded tube holder (ensuring that it is not rotated) and gently apply pressure toward the spring-loaded tube holder with the tube until the pins on the opposite end of the tube can be inserted into the stationary tube holder (see Figure 8).

(c) To withdraw the tube from a rotation-type tube holder, carefully rotate the tube (in either direction) until the tube base pins release from the contact detents in both tube holders, and remove the tube. To replace the tube, place the tube base pins in the tube holders and carefully rotate the tube (in either direction) until the pins engage with the contact detents.

(d) When a fluorescent light ballast unit has been replaced following a failure, it is recommended that the contacts in the tube holders be checked and that the tube or tubes be replaced, so as to avoid the possibility of faulty contacts or faulty tubes causing a further failure of the ballast unit as a result of overheating.

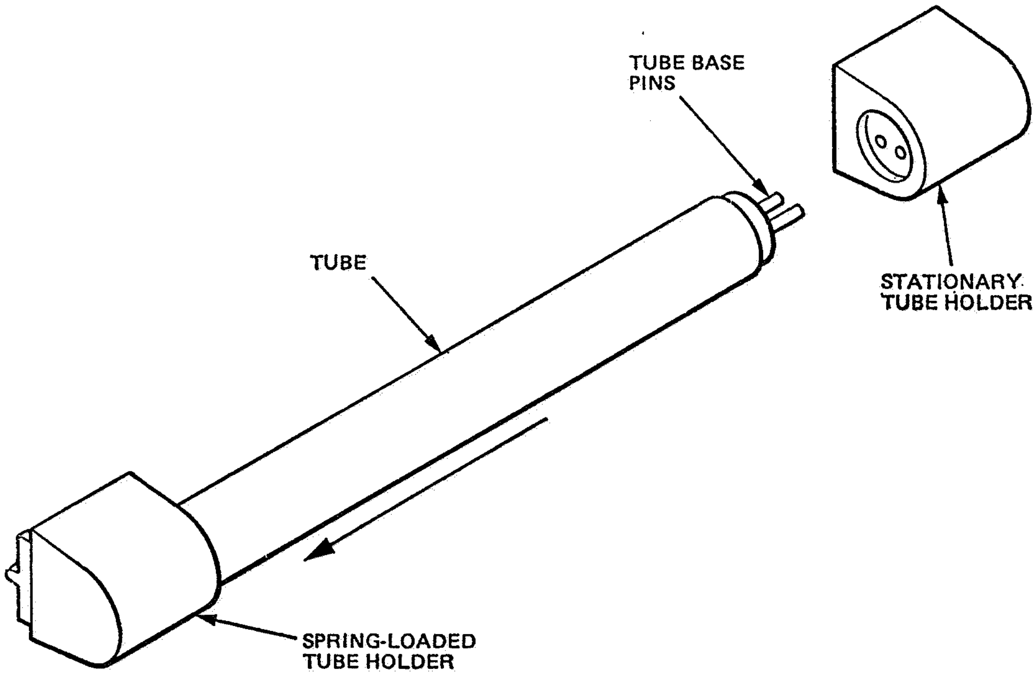



*Figure* 8 SPRING-LOADED TUBE HOLDER

5.5 **Strobe Lighting.** Strobe high intensity lighting can be dangerous to servicing personnel, as the energy storage capacitors are charged to voltages which can be lethal. Accordingly, a minimum of two minutes should be allowed for the capacitors to discharge after the circuit has been de-energised. In addition, it should be borne in mind that damage to the eyes may result from looking directly into high intensity light.

5.6 **Plastics Fittings and Fixtures.** Plastics fittings and fixtures are used extensively in aircraft lighting systems and also in the interior trim, therefore, extreme care should be taken when handling such parts. Where possible, the use of tools should be kept to a minimum, and only gentle hand pressures should be applied when removing plastics-based trim panels, light lenses and lens covers.

5.7 **Self-illuminating Signs.** The only possible hazard attendant upon the use of such signs is that due to inhalation or absorption into the body of gas released in the event of breakage of the glass envelope. Tritium gas is mildly radioactive, therefore, the signs should be handled carefully to avoid breakage. Should breakage occur, the aircraft should be evacuated and all doors left open to allow maximum ventilation. Disposal of broken signs are subject to the Radioactive Substances Act 1960 and the Radioactive Substances (Luminous Articles) Exemption Order 1962 and should, therefore, be returned to the manufacturer for disposal. All self-illuminating signs should be checked for luminosity level on initial fitting and at periods specified in the relevant maintenance schedule. Such signs usually have a scrap life of 5 years and should then be returned to the manufacturer for disposal.

EEL/2-1

*Issue* 1.

*December*, 1979.

# AIRCRAFT

## ELECTRICAL EQUIPMENT

## CHARGING ROOMS FOR AIRCRAFT BATTERIES

1 INTRODUCTION This Leaflet gives guidance on the setting-up and operation of rooms equipped for the purpose of charging aircraft batteries.

1.1 Mandatory provisions for the setting-up and operation of battery charging rooms are contained within the Factories Act.

1.2 The following Leaflets contain information associated with the subject covered by this Leaflet, and reference should be made to these, as appropriate.

**BL/1-7** Storage Conditions for Aeronautical Supplies

**EEL/1-1** Batteries—Lead-acid

**EEL/1-3** Batteries—Nickel-cadmium

2 BUILDING AND EQUIPMENT

2.1 **General**

2.1.1 In no circumstance should the same facility be used for both nickel-cadmium and lead-acid battery charging; and the ventilation arrangements shall be such that no cross contamination can occur.

2.1.2 Buildings and rooms used for the purpose of charging batteries should be well lit and cool, and should have a ventilation system which is capable of exhausting all the gases and fumes which may be present during the servicing and charging operations. The floor surface should be of a material which is impervious to acid and alkali, has non-slip qualities and is quick drying and able to be washed down easily. Examples of such materials are dustless concrete, bituminous compound or tiling. Adequate and suitable drainage should be provided for washing down purposes. Because of the fire risk, it is strongly recommended that doors should be fitted so that they open outwards, thus facilitating easy evacuation from the building in the event of fire. To permit free and easy movement of batteries, steps and thresholds should, where possible, be eliminated. If, however, different levels are unavoidable they should be linked by inclines.

2.2 **Water Supply.** At least one tap in each room where battery charging is carried out should be connected to a mains fresh water supply. Sinks and draining boards and a hot water supply should also be provided.

2.3 **Lighting.** The level of lighting within the charging rooms should be sufficient to enable the level of the electrolyte in individual cells of batteries to be easily determined without additional lighting. To prevent accidental ignition of gases all electrical fittings should be of a sparkproof design.

2.4 **Ventilation.** Hydrogen is given off at all stages of lead-acid battery servicing; the highest concentration being at the end of the charging cycle. Hydrogen is also produced when nickel-cadmium batteries reach the fully charged state; i.e. at the 'overcharge' point and for a 24 hour period thereafter. Heavy corrosive fumes are also emitted when mixing of electrolytes takes place. Therefore, a ventilation system is required which is capable of extracting all gases and fumes, whether heavier or lighter than air.

2.5 **Temperatures**

2.5.1 **Electrolyte Temperature.** The maximum permissible electrolyte temperature during charging is normally 50°C (122°F), but some batteries of special design, however, have lower limits; for such batteries the temperature limitations will be specified in the manufacturer's publication for that battery.

2.5.2 **Environmental Temperature.** Environmental temperatures exceeding 27°C (81°F) for lead-acid batteries and 21°C (70°F) for nickel-cadmium batteries impose time penalties in reaching the fully charged state and may also be deleterious to the batteries. The temperature of battery charging rooms should, therefore, be maintained at a temperature consistent with specified limitations, and with a free air flow around each battery or cell.

## 3 CHARGING BOARDS AND BENCHES

3.1 Detailed differences exist between the various types of charging board, but in general each board consists of a pair of terminals, to which the rectified a.c. supply is connected (or in the case of a board which has a built-in rectifier unit, to which the mains supply is connected), together with a number of pairs of output terminals, to which the batteries are connected for charging.

3.2 All the output circuits are internally connected in parallel, and are, therefore, independent of each other, with the level of charge being controlled separately for each output circuit. Each pair of output terminals is normally designed to have one group of batteries or cells connected in series.

**NOTE: Parallel connection of batteries to one pair of output terminals is not permitted.**

3.3 Charging boards should be mounted directly above the rear of the benches so that the necessity for long connecting cables is avoided.

3.4 Battery connecting cables should be well insulated and should be of a sufficient capacity to carry the charging current required. The free ends of connecting cables should be fitted with suitable connectors, which should be firmly secured to the battery and charging board before commencing charging operations. Connections to the charging boards should not be made or broken when power is switched on. On completion of the charging cycle, power should be switched off and the charging cables should be disconnected, first from the battery and then from the charging board.

### 3.5 Benches

3.5.1 Benches and associated equipment should be sited so that the need for personnel to lean over batteries is kept to a minimum. It is recommended that the height of battery charging benches be approximately 0·5 m (20 in) from the floor. At this height, lifting strain is minimised, and a more effective visual inspection of the batteries can be made.

3.5.2 The surfaces of battery charging benches should be acid and alkali resistive, and should facilitate cleaning. It is generally considered that batteries should not be allowed to stand directly on wood or concrete, but should rest on suitable grids.

## 4 POWER SUPPLIES

4.1 Transformer/rectifiers which normally provide rectified a.c. for charging board supplies should be sited in a fume free, dry and cool position, preferably in a separate room, located as near as possible to the charging boards. Charging boards which require 240 volts mains supply, should be supplied from a ring main system.

## 5 STORAGE

5.1 **Batteries.** In order to preserve an orderly flow of work through a battery charging room, storage facilities should be provided such that incoming unserviceable batteries may be separated from those ready for issue, preferably in clearly placarded areas. The storage facilities should be further grouped for those batteries requiring initial charge and those awaiting routine servicing. Batteries which are serviceable and awaiting issue are best stored in an area which is not subjected to excessive vibration. It is essential that whilst in store, lead-acid batteries be segregated at all times from nickel-cadmium batteries; preferably in separate store rooms. For further information on the long term storage of batteries, reference should be made to Leaflets **BL/1-7, EEL/1-1** and **EEL/1-3.**

### 5.2 Electrolytes

5.2.1 The handling and storage of electrolyte materials should always be in accordance with the manufacturer's instructions. It is, however, essential that when undertaking the mixing or breaking down of these chemicals, separate areas are provided. Glass, earthenware or lead-lined wood containers are suitable for the storage of lead-acid battery electrolyte (sulphuric acid), whilst plain iron, glass or earthenware containers are suitable for the storage of nickel-cadmium battery electrolyte (potassium hydroxide). Galvanised containers or containers with soldered seams must not be used. Each container should be clearly marked as to its contents and should be stored accordingly. Waste or surplus materials should be disposed of in accordance with locally approved instructions. If, however, doubt exists, all electrolytes should be neutralised prior to disposal (paragraph 5.4). All mixing vessels, mixing rods and other similar items should be clearly marked with "acid only" or "alkaline only", and their use should be restricted accordingly.

5.2.2 Stocks of electrolyte materials which are retained in a battery charging room should be restricted to the quantities required for immediate use. The storing of electrolytes mixed ready for use should be avoided as far as possible.

(a) Sulphuric acid containers should be kept tightly sealed when not in use, to prevent contamination. Only the container which is required for immediate use should be retained in the charging room.

(b) Potassium hydroxide is supplied in solid form contained in steel drums. Once a drum has been opened the contents are liable to carbon dioxide contamination. The entire contents should, therefore, always be mixed as soon as a drum has been opened. Any unused mixture should be stored in a stoppered glass container.

5.3 De-mineralised and distilled water are generally supplied in carboys, and should be stored separately from the electrolytes, so as to avoid contamination. Carboys should be firmly stoppered when not in use, and should be clearly marked as to the contents. Only the water container used for 'topping up' should be kept in the charging room, and the stopper should be refitted immediately after use.

5.4 The neutralising agents for the two types of electrolytes are given below, together with the action that should be taken in the event of contamination and/or spillage.

5.4.1 **Sulphuric Acid.** The neutralising agents are:—

(a) Saturated solution of bicarbonate of soda.

(b) Ammonia powder.

(c) Borax powder.

The acid should be soaked up with sawdust which should then be removed and buried. The affected area should be treated with one of the above, followed by washing down with copious amounts of fresh water.

5.4.2 **Potassium Hydroxide.** The neutralising agents are:—

(a) Boric acid solution.

(b) Boric acid crystals or powder.

The alkali should be soaked up with sawdust, which should then be removed and buried. The affected area should be treated with one of the above, followed by washing down with copious amounts of fresh water.

5.4.3 Containers of sawdust and neutralising agents should be clearly marked with their contents and use, and sited in readily accessible positions.

## 6 PROTECTION

6.1 To prevent the risk of burns, such personal items as rings, metal watches, watch-straps and identification bracelets should be removed, to avoid contact with connecting links and terminals. Personal protection against the harmful effects of acid and alkali contamination should be in accordance with the provisions of the Factories Act.

6.2 In general, smoking should only be permitted in rooms which do not have a direct access to battery charging rooms or chemical mixing areas. Naked lights, non-safety matches and automatic lighters should not be taken into battery charging rooms.

6.3 Fire extinguishers of the $CO_2$ type and buckets of sand should be placed at strategic points inside the building for use in the event of any chemical fires.

## 7 DOCUMENTATION

7.1 Records of battery servicing should be maintained to the standard recommended by Leaflets **EEL/1-1** for lead-acid batteries and **EEL/1-3** for nickel-cadmium batteries.

## 8 SERVICING AND TEST EQUIPMENT

8.1 Servicing of aircraft batteries should be carried out in accordance with the instructions contained in the manufacturers' Maintenance Manual.

8.2 In addition to the general engineering hand tools which may be required for aircraft battery servicing, the following specialised items will also be required:—

(a) Hydrometers.

(b) Thermometers.

(c) Battery kits (as supplied by battery manufacturers).

(d) Capacity test sets.

(e) Leakage tester (lead-acid batteries).

(f) Filler pumps (for transferring of liquids from one container to another).

(g) Calibrated test equipment:

- (i) Insulation resistance tester.
- (ii) Universal test meter.
- (iii) Digital voltmeter.

8.2.1 To prevent cross-contamination between the two types of aircraft batteries, two sets of equipment should be held, each being contained in separate cupboards and clearly marked "acid only" or "alkaline only" as appropriate to the application. Wherever possible, tools and equipment comprising the sets should be those constructed of an insulating material. Each item should be identified as to its application, and in the case of hydrometers and thermometers, this is usually best done on the instrument case.

*Issue* 3.
*June*, 1981.

# AIRCRAFT

## ELECTRICAL EQUIPMENT

### CABLES—INSTALLATION AND MAINTENANCE

1 INTRODUCTION This Leaflet gives guidance on the installation of the various types of electrical cables used for the wiring of general services in aircraft, and their attachment to various forms of terminations, but does not include information on the types of cables designed for specific functions, e.g. high voltage ignition supplies or radio-frequency services. The CAA requirements for electrical installations in aircraft are prescribed in Section J of British Civil Airworthiness Requirements, the relevant parts of which should be read in conjunction with this Leaflet.

1.1 To maintain general environmental suitability, only the types of cables specified by the aircraft or equipment manufacturer, or approved equivalents, should be used. This will ensure that the cables will be suitable for the voltages which will be applied to them under the conditions of operation and test, and that the current ratings will be such that when the cables are installed and carrying the most onerous loads in the most adverse ambient temperatures probable, the temperatures attained by the conductor will not cause damage to the cables.

NOTE: British Standard G212 gives general requirements for aircraft electrical cables.

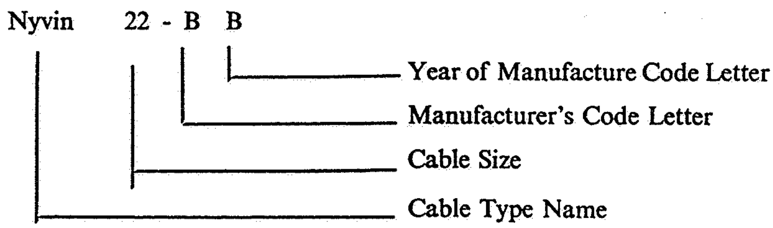
1.2 The following Leaflets contain information associated with the subject covered by this Leaflet, and reference should be made to them as appropriate:

**BL/6-1** Soft Soldering
**BL/6-2** Brazing
**EEL/1-6** Bonding and Circuit Testing
**AL/3-7** Control Systems

1.3 To obviate the need for the revision of this Leaflet when new issues of the specifications referred to are published, the prefix or suffix indicating the issue number of the specification has been omitted.

2 CABLE IDENTIFICATION Aircraft electrical cables are normally marked with an identification code as shown in the following examples:

(a) **Period 1963 to Mid 1970s:**



(b) **Period Mid 1970s to 31st December 1978:**

Minyvin G XX X 22

- 22 — Cable Size
- X — Year of Manufacture Code Letter
- XX — Manufacturer's Code Letter
- G — Country of Origin
- Minyvin — Cable Type Name

(c) With effect from 1st January 1979 the country of origin code for Great Britain was changed from G to GBx, although the rest of the code remained unchanged.

2.1 There is a further requirement that an adequate means of identification be provided for cables, connectors, terminals, plugs and sockets, etc., when installed in the aircraft, and methods of so doing for cables are described in paragraph 9.

3 DETERIORATION Aircraft cables are designed to provide the best possible combination of resistance to deterioration caused by extremes of temperature, mechanical damage and contamination by fluids, and in general, are suitable for installation without additional mechanical protection. Working conditions and environment, however, may necessitate the provision of extra protection in those places where the cables are exposed to the possibilities of local damage or conditions which could cause deterioration, and protection is described in paragraph 7.3.

4 RECEIPT AND STORAGE OF CABLES Prior to delivery, cable ends are sealed, so far as is practicable, to prevent ingress of moisture, and the cables are generally supplied on drums suitably labelled and protected to prevent damage during transit or storage. Smaller sizes of cable may sometimes be supplied in wrapped coils. Visual examination of cables on receipt, by nature of the packing, is often restricted to the outer turns. Such an examination is of little value in checking for faults in the cable, therefore, if the condition of the packing, as received, gives rise to doubt regarding the soundness of the cable, it should be returned to the manufacturer.

4.1 Cables should be stored in a clean, well-ventilated store. They should not be stored near chemicals, solvents or oils and, if necessary, protection should be provided against accidental damage. Loose coils, whether wrapped or not, must not be stored so that a heavy weight is imposed on them, since this may cause unacceptable distortion of the insulation or damage to the protective coverings. The ends of cables in store should be sealed against the ingress of moisture by the use of waterproof tape or a suitable sealing compound.

5 HANDLING OF CABLES It is important that cables should be handled carefully at all stages of storage and installation.

5.1 When taking long lengths of cable from a drum or reel, the cable should not be allowed to come in contact with rough or dirty surfaces. Preferably the drum or reel should be mounted so that it can rotate freely, but heavy drums may need some means of control over rotation.

5.2 Care should be taken to remove the twist out of each turn of cables drawn from loose coils, otherwise severe kinking, with consequent damage to the cable, may occur.

**6** MADE-UP CABLING Cable looms and cable runs made-up on the bench should be inspected before installation in the aircraft to check the following:

(a) That all cables, fittings, etc., are of the correct type, have been obtained from an approved source, have been satisfactorily tested before making up and have not deteriorated in storage or been damaged in handling.

(b) That all connectors and cable looms conform to the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing in respect of terminations, length, angle of outlets and orientation of contact assemblies, identification, and protection of connections.

(c) That all crimped joints (see paragraph 7.5.7) and soldered joints (see paragraph 7.5.8) have been made in accordance with the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing, are clean and sound, and that insulating materials have not been damaged in any way.

(d) That cable loom binding and strapping is secure.

(e) When required by the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing continuity, resistance and insulation tests should be carried out in accordance with those instructions. For further details and guidance see Leaflet **EEL/1-6.**

**7** INSTALLATION OF CABLING IN AIRCRAFT In addition to the checks outlined in paragraph 6, the cabling should be installed in accordance with the requirements of the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing. Guidance on the factors requiring special attention during the installation is given in the following paragraphs.

7.1 **Contamination.** To prevent moisture from running along the cables and seeping into the associated equipment, the cables should be so routed as to run downwards away from the equipment. Where this is not possible, the cable should incorporate a descending loop immediately before the connection to the equipment. Where conduits, tubes or ducts are used, they should be installed in such a way that any moisture accumulating in them will be able to drain safely away. Cables which are routed through such fittings should be capable of withstanding any such moisture as may be encountered.

7.2 **Interference.** Interfering magnetic fields may be set up by electrical equipment, electrical currents in the cabling, or the aircraft structure, and also by magnetic materials. Cables are required, therefore, to be installed so as to reduce electrical interference to a minimum and to avoid interaction between the different electrical services.

NOTE: Requirements for the avoidance of compass and radio interference are given in Chapter **J4-1** of British Civil Airworthiness Requirements.

7.3 **Protection of Cabling.** The cables are required to be protected from abrasion, mechanical strain and excessive heat and against the deleterious effects of fuel, oil and other aircraft fluids, water in either liquid or vapour form and the weather. Cables should be spaced from the skin of the aircraft so as to reduce the effect of the high skin temperatures likely to be reached in the tropics. The cables should not be run near the hot parts of an engine or other hot components unless a cooled-air space or heat barrier is interposed.

NOTE: Where it is not possible to install apparatus in a position protected from the weather, the requirements of Section J of British Civil Airworthiness Requirements must be taken into consideration.

7.3.1 Cables must not be supported or allowed to bear on sharp edges such as screw heads or ends, or on the edges of panels, metal fittings, bulkheads or lightening holes.

7.3.2 Where cables are routed through metal fittings or bulkheads, etc., the edges of the holes through which they pass must be radiused and smoothed and fitted with an insulated bush or sleeve. Cables which are drawn through holes or tubes must be an easy fit requiring only a moderate, steady pull, care being taken to keep the cables parallel to one another and to avoid the formation of kinks (which may cause fracture of the conductor).

7.3.3 Conduits, ducts and trunking used for carrying cables should have smooth internal surfaces. Rigid ducts and conduits should be adequately flared at the outlet or bushed with insulating material.

7.3.4 Cables being fitted through pressure bungs should be fitted into the correct size holes for the size of cable, to ensure efficient sealing. Only the recommended cable threading tool should be used for this purpose to avoid damaging the bung membrane. Bungs without membranes should have filler plugs fitted in unwired holes.

7.4 **Support of Cabling.** The cabling must be adequately supported throughout its length, and a sufficient number of cable clamps must be provided for each run of cable to ensure that the unsupported lengths will not vibrate unduly, leading to fracture of the conductors or failure of the insulation or covering. Bends in cable groups or bundles should not be less than eight times the outside diameter of the cable group or bundle. However, at terminal blocks, where the cable is suitably supported at each end of the bend, a minimum radius of three times the outside diameter of the cable, or cable bundle, is normally acceptable.

7.4.1 Cables must be so fitted and clamped that no tension will be applied in any circumstances of flight, adjustment or maintenance, and so that loops or slackness will not occur in any position where the cables might be caught and strained by normal movement of persons or controls in the aircraft, or during normal flying, maintenance or adjustment.

7.4.2 Where it is necessary for cables to flex in normal use, e.g. connections to retractable landing gear, the amount and disposition of slack must be strictly controlled so that the cable is not stressed in the extended position, and that the slack will not be fouled, chafed, kinked or caught on any projection during movement in either direction.

7.4.3 Cables should normally be supported independently of, and with maximum practicable separation from, all fluid and gas carrying pipelines. To prevent contamination or saturation of the cables in the event of leakage, cables should be routed above rather than below liquid carrying pipelines. Cables should not be attached to, or allowed to rub against, pipelines containing flammable fluids or gases.

7.5 **Cable Terminations.** There are several methods by which cables are terminated, but the one most commonly used is the solderless or crimped termination. The soldered method is also used, but is generally confined to the joining of internal circuit connections of consumer equipment and in some cases, to the connection of single core cables and plug and socket contacts. The means of terminating cables and effecting junctions between cables and equipment must be in accordance with the requirements of the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing. Therefore, the information given in the following paragraphs is of a general nature and is intended only as a guide.

7.5.1 **General Requirements.** The conductors should be firmly secured to the connections on the equipment, using the appropriate method for the particular installation. The surfaces of electrical contacts should be clean, and the mating parts should be in contact over the full area. The protective sleeves fitted over connections should be undamaged and positioned correctly. Holding screws and nuts should be properly locked where provision is made for this to be done; particular care should be taken where varnish is the locking medium as it must not be allowed to spread onto, or over, the electrical contact surfaces. Torque loading of holding screws or nuts should be to the recommended values and should be marked in accordance with the maintenance instructions. The connections should not place either the cable or the equipment in a state of tension. Twisting and kinking in the vicinity of the connection should be avoided, as this may lead to a fracture if the cable is subjected to vibration.

7.5.2 To facilitate installation, maintenance and repair, cable runs and looms are broken down at specified locations by junctions, such as connectors or terminal blocks. Before assembly to these junctions, cables should be cut to the required length, with the cut being clean and square, and the wire conductor not deformed. If necessary the conductors of large diameter cables should be re-shaped after cutting. Good cuts can only be made if the blades of cutting tools are sharp and free from nicks. A dull cutting edge will deform and extrude the conductor strands.

7.5.3 Before cables can be assembled to connectors, terminals, crimps, etc., the insulation must be cut back and stripped from the connecting ends to expose the wire conductors. Care should be taken when stripping cable that the conductor strands are not cut or nicked. If the lay of the wire conductor strands is disturbed, it should be re-imposed by a light twisting action. Excessive twisting should be avoided as this will increase the diameter of the cable and may result in a defective joint.

7.5.4 On small diameter cables, only the recommended stripping tools should be used for removing the insulation. On no account should a knife or side cutting pliers be used because of the high risk of damage to the conductor strands. For size 8 or larger diameter cables a knife may be used to make lengthwise cuts partially through the outer covering and insulation; these should then be bent back and cut off with side cutters or scissors. The stripped cable should be examined for signs of damage, severed strands and cleanliness, before it is connected up.

7.5.5 The following general precautions are recommended when stripping any type of cable:

(a) When using any type of cable stripper, hold the stripper so that the cutting blade is square to the cable.

(b) Follow the manufacturer's instructions when adjusting automatic stripping tools, to avoid damaging the conductor strands by cutting or nicking; this is especially important for aluminium cables and the smaller sizes of copper cables. Cut-off and re-strip (if length is sufficient), or reject and renew any cable which has been so damaged.

(c) Ensure that the outer covering and the insulation are clean cut, with no frayed or ragged edges.

(d) When using hand-operated strippers to remove lengths of insulation longer than 19 mm (0·75 in), the stripping should be accomplished in two or more operations.

(e) Re-twist conductor strands by hand, or with pliers, if necessary, to restore the natural lay and tightness of the conductor strands.

7.5.6 **Aluminium Cables.** The use of aluminium cables in aircraft has been brought about chiefly by the weight advantage of this metal over copper. However, in order to obtain satisfactory electrical connections, certain special installation techniques are necessary.

(a) Aluminium cables should be stripped very carefully, since individual conductor strands will break very easily after being nicked.

(b) Bending of aluminium cables will cause "work hardening" of the conductor strands, resulting in failure or breakage of strands much sooner than in cables with copper conductors.

(c) Aluminium, when exposed to the atmosphere, forms an oxide film which acts as an insulator. This film can, if left untreated, cause corrosion at connecting joints, and as it also increases in thickness as heat is generated by current flow, it will further increase the electrical resistance of that joint (see paragraph 7.5.7 (d)).

7.5.7 **Crimped Connections.** A crimped connection is one in which a cable conductor is secured by compression to a termination so that the metals of both are held together in close contact. A typical crimp termination has two principal sections, crimping barrel and tongue (see Figure 1), together with, in some types, a pre-insulated copper sleeve which mates with the crimping barrel at one end and is formed, during the crimping process, so as to grip the cable insulation at the other in order to give a measure of support. The barrel is designed to fit closely around the cable conductor so that after pressure has been applied a large number of points of contact are made. The pressure is applied with a hand or hydraulically operated tool fitted with a die or dies, shaped to give a particular cross-sectional form to the completed joint.

(a) The precise form of the crimp is determined by such factors as the size and construction of the conductor, the materials, and the dimensions of the termination. It is, therefore, most important that only the correct type of die and crimping tool should be used, and that the necessary calibra'ion checks have been made to the tool.

NOTES: (1) British Standard G178 gives information regarding the production and testing of crimped joints for general purpose electrical cables. Reference should also be made to the appropriate manufacturer's technical literature on this subject.

(2) British Standard G180 gives information on the permanent splicing of aircraft electrical cables.

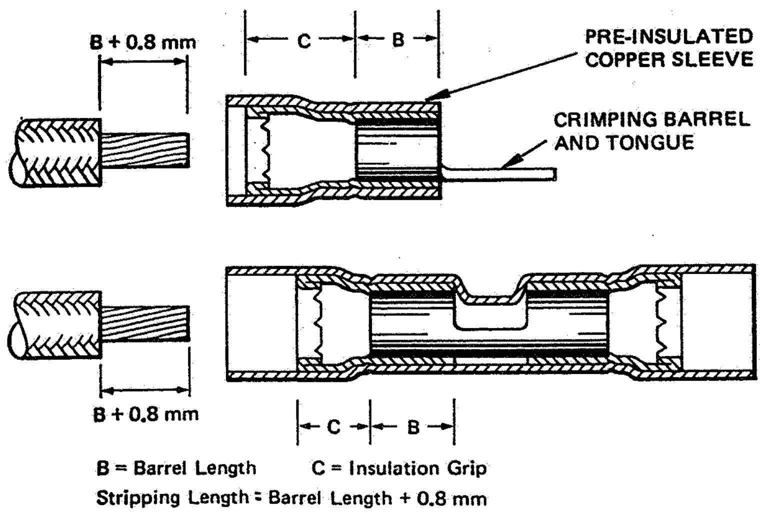



*Figure* 1 TYPICAL CRIMP TERMINATIONS

(b) Hand crimping tools (see Figure 2) normally have a self-locking ratchet which prevents opening of the tool until the crimping action is complete. Some tools are equipped with a nest of various size dies to allow for a range of different sizes and types of terminations, while others are suitable for one size and type only. In addition, many of the tools and/or dies are colour coded to correspond with the colour marking used on some terminations. It is essential that the recommendations and instructions of the relevant aircraft or equipment manufacturer should be strictly complied with when undertaking work of this nature.

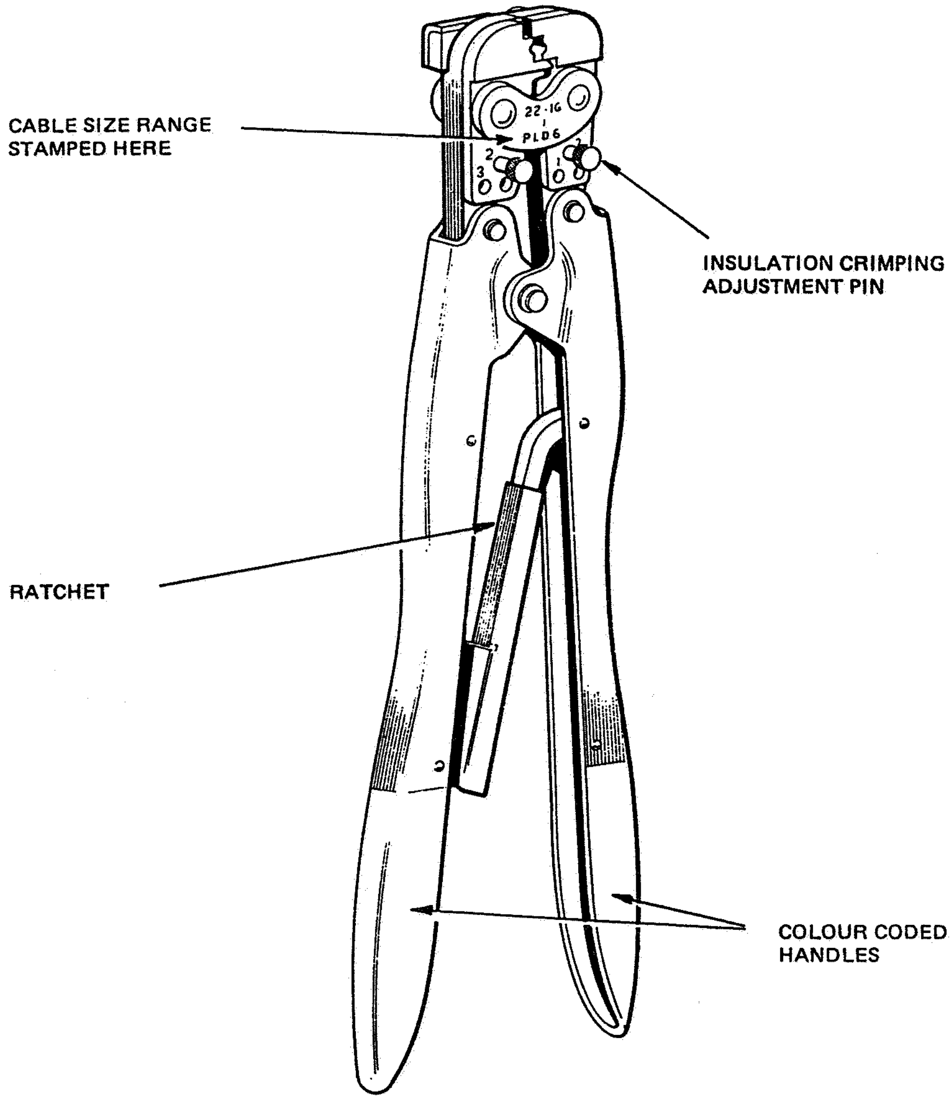



*Figure* 2 EXAMPLE OF A HAND OPERATED CRIMP TOOL

(c) There is a vast range of terminations available, many of which are colour coded, and suitable for use only with specific types of aircraft cable. It is, therefore, vital that the appropriate manufacturer's instructions regarding the use of cables and terminations are followed.

(d) Only aluminium or bimetal (AICu) terminations should be used to terminate aluminium cables and the cable should be stripped immediately prior to making the joint. The barrel of some aluminium terminations may contain a quantity of inhibiting compound, others not so filled require that inhibiting compound be applied before crimping takes place. Some specifications also require additional sealing after crimping. The compound will also minimise later oxidation of the completed connection by excluding moisture and air.

(e) The following general precautions are recommended when making crimped cable joints:

(i) When initially inserting the appropriate termination tongue-first into the barrel crimping jaws of the crimping tool, ensure that the termination barrel butts flush against the tool stop (see Figure 3).

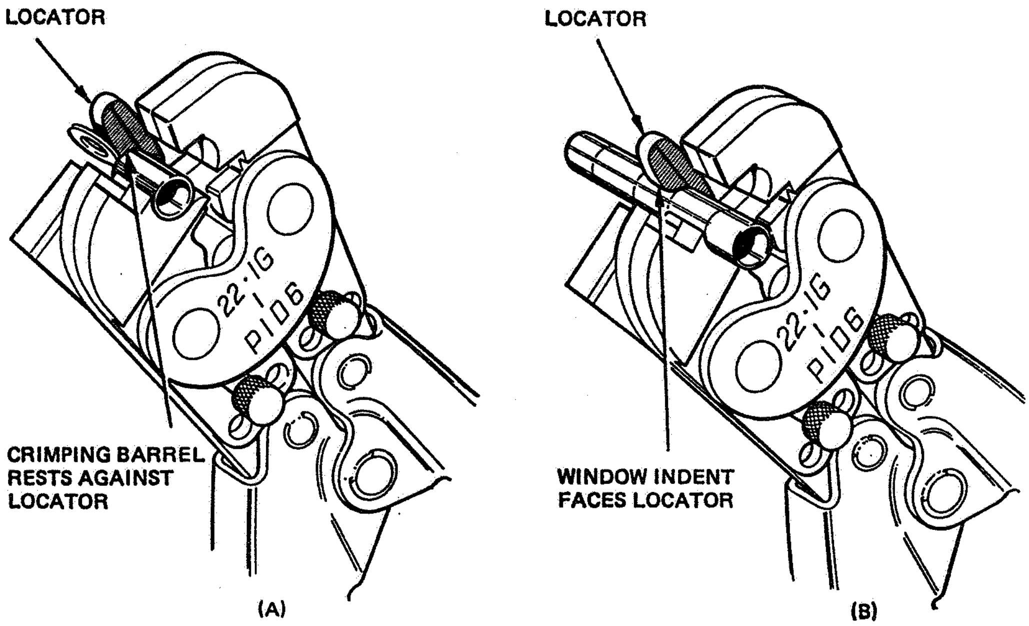



*Figure* 3 CORRECT LOCATION

(ii) When positioning the prepared cable end into the terminal barrel of an uninsulated termination, ensure that the cable dielectric butts flush against the end of the barrel, or for a pre-insulated termination to the top of the insulation support.

(iii) Ensure that the tool handles of a hand operated tool are squeezed fully together, or in the case of power operated tools, the pressure relief valve has operated, to ensure that the crimp has been completed and allow release of the jaws.

7.5.8 **Soldered Connections.** In general, aircraft installations are such that it should not be necessary to make soldered joints within the aircraft. If, however, soldering is required, it should be carried out strictly in accordance with the procedures in the relevant aircraft Maintenance Manual or Wiring Diagram Manual. Soft soldering and silver soldering are the two methods used for aircraft electrical cabling systems.

(a) **Soft Soldering.** Where electrical connections are made by the soft soldering method special care is necessary because over-heating and slow cooling of conductors or terminal fittings will cause brittleness. The connections to socket inserts, plug pins, etc., should be free from excess solder which may cause short-circuits, impair the operation of spring contacts, or obstruct the mating of plugs and sockets. Further information on soft soldering will be found in Leaflet **BL/6-1.**

(b) **Silver Soldering.** Low temperature brazing, also known as silver soldering, is a brazing process which uses filler alloys based mainly on silver and copper, with a melting range of 505 to 850°C. Silver soldering is typically employed on certain EGT/JPT/TGT compensating lead terminations.

7.5.9 **Looped Connections.** In the case of some small instruments on older types of aircraft, the wire conductors may be looped around the terminal screw, but it should be ensured that the wire conductors are securely held between a plain washer and the metal base or insert. To reduce the likelihood of breakage under vibration, such connections should not normally be soldered, unless a double-back loop is formed and reinforcement is provided at the end of the soldered portion, and care is taken to ensure that wicking does not occur.

7.5.10 **Screened Cables**

(a) There are several methods of connecting the metal braided screens of cables, each depending on the circuit application and type of cable being used. Therefore, for precise details, reference to the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing should be made. In general, however, the connections will normally be made utilising either soldered sleeves or crimping, and in one of the following forms:—

(i) "High"—fitted with no ground wire.

(ii) At the end with a ground wire.

(iii) At the end with link wires to other screens and ground wire.

(iv) Mid-span with a ground wire.

(v) Mid-span with link wires to other screens and ground wire.

(b) When preparing screened cables for the required screen termination, care should be taken to ensure that removal of any outer protective covering does not cause damage, in the form of cuts and nicks, to the metal braiding. If the connection is such that the metal braiding has to be cut off it should be done squarely and cleanly, ensuring that the braiding is not frayed at the cut edge. Where the braiding is to form the tail of the connection, it should be picked out of its mesh and the individual wires should be carefully twisted together. When cutting and preparing the metal braiding, care should also be taken to avoid damaging the insulation of the conductor.

8 PLUG AND SOCKET CONNECTORS To prevent damage and the entry of dirt, the protective caps which are provided with connectors should be fitted at all times other than when the connectors are being worked on. During work protection may then be in the form of a linen or plastic bag, totally enclosing the connector and secured to the cables. This temporary protection should only be removed just prior to connection being made in the aircraft. When a connector is disconnected, and it is intended that it be left open for a period of time, then both plug and socket should be protected to prevent damage and the entry of dirt.

8.1 **Miniature Connectors.** Extreme care should be taken when handling and connecting miniature and sub-miniature connectors. Both plugs and sockets should be checked for any signs of dirt, bent pins or physical damage to the shells before attempting to connect. If connectors will not mate, check for the reason, and rectify or renew. On no account should force be used to effect mating.

8.2 **Lubrication.** Some ranges of plugs and sockets require the engaging threads to be lubricated with a suitable lubricant to ensure that they can readily be disconnected. Lubrication should be carried out in accordance with the recommendations in the relevant aircraft Maintenance Manual, Wiring Diagram Manual or Modification Drawing.

8.3 **Assembly and Maintenance of Electrical Plugs and Sockets.** There are many different types of plug and socket connectors, each having its own maintenance requirements, therefore, reference should always be made to the relevant manufacturer's Maintenance Instructions and aircraft Maintenance Manual or Wiring Diagram Manual for precise details of cable preparation, special tool requirements (including insertion and extraction tools) and crimping information. The following paragraphs are, therefore, only intended as a guide on general maintenance practices and the safety precautions which should be observed.

8.3.1 **General Maintenance and Repair**

(a) The appropriate contacts and inserts for all the contact holes should be selected.

(b) All unused holes in the cable sealing grommet should be fitted with an approved filler plug.

(c) For connectors with cable clamps which are not provided with resilient bushings, it may be necessary to increase the diameter of the cables to enable a firm clamp to be obtained without distorting the cables. This may be achieved by one or more of the following methods, but whichever method is used, care should be taken to ensure that cables are not forced against any metal parts of the clamp; that the clamp is not over-tightened so as to crush or deform the cables; or that any cables connected to an outer ring of contacts are not forced to the clamp centre causing the holes in any sealing grommet to become deformed and consequently straining the contact joints.

(i) A plain insulation sleeve may be fitted over the cable bundle.

(ii) A plain insulation sleeve may be fitted over each individual cable.

(iii) The cable bundle may be wrapped around with a number of turns of a suitable tape.

(iv) A small roll of a suitable tape may be placed in the centre of the cable bundle.

(d) Where cable clamps are fitted with resilient bushings, care should be taken to ensure that the bushings used are of such size that the cables are firmly held in place but do not crush or deform the cable insulation when the clamp is tightened. To provide the proper fit for bushings, the following procedure should be applied. The smallest size or sizes of bushings to be omitted or the next smallest size or sizes shall be added, whichever is required.

(e) Some connectors have a "ground" connection point, provided with a "grounding" screw and washer, which should always be removed if a ground wire is not being connected.

(f) When connectors are installed as a provision for the installation of equipment at a later date, they should be protected by dust caps. Unused connectors supported only by the cables should be protected with an insulating sleeve pulled over the connector and cables so that it extends sufficiently to enable the end to be folded back and secured. This should then be clamped to the aircraft structure.

8.3.2 **General Maintenance and Repair Procedures.** The following procedures should be followed for the maintenance and repair of aircraft electrical plugs and sockets:

NOTE: No attempt should be made to straighten bent contacts since the resulting work-hardening may result in failure of the contacts.

(a) **Preparation**

(i) The cable clamp securing screws should be loosened and any packing should be discarded.

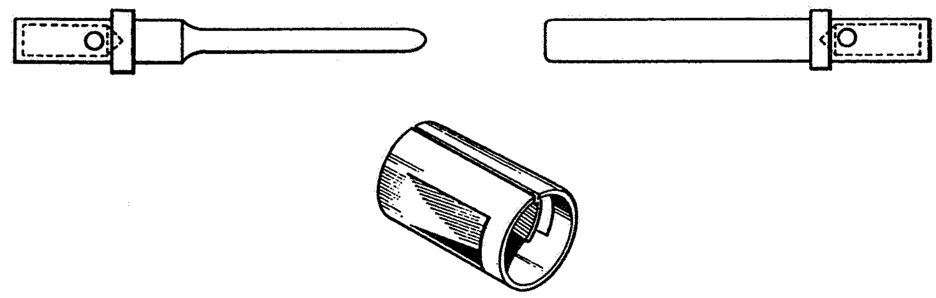
(ii) The threaded backshell should be unscrewed and eased back over the cables.

(b) **Removal of Wired Contacts.** There are two basic types of contact retention used in plug and socket connectors in aircraft, one with the contacts being released for removal from the rear of the contact insert and the other from the front. Each system requires the use of different types of insertion/extraction tools, therefore, it is essential that the correct procedures and tools are used for a particular type of plug or socket.

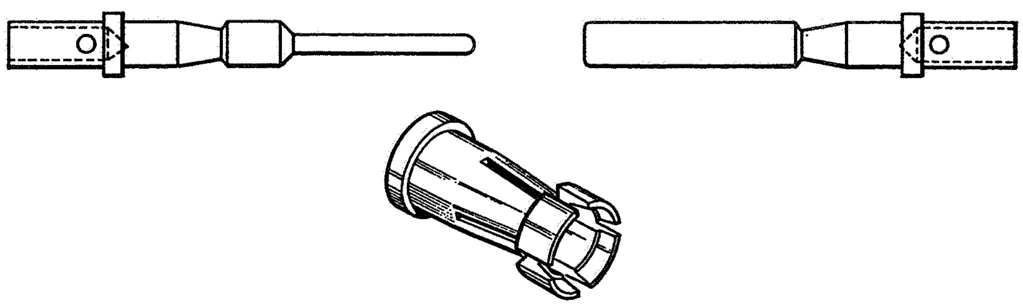
(i) **Rear Release.** The appropriate extraction tool should be positioned over the cable connected to the contact to be removed. To ensure that the contact retention system has been released (see Figure 4A), the extraction tool should be slid slowly into the contact insert hole in the plug or socket until a positive resistance to further movement is felt. With the cable held against the extraction tool, the contact should be removed by pulling the cable and tool from the plug or socket insert.

(ii) **Front Release.** The appropriate extraction tool should be positioned over the contact to be removed and, with the central plunger of the tool held back, pushed into the plug or socket to release the contact retention system (see Figure 4B). Depressing the central plunger of the extraction tool will eject the contact rearwards, out of the plug or socket. Extreme care should be taken when using this type of tool as their tips are easily damaged, which unless identified and replaced with a serviceable one, can cause damage to inserts and contacts.

NOTE: In repair operations only one contact at a time should be removed and repaired, so as to avoid the possibility of misconnection.



(A) REAR RELEASE



(B) FRONT RELEASE

*Figure* 4 COMPARISON OF RELEASE SYSTEMS

(c) **Removal of Unwired Contacts.** The sealing plug should be removed and the appropriate unwired contact extractor should be slid slowly, and straight, into the contact insert hole. Stopping of the extractor will indicate that it has bottomed on the contact shoulder. The contact should then be removed by slowly pulling the extractor and contact from the plug or socket.

(d) **Preparation of Cable and Crimping the Joint.** Stripping of coverings and insulation of cables should be done as recommended in paragraph 7. It should be noted, however, that if wire strands are damaged during this operation, the cable end should be cut off and the stripping procedure repeated.

(i) The appropriate contact for the plug or socket should be selected and the prepared cable should be inserted into the contact barrel ensuring that the wire conductors are visible through the inspection hole positioned at the base of the crimp barrel of the contact.

(ii) Where more than the required length of wire is exposed between the insulation and the contact, the wire end should be trimmed by cutting off the surplus without deforming the wire end. If the wire becomes deformed, the complete end must be cut off and the preparation should be repeated.

(iii) The contact should be inserted into the appropriate crimping tool and the prepared cable should be positioned and then the handles of the recommended calibrated crimping tool should be closed in a continuous movement. Most hand operated tools are provided with a ratchet assembly which will not release the jaws until a full stroke has been completed.

(iv) A check of the contact for any distortion because of a faulty tool or die should be made. If distortion has occurred the tool should be replaced with a serviceable one, the bent contact cut off and a new joint made.

(e) Inspection for a correctly formed crimp joint should be carried out in the following manner :

(i) It should be ensured that the conductor is visible though the inspection hole of the crimp connection barrel.

(ii) The crimp pattern should be clean, with the crimp indentations evenly spaced.

(iii) The crimp identification pattern must not break over the cable entry end of the connection barrel or the shoulder of the contact.

(iv) There must not be any cracks visible at the edge of the inspection hole or at the cable entry end of the connection barrel.

(f) Insertion of wired contacts into the plug or socket should be carried out in the following manner:

(i) The connected cable should be placed into the recommended insertion tool with the tool tip butting against the contact shoulder. The contact should be pushed slowly and straight into the rear of the contact insert. Firm stoppage of the contact indicates that it has seated in the insert. The cable should then be released from the tool and the tool removed by pulling it backwards.

(ii) If contacts are to be inserted into holes near the edge of the insert, the open side of the tool should always face the edge of the insert; this avoids excessive strain on the insert.

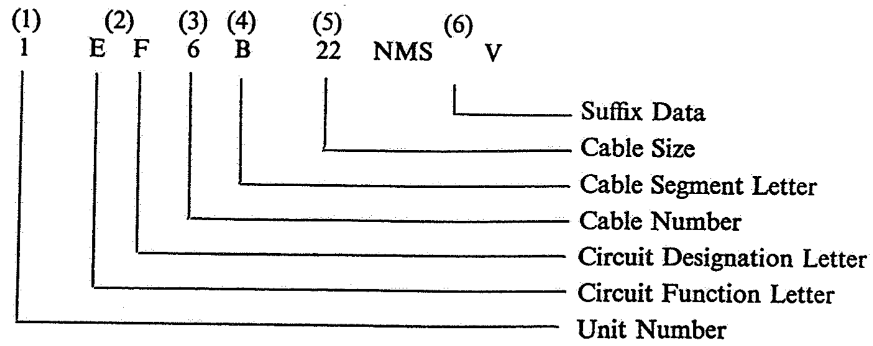
(iii) The proper size contacts and sealing plugs should be fitted into any vacant contact insert holes and the plug or socket should be reassembled by screwing on the backshell. Re-fitting of the cable clamp assembly is described in paragraph 8.3.1 (c) and (d).

8.3.3 **Inspection and Testing.** The test probes used for inspection and testing should be of such size that the contacts are not damaged or spread. On socket contacts the test probes should be of the same size or less than the mating plug contact. This is most important as the use of oversize test probes can result in open circuits and intermittent connections when the plug and socket are mated.

9 IDENTIFICATION OF INSTALLED CABLES Aircraft cables are normally marked with a combination of letters and numbers to provide the necessary information to identify the cable, the circuit to which it belongs, the cable size, and any additional information necessary to relate it to a circuit diagram or routeing chart. Such a code is usually either of the aircraft manufacturer's own specification or one devised by the Air Transport Association of America under Specification 100 (ATA 100) which has been accepted as a standard.

9.1 The ATA 100 Specification basic coding consists of a six position combination of letters and numbers, which are printed on the outer covering of the cable. The identification code is normally printed at specified intervals along the length of the cable. Where printing is not practical the code is printed on non-metallic sleeves and positioned along the cable length.

9.1.1 **Basic Cable Coding System**




Position 1—Unit number, used where components have identical circuits.

Position 2—Circuit function letter and circuit designation letter which indicate circuit function and the associated system.

Position 3—Cable number, allocated to differentiate between cables which do not have a common terminal in the same circuit. Generally, contacts of switches, relays, etc., are not classified as common terminals. Beginning with the number one, a different number is given to each cable.

Position 4—Cable segment letter, which identifies the segment of cable between two terminals or connections, and differentiates between segments of the circuit when the same cable number is used throughout. Segments are lettered in alphabetical sequence, excluding the letter I and O. A different letter is used for each of the cable segments having a common terminal or connection.

Position 5—Cable size.

Position 6—Suffix data, used to indicate the type of cable and to identify its connection function. For example, in the example code NMS V indicates nyvin-metsheath ungrounded cable in a single-phase system.

NOTE: Full details of the cable coding system will be found in the Maintenance Manual or Wiring Diagram Manual for the relevant aircraft.

9.1.2 To assist the fitting and positioning of insulating or indentification sleeves to cables, full use of the recommended lubricants should be made. To prevent over extension of small diameter sleeves it is recommended that thimble jigs or needle tools are used. Three-prong fitting pliers can damage overlays on sleeves and should only be used on the larger diameter sizes and then only extended to approximately 300% of the sleeve internal diameter. When positioning sleeves on cables care should be taken to ensure they slide and not roll.

## 10 INSPECTION AND TESTING OF CIRCUITS

10.1 Before carrying out tests, or when inspection is specified in the approved Maintenance Schedule, all aircraft circuits, together with plugs, sockets, terminal blocks and equipment terminals, should be examined, as appropriate, for signs of damage, deterioration, chafing, poor workmanship and security of attachments and connections. Information and guidance on the inspection and testing of electrical circuits are given in Leaflet **EEL/1-6**.

10.1.1 The methods of testing and inspection will vary with different types of aircraft and the equipment fitted, therefore, reference must be made to the relevant Maintenance Manuals for detailed information.

10.2 **Test Equipment.** Each test requires specified equipment and care should be taken that it is correctly used. To ensure the reliability of test equipment, it should be carefully serviced and certified at the periods recommended by the manufacturer. The performance of equipment should also be checked before and after use.

10.2.1 After completion of all tests, the installation should be inspected to ensure that all connections have been re-made and secured, and that test equipment, tools, etc., have been removed. This should be carried out immediately prior to the fitting and securing of panels, etc. The circuits should then be proved, as far as the installation permits, by making ground functioning checks of the services concerned.

10.3 Any disconnection or disturbance of circuits associated with flying or engine controls will require duplicate inspection and functioning test as outlined in Leaflet **AL/3-7.**

**MMC/1-1**

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# AIRCRAFT

# MICROMINIATURE CIRCUITS

## PRINTED WIRING BOARDS

1 INTRODUCTION The assembly of the various circuits which form part of the units employed in aircraft electronic systems, necessitates the interconnection of many components by means of electrical conductors. Before the introduction of printed wiring, these conductors were formed by wires which were connected to the components either by soldering, or by screw and crimped terminal methods. In the development of circuit technology, the significant trends towards micro-miniaturisation, rationalisation of component layout and mounting, weight saving, and the simplification of installation and maintenance, became essential factors; and, as a result, the technique of printing the required circuits was adopted. In this technique, a metallic foil is first bonded to a base board made from an insulating material, and a pattern is then printed and etched on the foil to form a series of current conducting paths, the pattern replacing the old method of wiring. In some cases, an additive process (see paragraph 7.2) may be adopted whereby copper is deposited only in those areas where conducting paths are required. Connecting points and mounting pads, for the soldering of components appropriate to the circuit, are also formed on the board, so that, as a single assembly, the board satisfies the structural and electrical requirements of the unit of which it forms a part. If the circuit is a simple one, the wiring may be formed on one side of a board, but, where a more complex circuit is required, wiring is continued on to the reverse side, which also serves as the mounting for components. In addition, complex circuits may be incorporated in multi-layer assemblies. A typical example of the printed wiring technique, as it is applied to a double-sided board, is shown in Figure 1. In this example, connections to and from the circuit are made by finger or edge contacts, which plug into a correspondingly shaped socket. Other methods of connection include flat cables and plugs, flexible printed wiring, and board-mounted connectors.

1.1 The design of printed wiring boards and the production of complete assemblies are of a specialised nature, and both may vary according to individual circuit requirements and specifications. The information given in this Leaflet is, therefore, intended purely as a general guide to typical production methods and inspection procedures, and is set out as follows:—

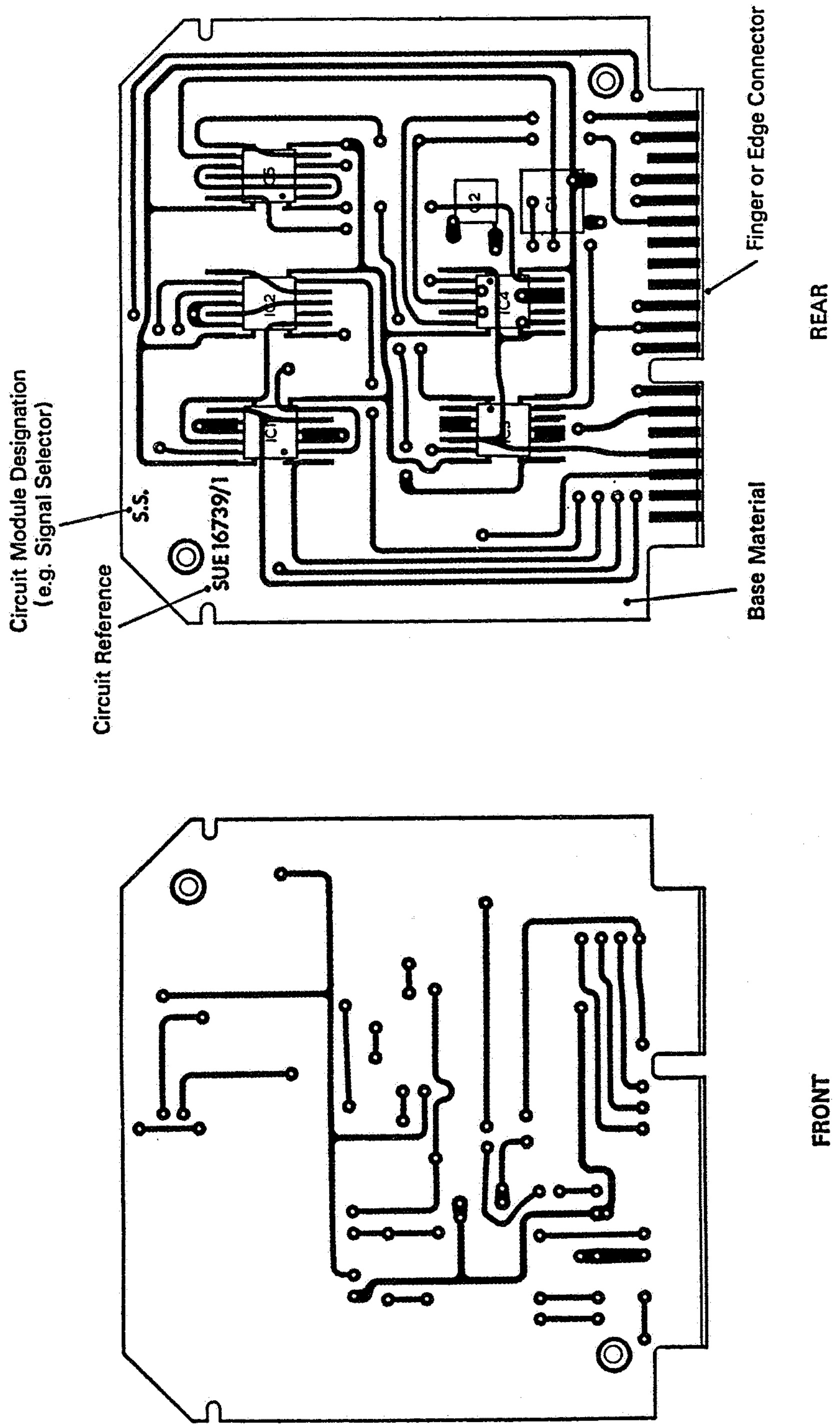



*Figure* 1 TYPICAL DOUBLE-SIDED BOARD

1.2 Other relevant information is contained in Leaflets **BL/1-12** and **BL/6-1**, and in the following specifications:—

| | | |
|---|---|---|
| BS 2572 | Phenolic Laminated Sheet. | |
| BS 2782 | Methods of Testing Plastics. | |
| BS 4025 | General Requirements and Methods of Test for Printed Circuits. | |
| BS 4584 | Metal-clad Base Materials for Printed Circuits. | |
| BS 4597 | General Requirements and Methods of Test for Multi-layer Printed Wiring Boards using Plated-through Holes. | |
| DEF STAN 59-47 | Protective Coatings for Printed Wiring Boards. | |
| DEF STAN 59-48 | Part 1 | Test Requirements for Single and Double-sided Printed Wiring Boards. |
| | Part 2 | Test Requirements for Multi-layer Printed Wiring. |

NOTE: With the introduction of the BS 9000 series of specifications, it is probable that certain of the specifications noted above will be affected, and that the relevant information will be withdrawn or combined under a new number.

**2** BASE MATERIAL The base material, or laminate as it is sometimes called, is the insulating material to which the conducting material is bonded. The base material also serves as a mounting for the components which comprise the circuit. The base material is commonly made up either of layers of phenolic resin impregnated paper, or of epoxy resin impregnated fibre glass cloth which has been bonded to form a rigid sheet, which can be readily sawn, cut, punched or drilled. The thickness of the base material depends on the strength and stiffness requirements of the finished board, which, in turn, are dictated by the weight of the components to be carried, and by the size of the printed conductor area.

2.1 The resin of the base material is brought to a state of partial cure (known as 'B' – stage or 'prepreg' material) in which it is dry and not tacky, but on heating it again flows and regains its adhesive properties. The base material is normally stored at a low temperature in the 'B' – stage state until it is required for the next stage in the manufacture of a circuit board, which is the bonding to it of the conducting material.

**3** CONDUCTOR MATERIAL The most commonly used conducting material is copper foil, the minimum purity value of which is 99·5%. The normal weights per unit area of the foil are as follows:—

(a) 1 oz/ft² (0·0014 in. thick approx.)

(b) 2 oz/ft² (0·0028 in. thick approx.)

(c) 3 oz/ft² (0·0045 in. thick approx.)

4 BONDING OF CONDUCTOR MATERIAL For the manufacture of a typical circuit board, the base material and copper foil are cut into sheets, and are then inspected and assembled inside a clean room (see Leaflet **BL/1-12**) in alternate layers with stainless steel separator plates (known as cauls) interposed between the layers, as shown in Figure 2. The steel plates, which are accurate in thickness to within 0·001 inch, are very hard, and have a delicately grained surface which is imparted to the finished boards. The layered sheets (the assembly) are then passed out of the clean room to be bonded in a hot press. During the pressing operation, the heat melts the resin in the base material, so that it flows and fully wets out the material and the copper foil. The pressure applied is adjusted so as to exclude all air and vapour from any residual volatiles. As polymerization of the resin mix proceeds, each layer of base material reaches the fully cured state ('C' – stage) with the copper foil firmly bonded to it. After cooling has taken place, the individual copper-clad boards are trimmed to the required size, inspected, and packed in sealed polythene bags.

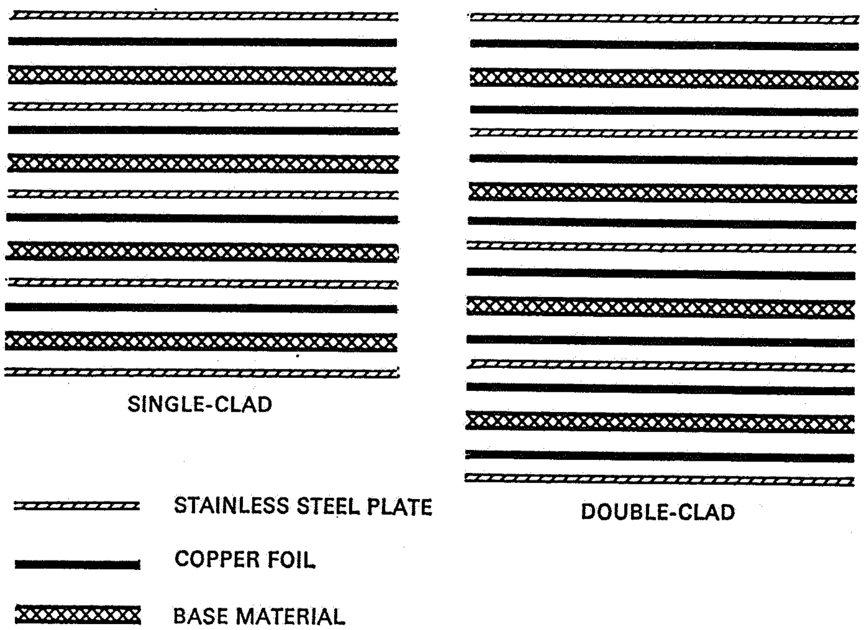



*Figure* 2 BONDING OF CONDUCTOR MATERIAL

4.1 **Inspections and Tests.** After manufacture, all boards should be inspected, and tests should be carried out on selected samples, in accordance with the relevant specifications. The details given in the following paragraphs are intended only as a guide to the inspections and tests which are generally required.

4.1.1 **Appearance.** The copper surface should be free from resin and from undesirable defects, such as blisters, wrinkles, pinholes, bumps, deep scratches, and pits. Any discolouration or contamination of the surface should be removed by an aqueous solution of hydrogen chloride, or by a suitable organic solvent.

4.1.2 **Thickness.** The thickness of a board should be checked, to ensure that it does not depart at any point from the specified nominal thickness. A typical thickness range is from 0·031 to 0·125 in. and the preferred tolerances over this range are from ±0·0035 to ±0·008 in. for paper base material, and from ±0·006 to ±0·012 in. for glass cloth base material.

4.1.3 **Bow and Twist.** Bow should be measured parallel to the edges of the board. The board should be laid, concave side uppermost, on a flat horizontal surface, and a straight edge should be offered to the upper surface, in the direction of maximum curvature. The maximum clearance between the board and the straight edge should be taken as the measure of bow. Twist, which should be measured with the predominantly concave side of the board downwards on a flat horizontal surface, is taken as the separation of any one of the corners of the board on the concave side with the three other corners held lightly in contact with the surface. The permissible limits of bow and twist are governed by such factors as board thickness, weight of copper foil, and type of assembly, e.g. single-clad or double-clad.

4.1.4 **Peel Strength.** Peel strength is the minimum load required to pull a strip of foil (either 1 inch or ⅛ inch wide) from the base material. The foil should be detached from one end of the specimen, and pulled in a direction perpendicular to the plane of the board, so as to peel off a specified length of foil at a steady rate (e.g. a 1 inch length at 2 inches per minute). The load should be measured by any suitable load measuring device, e.g. a spring balance, and should be within the limits specified. Typical values of peel strength are, not less than 12 ozf per ⅛ in. width for phenolic paper base, and not less than 24 ozf per ⅛ in. width for epoxy glass.

4.1.5 **Heat Resistance by Solder.** For this test, a one inch square specimen of the board should be floated, with the copper face downwards, on to the surface of clean molten solder. The temperature of the solder should be measured by a thermocouple and potentiometric apparatus, and should be within the limits specified for the test; a typical value is 250°C ±2°C. The specimen should be left in contact with the solder for 10 seconds. The copper should not show any signs of blistering, or of delamination, at the end of this time. For double-clad boards, a fresh specimen should be used for testing each side.

4.1.6 **Pull-off Strength.** For this test, a specimen of the board, of any convenient size, is printed (see paragraph 7) with a test pattern consisting of up to ten lands. A hole is drilled through the centre of each land, and, after tinning of the lands, a short length of hard-drawn brass wire is passed through each hole, and is soldered at right angles to the lands. A load is applied to the free end of each wire in turn, in a direction perpendicular to the surface of the board, by a tensile testing machine, and the load is increased until the land is pulled from the base material. The minimum pull-off force required should not be less than the value specified; a typical value for phenolic paper base materials is 7 lbf and a typical value for epoxy glass base materials is 15 lbf.

4.1.7 **Electrical Tests.** On each batch of boards, it is also necessary to investigate certain electrical properties, and, for this purpose, specimens should be printed with specific circuit patterns. The following tests are those generally carried out:—

(a) **Surface Resistance.** This test is designed to ascertain the insulation resistance (in megohms) between adjacent printed conductors when a test voltage of either 85 volts d.c. ±10% or 500 volts d.c. ±10% is applied to the conductors for one minute.

(b) **Loss Tangent.** The loss tangent (sometimes called the dissipation factor or power factor) of a material, is a measure of its insulating characteristics in an alternating electric field. The lower the loss tangent, the smaller is the power wasted in the form of heat.

(c) **Foil Resistance.** The resistance of a strip cut from a board should be measured with a suitable electrical bridge. Care should be taken to ensure that the bridge current used is not so high as to cause any appreciable heating of the strip.

NOTE: Details of electrical test methods and values are given in the relevant British Standards and DEF Specifications.

5 MACHINING OF BOARDS All boards require machining, e.g. guillotining, sawing, punching, and drilling during the various stages of production.

5.1 **Guillotining.** This is one of the quickest and most economical methods of cutting sheets of copper-clad laminates into strips and panels, and it is frequently employed in conjunction with subsequent punching operations. Correctly performed guillotining results in a clean, burr-free edge, with no wastage of stock.

5.1.1 There is no advantage in heating epoxy/glass laminates. However, with phenolic/paper laminates, the best guillotined edge can be obtained by pre-heating them within the temperature range recommended for the particular grade of material. This temperature range may vary between 40°C to 130°C, although lower temperatures can be used for trimming, where only the edge on one side of the cut is important. Heating by radiation, infra-red or convection, is suitable, and so far as is possible a sheet of laminate should be heated on both sides thereby preventing the tendency for the sheet to curl. Overheating of the material must be avoided, as this results in blistering, which in effect hardens the board and makes subsequent drilling or punching operations more difficult.

5.1.2 Machines, not specifically designed for guillotining laminates, may be used, but difficulties in producing a clean edge may arise. Blades set specifically for sheet metal cutting have a 'scissor' action, and cutting laminated sheet with such blades produces irregular and chipped edges, which may start cracks running into the material at an angle from the edges. Raising the pre-heating temperature of the sheet can alleviate the problem in some instances, but it is better to reposition the blades, so that the cutting edges are at an approach angle of ½° to 1½° for cutting speeds of 600 ft/min to 1,000 ft/min respectively, across the surface of the laminate.

5.1.3 Laminates are abrasive and, therefore, the sharpness of cutting edges must be monitored. Clearance between the blades should be kept to a minimum, bearing in mind that during use thermal expansion of the blades will occur.

5.1.4 Adjustable stops are essential if dimensional and angular accuracy is to be maintained, and under these controlled production conditions, strip width can be kept within ±0·010 inch over a length of 4 feet. The constant use of one section of the blades, e.g. when cutting strips into panels, will result in uneven wear; to prevent this accurate adjustments should be made to the blades so that their entire length is brought into use.

5.1.5 As copper surfaces are easily scratched, the careful handling of laminates and the removal of swarf during guillotining is essential.

5.2 **Sawing.** Cutting with a circular saw is superior to guillotining as it gives a cleaner edge, especially so as the thickness of the laminate increases. Wood-cutting machinery is satisfactory for laminates, but certain features are essential in order to maintain efficiency and accuracy over long production runs. Table size should be compatible with the largest sheet likely to be cut, otherwise excessive overhang of the sheet will result in chipped edges and slower work. A moving table is ideal; a sheet can be clamped to it, and a straight edge can readily be obtained by working against a fence.

5.2.1 The saw blade gap should be such that a clearance of not more than 0·062 in. is obtained on each side of the blade; the height of the blade, relative to the table, should be adjustable. A blade set too high will give a rather ragged edge, while too low a setting may result in some lifting at the top edge of the work. Paper based sheets may be cut with high speed steel blades, but these blades may require frequent sharpening as some deterioration of the finish of the sawn edges may become evident after one or two hours of operation. The blades may be hollow ground and from 8 in. to 12 in. in diameter, with 0·187 in. tooth pitch. Teeth may be sharpened square, or with a 20° angle right and left, for staggered points. For regular use, tungsten carbide-tipped blades are preferable for cutting paper based sheet. Such blades may be from 8 in. to 12 in. in diameter with a 0·375 in. tooth pitch.

5.2.2 Both steel and tungsten carbide-tipped blades can be used at cutting speeds of up to 10,000 ft/min, with a corresponding feed of about 30 ft/min for 0·060 in. thick material. Too fast a feed will result in chipping and flaking of the material; if the feed is too slow, overheating of the blade and of the material may result. Any burring of the cut edge of the copper should be removed with either a hand, or mechanical, scraper.

5.2.3 The life of tungsten carbide-tipped blades is considerably reduced when cutting copper-clad epoxy/glass laminates. A 12 in. diameter steel disc with the edge resin-coated and embedded with diamond grit will be more durable. The disc can be used dry, but when so used an extraction system for the removal of glass dust should be installed. A cutting speed of approximately 10,000 ft/min is suitable, but the feed rate should be less than when using a toothed blade.

5.3 **Drilling.** The type of resin, base material and the degree of cure, are the main factors affecting the drilling characteristics of a laminate. All laminates are abrasive, particularly those with glass fibre base material, and drilling techniques should be adapted to suit. The drill can be quickly blunted, which causes overheating and degradation of the work; it is, therefore, most important that cutting edges are kept sharp, and friction is reduced to a minimum. Other aspects to be taken into account are the type of drilling machine, type of drill, drilling speed, length of run, and accuracy and finish of holes.

5.3.1 Machines are normally specially designed for printed circuit board drilling, and they incorporate multi-spindles, the location and feed of which are controlled automatically. Control may be effected by numerical information recorded on punched cards or tapes, or by means of a template and stylus.

5.3.2 Sharp-pointed, slow-spiral, high-speed steel drills should be used for drilling boards with a phenolic/paper base, while epoxy/glass base boards should be drilled with solid tungsten carbide drills.

5.3.3 Drilling speed may be kept as high as possible, but is limited by feed rate. A high speed/feed ratio results in excessive friction and overheating, to the detriment of both the drill and the work; after cooling down, holes shrink and are no longer round. The diameters of holes specified for printed circuit boards are generally in the range 0·030 in. to 0·050 in. and, when an automatically-controlled machine is used, the best results are obtained at speeds in the range 15,000 to 25,000 rev/min. With manually-operated machines optimum results will be obtained at slower speeds. Boards drilled singly will allow for cooler and faster running than those drilled in packs, which is similar to drilling a thick section, and, therefore, requires slower speed and frequent drill withdrawal to clear the swarf.

5.4 **Punching.** Where large quantities of laminates are required, and cost of tools is acceptable, punched parts can be produced by conventional pierce and blank methods; such methods are most commonly adopted for copper-clad phenolic/paper base laminates. The quality of the work and the ease with which it can be carried out depend mainly on whether the job has been planned within the mechanical limitations of the material, and on whether due consideration has been given to its characteristics. Reference should be made to the data sheets relevant to the particular material grades, but the observations given in the following paragraphs generally apply.

5.4.1 Better results are usually obtained when the phenolic/paper base laminates are heated, particularly for complex shapes. The blanking operation is more critical than piercing, and the best grades of punching materials will produce simple shapes, at thicknesses up to 0·060 in. approximately, without heating. When the material is heated through the range 60°C to 120°C, according to grade, thicknesses up to 0·125 in. can be blanked. With the better grades of materials, heating is not required for piercing unless the standard required is very critical.

5.4.2 Copper-clad epoxy/glass laminates have very good punching properties at room temperature, although tool wear is high because of the abrasive nature of the material. For work that is to be plated through the holes however, the smoother finish obtained from drilling is recommended.

5.4.3 The heating methods adopted for guillotining epoxy/glass laminate may also be employed for punching. To avoid excessive chilling of a laminate, the punching tool should also be heated to approximately two-thirds of the temperature of the laminate. Strip may be passed through an electric tunnel heater attached to the tool, thereby serving a dual function of heating the stock and the punching tool. Optimum clearances vary according to working temperatures, but the following features, if incorporated in press tool design, can assist trouble-free operation:—

(a) Laminates shrink on to a punch when holes are pierced. The punch should, therefore, be oversize irrespective of hole diameter required. Typical oversize values are 0·003 in. for cold piercing and 0·006 in. for hot piercing on stock of 0·062 in. thickness.

(b) Punch and die clearance should be a minimum (0·001 in. overall) if straight sided holes are required. If tapered holes are acceptable, up to 0·0045 in. overall tolerance will give less wear and drag on the punch and will reduce the tendency towards surface lifting of the stock on withdrawal.

(c) Clearance for blanking should be kept to a minimum and should certainly not be more than 0·002 in. overall. Blanking dies should be undersize to a degree depending on the thickness of the material, and on whether it is being worked in a cold or heated condition. Typical values for 0·06 in. material are 0·003 in. (cold) and 0·0015 in. (heated).

5.4.4 Holes may also be pierced in boards on semi-automatic turret presses using a drilled template. The template holes are colour-coded to aid in the selection of the designated punch size. When a stylus point is depressed into a hole the press is tripped to operate and to pierce the board.

CIRCUIT ARTWORK The quality of a printed wiring board is, in the first instance, dependent on the production of master artwork which must show precisely the circuit conductor pattern required, where components are to be located, circuit module designations and other essential references. Artwork production requires the use of dimensionally stable base materials, and the application of skilled drafting techniques, because, unlike conventional electrical drawings, which are used as a guide to the build-up of an assembly of wiring and connections, a printed wiring board is an actual reproduction of the original artwork produced for it.

6.1 Artwork is normally prepared under controlled temperature and humidity conditions (typical figures are 20°C ±2°C and 50% ±5% R.H.) and, under these conditions or variations therefrom, the materials for artwork layout are required to exhibit minimal changes in dimensions; thus, dimensional stability is of great importance. Materials which are satisfactory in this respect, and which are in common use, are:—

(a) Polyester film.

(b) Optical glass plate.

(c) Foil card, made up of a sheet of aluminium with a white paper surface on each side.

(d) Aluminium sheet coated with several coats of white enamel.

6.2 Optical glass plate is the most stable of materials for artwork production, but, as it is difficult to work on direct, other methods of laying out circuit patterns are desirable. Two methods which are generally recommended are:—

(a) Initial preparation of the artwork on polyester film, followed by photographic transfer to the glass under controlled environmental conditions.

(b) Preparation of the artwork direct onto the glass by means of a numerically-controlled drafting machine.

6.3 The required circuit patterns may be drawn in ink, or, as is more usual, by the application of self-adhesive black material specially produced in tape form to represent conductors, and in other shapes to represent terminal points, edge connector contacts, drilling points, connector pads, etc. The material is produced in a wide range of sizes to suit both the scale selected for the drawing and the reduction ratio required for the subsequent photographic and printing processes.

6.4 The layout and drafting of master artwork vary according to both the skill of the draftsman concerned and the environmental conditions existing at the photographic stage. In order to normalise the photographic film, environmental conditions at the photographic stage should be the same as those under which the artwork was produced. Other factors which may cause inaccurate reproduction include, damage to artwork during handling and storage, shrinkage of tapes causing breaks in connections, tape overlaps causing distortion of sharp edges, and lack of temperature stabilisation of artwork before the photographic stage.

6.4.1 Human error in drafting can be reduced, and, in certain cases, eliminated, by the use of numerically-controlled drafting machines. These are accurate X and Y co-ordinate plotting machines which are capable of automatically plotting a point, or line, on a surface whether it be on a film or glass base. To eliminate problems which arise with drawing tape deterioration or movement during the course of time, a copy of the original master artwork should be made immediately on highly stable material. All subsequent modifications to the artwork can then be carried out on the new master, and copies can be made from it. Artwork should be allowed to stabilise under the specified controlled environmental conditions before being photographed, and variations in these conditions between photographic and board production stages should be kept to a minimum. This is particularly important with multi-layer circuit assemblies, and when artwork has to be moved from one place to another.

6.5 For circuits which are to be printed on both sides of a board, accurate registering during the photographic stage is essential, and, where numerically-controlled drafting machines are available, they should be used. An alternative technique for accurate registration of double-sided boards, consists of drafting both circuit patterns on a single piece of artwork material with tapes of different colours. Red tape is used for one pattern, and blue tape for the other; while black tape is used for those conducting paths which are common to both patterns and which must appear on both sides of the boards. During the photographic process, colour filters are used, in turn, to eliminate the red and the blue tape images, so that two negatives are produced, each of which shows a separate side of the board in perfect register.

7 PRINTING OF CIRCUITS The printing of circuits is carried out using either an etching process or an additive process. Both of these processes, which are shown in Figure 3, are briefly described in the following paragraphs.

7.1 **Etching Process.** In this process the copper foil is first cleaned, either chemically or mechanically, and is then coated with a photo-sensitive solution known as a 'resist'. A wide range of these solutions is available, but mostly they are allied to the dichromated glues, which have the property of becoming soluble when exposed to strong light. A photographic positive of the circuit artwork is then placed over the sensitised board and time-exposed in a special printing machine. After exposure, the resist is washed away to leave unprotected areas of copper around the circuit pattern, and the board is dried by a clean, oil- and water-free air blast. The complete board is then inspected to ensure that no resist has been removed from any part of the conductor pattern itself, and that no resist particles are present in areas which are to be etched away. The board is then placed in a bath which contains an etching solution, such as ferric chloride or ammonium persulphate, which etches away all the unprotected copper. In order to minimize 'undercutting' by the etching solution, the solution is either agitated over the immersed board, or directed over its surface by spray jets. The etching time is dependent on such factors as bath temperature, specific gravity and pH value of the etching solution; checks on the pH value are of particular importance when ferric chloride is used. When the etching process has been satisfactorily completed, the board is thoroughly washed in water in order to remove all traces of etching solution, and is then dried and given a final inspection.

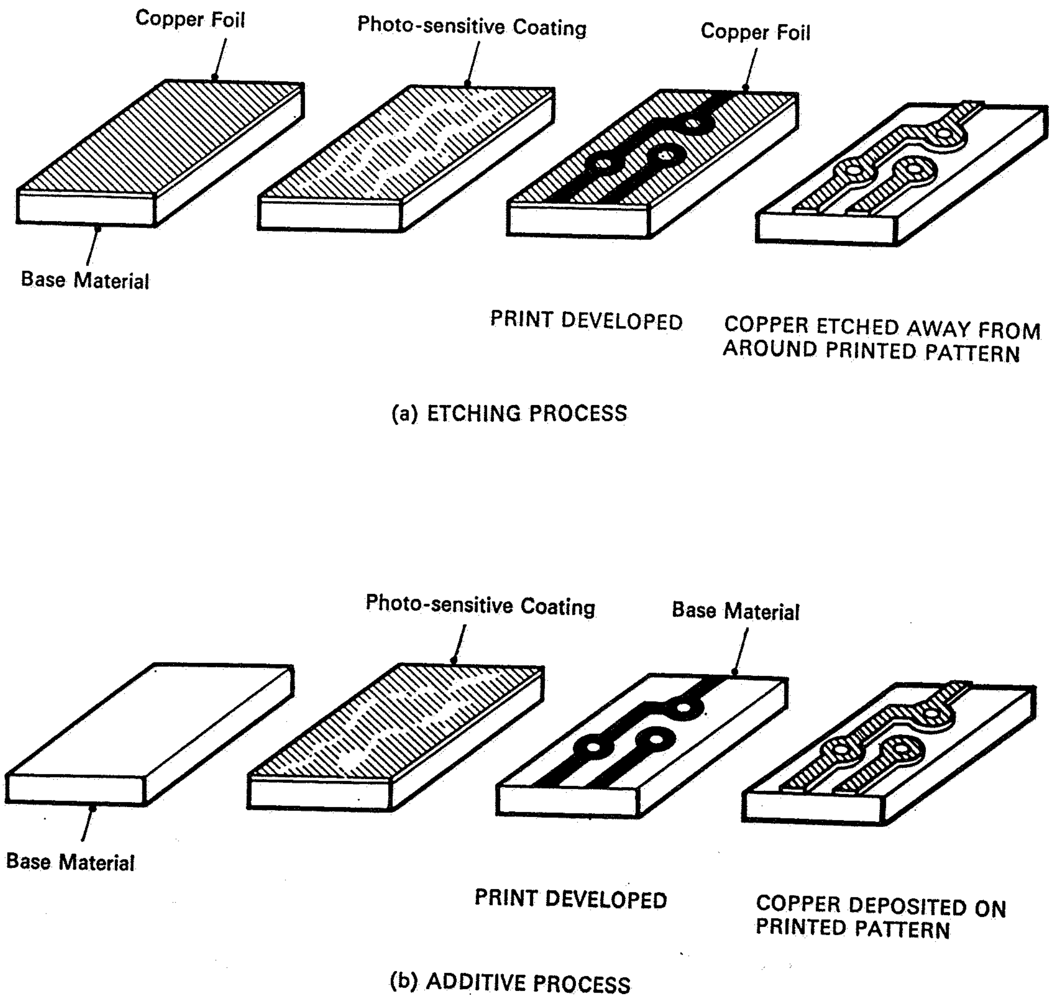



*Figure* 3 PRINTING PROCESSES

7.1.1 As printed circuit boards with the same circuit pattern are often required in large numbers, the simple 'print and etch' process which is described in paragraph 7.1 is generally superseded by a screen printing process. This process involves the preparation, by photographic means, of a gelatine stencil which is applied to a silk screen. The circuit pattern is then printed through the screen with rapid drying resist inks. It is a common practice to print the circuit on the board as a negative, i.e. leaving the copper foil bare over the areas where it is to remain on the finished board. A metal which will be resistant to the etching solution is then applied to the copper. This may be done either by immersing the board in solder, or by plating on a suitably resistant metal. The ink is then removed from the remaining areas of the board, and the exposed copper is etched away.

7.2 **Additive Process.** In this process, copper is deposited only in the areas where conductors are required. To achieve this the base material is pre-coated with a suitable adhesive, the circuit holes are pre-fabricated, and the board is sensitised with a photo-resist solution. A negative of the circuit pattern is then screen printed onto the board so that the exposed areas define the conductor network. These exposed areas are chemically activated, and the board is then immersed in an electroless copper plating solution. After a period of time consistent with the deposition of the required thickness of copper, the board is removed from the bath. The major advantages of the additive process are; no chemical etching takes place, thereby eliminating wastage of copper and problems associated with undercutting; the thickness of the deposited copper can be reduced and made more uniform, the conductor widths and spacings are less restricted, and the hole diameters can be reduced, thereby increasing the board area available for routeing of conductors.

7.3 **Inspection.** After printing, circuit patterns should be inspected and particular attention should be paid to the following:—

(a) **Dimensional Accuracy and Condition of the Edges of Conductors.** Ragged edges, tapering of end contacts and burning of conducting areas under edges of the resist material, may all be caused by over-etching, which would lead to rejection of the board. Minor imperfections may be accepted, provided that the reduction in the total width of the conductor does not exceed the values specified for the pattern.

NOTE: The inspection of conductor patterns can be aided by the use of a light box, or of an optical system.

(b) **Condition of the Pattern Surfaces.** These should be clean, and free from hairline cracks, blistering, large pinholes, dents and scratches. Minor superficial dents may be accepted provided that they are parallel to the track of a conductor, and so long as they do not affect the bond of the conductor.

(c) **Particles of Copper in Unwanted Areas.** These particles, which are produced as a result of under-etching, should always be removed.

(d) **Insulation Areas.** These should be free from flaking, crazing, resin starvation and similar imperfections.

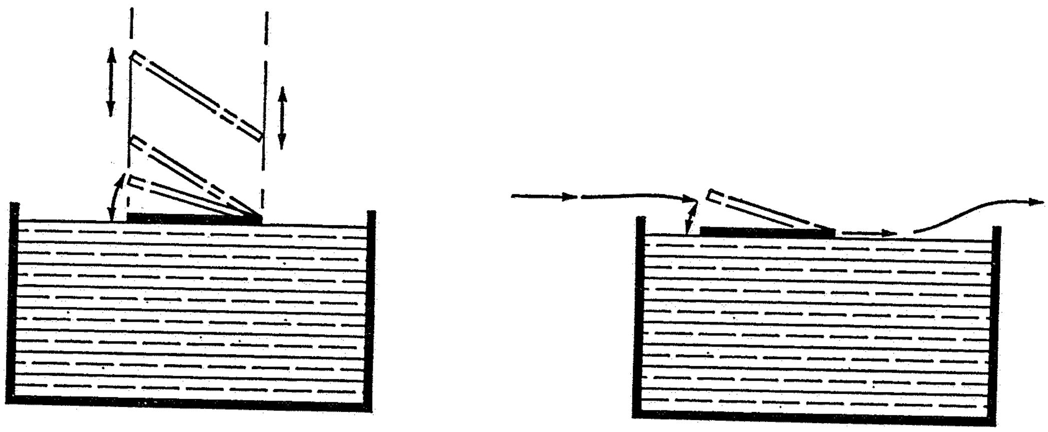
(e) **Lack of Resin Bond in Etched Areas.** This is indicated by changes in colour (fogging) of the base material.

8 SOLDERING METHODS There are two main methods of soldering employed in connection with printed circuit boards; (a) hand soldering and (b) mass soldering.

8.1 **Hand Soldering.** This method is used for soldering joints separately, e.g. in limited batch production, and when a component or a wire is replaced after a test or a repair has been carried out. This method involves the use either of electrically heated hand irons, or of resistance type hand tools when the use of these is permitted (see also Leaflet BL/6-1).

8.2 **Mass Soldering.** In this method, all joints of a finally assembled board are soldered simultaneously, by bringing the board into contact with an oxide-free surface of molten solder, which is contained in a special type of bath. Mass soldering may be carried out in any one of five different ways: some details of each are given in the following paragraphs.

8.2.1 **Flat or Static Dipping.** In flat or static dipping (see Figure 4(a)) one edge of the board is first lowered on to the solder, and the other edge is then lowered slowly to allow flux and solvent vapour to escape. An angled path is also adopted when withdrawing the board; this assists the solder to drain, and thus prevents 'icicling' (see paragraph 11.2.1). This technique can also be automated, for production line purposes, by conveying the boards across the surface of the solder as shown in Figure 4(b).



(a) (b)

*Figure* 4 FLAT OR STATIC DIPPING

8.2.2 **'Wave' Soldering.** In wave soldering (see Figure 5), the surface of the solder is maintained free of dross by pumping the solder from the bottom of the solder bath through a narrow slot, so that a symmetrical 'standing wave' of solder is produced across the width of the bath. The height of the wave is governed by the impeller pump speed, which is usually variable (typical wave heights vary between ⅛ in. and ¾ in.). In order to assist in drainage of the solder from the board, the wave forms may be varied as shown in diagrams (b) and (c) of Figure 5.

(a) The wave soldering technique is part of an automated soldering process whereby a circuit board after being fluxed, either manually or automatically, is passed against the crest of the solder wave by a conveyor (see Figure 6). Each solder joint area is in contact with the solder for only a few seconds to prevent distortion and damage to the board and its assembled components. The width of the solder wave determines the maximum width of the circuit board which can be treated, but there is no limit to the length of the board since it is traversed by the conveyor.

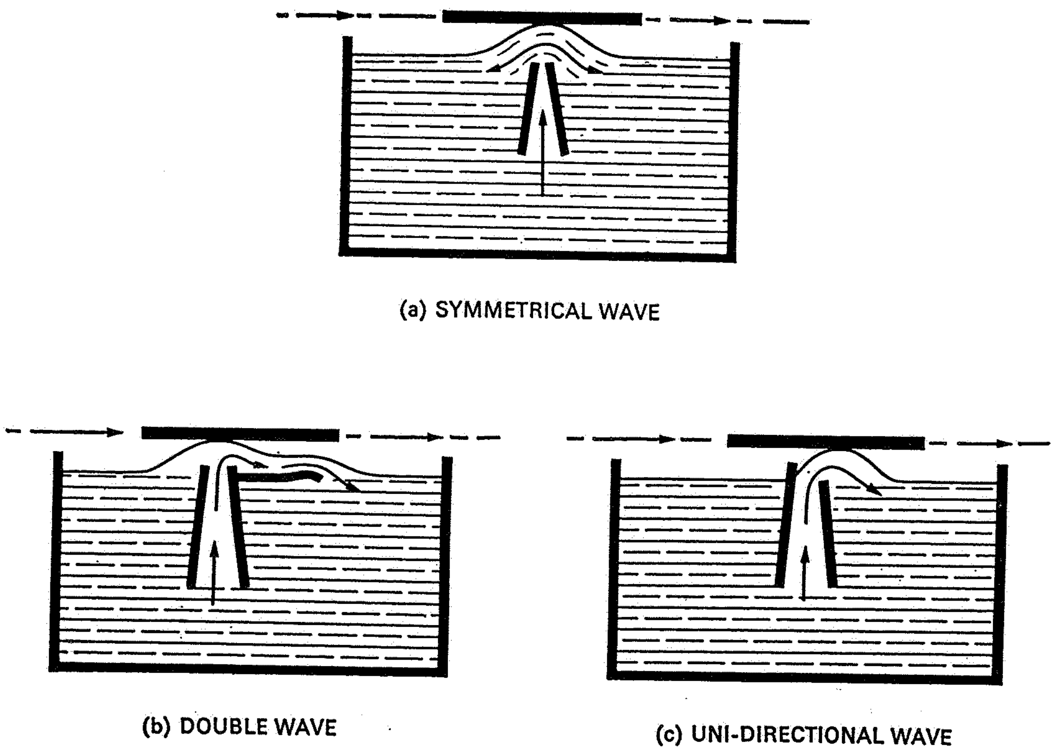



*Figure* 5 WAVE SOLDERING

(b) A typical machine employing this technique is shown in Figure 6. The assembled circuit board is clipped, with the side to be treated downwards, into the carrier, which is then placed on the conveyor for traversing at the required speed selected on the control console. The console also contains controls for pump speed, solder wave height, solder temperature, fluxing and pre-heating of the board. The board is first conveyed over the fluxer unit, the joints to be soldered passing against the crest of a flux wave produced by a pump. After being fluxed, the board passes over radiant heaters, which pre-heat the board and condition the flux. The conditioned board is then conveyed over the wave soldering unit for soldering of all joints. The combined molten solder flow and traversing of the board provide a 'washing' action around the joints of the board, thereby assisting in solder penetration, and the removal of excess flux, or unwanted metallic coatings, which could have weakening effects on joints.

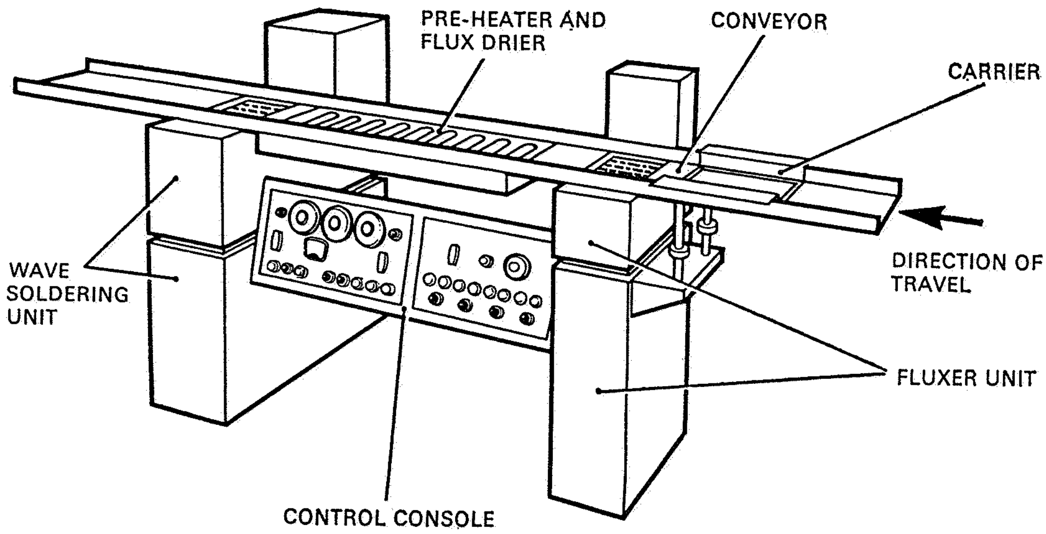



*Figure* 6 WAVE SOLDERING MACHINE

8.2.3 **Weir and Cascade Soldering.** These systems (see Figure 7) are of the moving solder type, the solder flowing down a trough by gravity, and then being returned to the main bath by a pump. In weir-soldering (diagram (a)) a circuit board is lowered on to the solder; while in cascade soldering (diagram (b)) a board is conveyed across the crests of solder waves in a direction opposite to the solder flow.

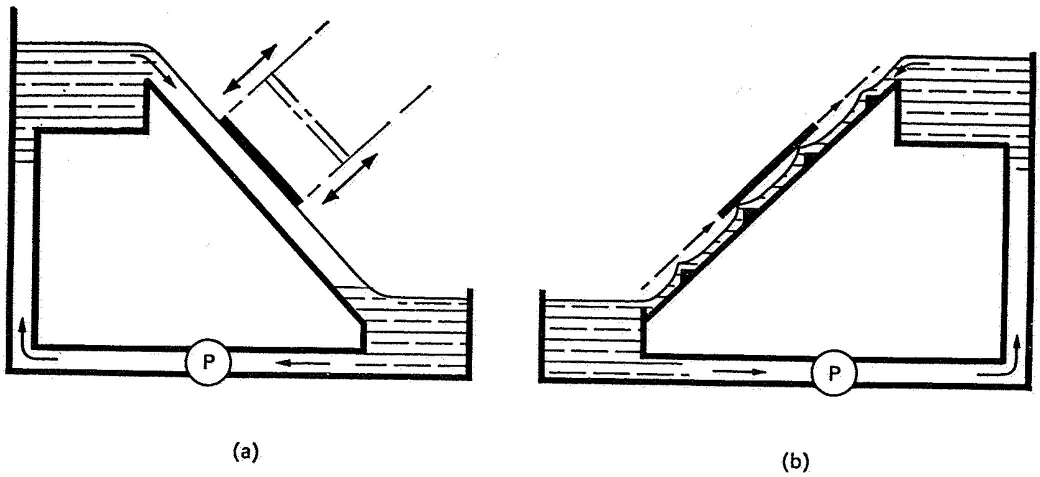



*Figure* 7 WEIR AND CASCADE SOLDERING

8.2.4 **Reflow Soldering.** This automated soldering process (also known as 'heat cushion' soldering) is applied particularly to circuit boards on which microcircuits and associated devices are to be assembled. These efficient but costly components require a special soldering technique, so that their full potential as surface-mounted devices can be realised. The reflow technique (see (a)) is generally recognised as the best method, since the soldered joints are easier to inspect and to remake when a faulty component has to be replaced. In addition, soldering times and the risk of overheating sensitive components are reduced, and distortion of leads is prevented.

(a) A reflow soldering machine, which may be either bench-mounted or free standing, consists primarily of an electrically-heated electrode, which is lowered, by a pneumatic ram, to make contact with the joint to be soldered. A control panel is provided for lowering the ram, for pre-selecting the load to be applied, and also for pre-selecting the heating power to the electrode. A pre-set timing device is also provided, both for cutting off the heating power, and for supplying a blast of air for subsequent cooling of the soldered joints.

(i) The sequence of reflow soldering is shown in Figure 8. The leads of the circuit or component, and the relevant lands on the circuit board which have been pre-tinned by such methods as wave soldering or dip soldering, are first brought into contact with each other and accurately aligned. The sequence is then initiated by lowering the electrode on to the lead to be soldered. Shortly before the electrode makes contact with the lead, the pre-set heating power is automatically switched on. The electrode is then pressed on to the lead under a load which gradually increases until the pre-selected value is reached. The solder melts, and in reflowing, it forms a 'cushion' through which the lead is pressed against its corresponding land of the circuit board. As soon as the cushion is formed, the timing device cuts off the heating supply. After a 0·75 second delay, an air blast is delivered to cool the soldered joint; this accelerates the completion of the soldering process, and also improves the quality of the joint. At the end of the cooling period, the load is relieved, and the electrode is automatically raised ready for the next operation.

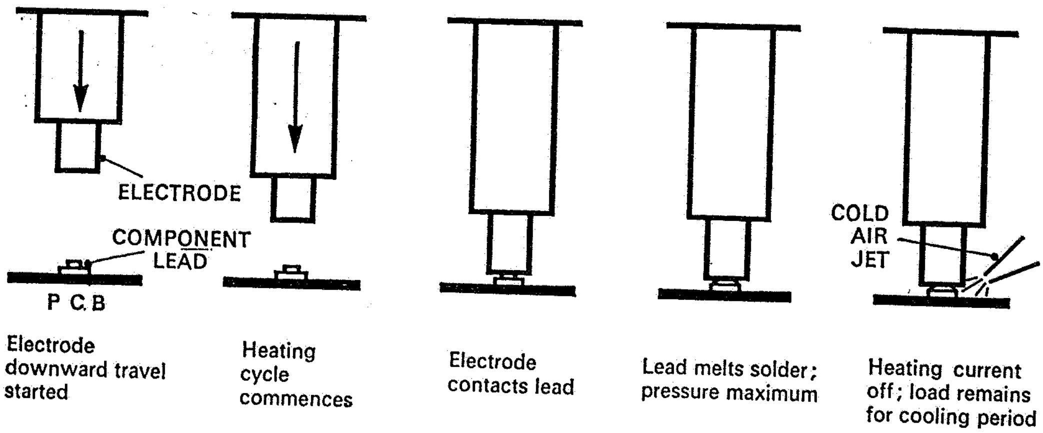



*Figure* 8 REFLOW OR 'HEAT CUSHION' SOLDERING

9 SOLDER SPECIFICATION For the mass-soldering of printed wiring boards, solder complying with BS 219 Grade K (60/40 tin/lead) is the one most commonly used, since it has a free-flow characteristic which permits good joint formation in the short period during which boards are in contact with the solder.

9.1 Solder is normally supplied in the following forms:—

(a) Bars, for use in machines which are provided with an automatic system of feeding solder during machine operation.

(b) Wire, for use in machines which have an electronically controlled wire feeder system.

(c) Sticks, for the filling and replenishing of machines which are not fitted with an automatic feed system; and for use in static dip solder baths.

(d) Pellets, for the initial charge of some machines and for the topping up of small baths, where rapid melting is required with minimum loss of temperature.

(e) Flux-cored wire.

9.2 The soldering temperature is chosen for each individual combination of board and types of material being processed, but it should normally be within the range 220°C to 260°C. Given components of good solderability, complete wetting and filling of the joints should be achieved within a few seconds. Higher temperatures and longer times may cause trouble because of distortion of boards and deterioration of the components mounted on the other face.

10 FLUXES AND THEIR APPLICATION To assist in the wetting of surfaces by molten solder, a flux must be used both to prevent oxidation during joint formation, and to dissolve the thin oxide films which may already be present on the surfaces which are to be joined, and on the solder itself. Fluxes are, therefore, substances that yield an acid when they are heated to the soldering temperature. Once the oxide films have been dissolved by the acid, the flux must be readily displaced by the molten solder as it wets and spreads over the surfaces.

10.1 **Types.** The flux to be used is most often dependent on the type of materials being soldered, but in the majority of applications a rosin-based flux is required. The types most commonly used are activated by organic agents in an organic solvent to provide some slightly increased rate of dissolution of metal oxides with a minimum risk of subsequent corrosion. In some cases, special additives may also be included to provide a self-supporting foam for transferring the correct amount of flux to a board, and also to prevent spattering, thereby ensuring an even flux coating.

NOTE: Foam fluxes are not compatible with protective coatings and these should, therefore, be removed before commencing a soldering operation.

10.2 **Application.** Fluxes may be applied to printed wiring boards by any of the following methods:—

(a) Dipping on to the surface of a bath of flux.

(b) Brushing.

(c) Spraying.

(d) Rolling on, by contact with a plastic foam roller.

(e) Wave fluxing, i.e. by passage over a standing wave of flux.

(f) Foam fluxing, i.e. by passage over a standing wave of foamed flux produced by aeration from a submerged porous element.

10.3 **Heating of Fluxes.** When mass soldering, by either the wave, weir or cascade methods, it is necessary for some of the volatile solvent from the flux layer to be removed, in order to prevent the formation of gases which would result in non-wetted areas of a board (see also paragraph 11.1.1). Solvent is removed, between the fluxing and soldering stages, by passing the boards over controlled infra-red heaters or hot air blowers.

10.4 **Removal of Flux Residue.** The residue from certain types of activated flux dries into a hard, non-hygroscopic, non-conductive and non-corrosive deposit, which is fully soluble in denatured ethyl alcohol or in isopropyl alcohol. This deposit may also be removed by aromatic solvents, e.g. xylol and toluol, or by chlorinated hydrocarbon solvents, e.g. trichlorethane and freon. If such solvents are used, ultrasonic cleaning, spray or jet washing, or brush cleaning methods may be adopted for complete removal of residue, bearing in mind any detrimental effects the cleaning methods may have on specific board components. Foam fluxes leave a thin residue, which is readily removed by warm water.

11 SOLDERABILITY AND SOLDERING TECHNIQUE DEFECTS On completion of a soldering operation, it is necessary to check that the soldered connections have the highest possible level of quality. When tin-lead alloys containing 60-65% tin are used, all soldered connections should be bright, and should have smooth concave fillets joining the circuit board and component termination. Usually these checks entail inspection of the whole, or a selected portion of the work, using a magnifier of about ×10 power. For these operations to be effective, personnel engaged on inspection should have a full understanding of what constitutes a satisfactory soldered joint, and should readily be able to recognise solderability defects and defects which arise from the soldering process itself.

11.1 **Solderability Defects.** Solderability is assessed as the extent of wetting by the solder, and, in this connection, there are normally three classes of defect which must be recognised. Guidance on these is given in the following paragraphs.

11.1.1 **Non-Wetting or Partial Wetting.** This defect arises from incomplete coverage (wetting) of the surface by the film of solder. In the non-wetted areas the colour of the original base metal is exposed, although this may not be clear if a metallic coating of similar colour to solder had been electro-deposited on the base metal prior to soldering. Thus, a partially wetted solder film on palladium may be difficult to distinguish from one which has de-wetted.

(a) Flux residues tend to remain adhered to non-wetted areas, but to drain away from a continuous wetted film of solder. Non-wetting is usually the result of an inadequate time-temperature cycle, or of insufficient flux activity, for the particular surface being soldered. Non-wetting may also arise in small areas for other 'mechanical' reasons, such as splashed solder resist, or soldering near large components which act as heat sinks.

(b) A very small amount of non-wetting may reveal itself merely as pinholes or porosity in the solder film, and if examined under a microscope only exposed base metal will be visible at the base of these pores. If such porosity is not concentrated in one area, and constitutes less than about 5% of the total area soldered, it may be considered that this is the limit of acceptability.

11.1.2 **De-wetting.** De-wetting of a solder film presents an appearance similar to that of water on a greasy surface. De-wetting occurs when a surface is initially wetted and the solder adheres to the surface, but after a time the solder coating retracts because of radial increase in contact angle, causing the solder to collect into discrete globules and ridges. The remainder of the base metal surface, however, remains a solder colour, but has a very small thickness of solder retained on it and poor solderability.

(a) De-wetting arises from contamination of the base metal surface, e.g. by embedded cleaning abrasive, and normally causes a breakdown of fillets between terminations and board connectors. Although the breakdown of the fillet may not be considered as harmful, it, in fact, results in poor formation of soldered joints. If the area being soldered is restricted by a layer of solder resist (e.g. surrounding a land) excessive solder applied to the land may mask de-wetting, and simply embed the component termination, thus giving the appearance of a good soldered joint. The poor wetting may, however, result in interface penetration by atmospheric gases, leading to a high electrical resistance in the soldered connection.

NOTE: In extreme cases of surface contamination, non-wetting and de-wetting occur simultaneously. In such cases it is most unlikely that any time-temperature combination will be effective in producing a good joint.

11.2 **Soldering Technique Defects.** Guidance on some of the more common defects which may result from the soldering technique and method adopted, is given in the following paragraphs.

11.2.1 **Icicling.** Icicles of solder arise mostly in wave soldering operations in which the printed wiring board approaches and leaves the solder bath in the horizontal plane. The icicles form as a result of the 'peel back' of the solder film from the board as it leaves the solder, the solder solidifying before it can flow back into the bath. The situation may be alleviated by the use of an angled exit from the solder, but such factors as the temperature, speed of movement and flux composition are also involved in curing this trouble. Impurities in the solder may also give rise to an excessive amount of icicling.

11.2.2 **Bridging.** A bridge of solder between adjacent termination wires or conductors on printed wiring boards may arise from the same cause as icicles. Other causes may be, incorrect spacing of conductors, or the formation of oxide film on the surface of the solder. The type of flux employed may also have an influence.

11.2.3 **Porosity.** Pores in a soldered joint may arise from solidification of the solder around an escaping bubble of air or flux vapour. This hole or cavity may be small, and it may not reduce the volume of the solder fillet by any significant extent, in which case, it may be considered as a minor defect, but larger holes or cavities may be a reason for rejection of the work. It should be remembered that, when liquid solder solidifies, there is approximately 3% contraction in its volume. This contraction will produce a small surface indentation, which is distinctly different from a cavity which has been produced by the entrapment of air or flux vapour. Normal shrinkage may not be considered as a cause for rejection.

(a) In the case of boards with plated-through holes (see paragraph 13.2) bad cases of blistering of the solder fillets on a land, or of cavities or incomplete fillets, may arise if the quality of the plating of a hole is poor. Incomplete plating of the surface of the hole first allows the escape of gases or water vapour from the laminate itself, and also allows liquid flux to adhere to the hole. This subsequently gives rise to vapour as the solder above the flux solidifies, forming blisters in the solder. The application of excessive flux, or the inadequate pre-drying of the flux in order to remove solvents, may also cause porosity in the fillets of joints.

11.2.4 **Dull, Rough or Gritty Solder.** Soldered joints made with tin-lead alloys, and especially those in the region of the eutectic composition, will normally present a brilliant and smooth appearance. If the surface of the solder is dull, and the normal smooth contour of the joint is correct, it is an indication that some vibration or movement had occurred as the solder solidified. If the surface of the solder is also irregular and rough, this may indicate that the soldering temperature was too low, thus producing a 'cold' joint.

(a) A matt or dull finish on the solder can arise when impurities are present in a solder. The presence of copper will produce a dull surface when its concentration is not in excess of approximately 0·3 to 0·4%. Above 0·5% (in 60/40 solder) the silicon, lead and copper eutectic composition is exceeded, and primary crystals of copper and tin intermetallic compound will be present, giving a gritty or sandy appearance to the solder. The presence of other elements, such as gold, silver, iron and nickel, in excess of their solubility can also produce similar effects.

11.3 **Solder Contamination.** Molten solder readily dissolves many metals with which it comes in contact, so that after a period of use the solder is not as pure as when it was originally charged into the appropriate soldering machine. Solder should be checked for contamination at a frequency consistent with usage, and should be changed when necessary. The metals most likely to produce solder impurity are as follows:—

(a) **Copper.** Copper is unavoidably picked up by solder, from the conductor patterns of boards and from component lead wires. The amount of copper which is soluble in the solder bath depends on the tin content and on the temperature of the solder. Some solder alloys have a higher tolerance for copper than others, and at the normal working temperature can hold 0·5% of copper in solution before the gritty intermetallic compound appears in the melt. Normally, however, a limit of 0·3% of contamination should not, and need not, be exceeded.

(b) **Zinc and Cadmium.** Contamination with zinc can arise from an excessive number of brass tags or other brass components on the underside of circuit boards. A few brass pins per board do no harm, but, if brass surfaces are large, pre-tinning after nickel plating of surfaces will prevent zinc from being picked up. Cadmium contamination is mainly caused by cadmium-plated components coming into contact with the molten solder. The maximum permissible limits of zinc and cadmium contamination are 0·002% and 0·003% respectively.

(c) **Iron.** The iron content should not exceed 0·003%. Iron may be picked up from tinned steel components, such as tags or board chassis, or from the inside of the solder bath if this has become tinned through the use of an unsuitable cover flux, or through severe overheating.

(d) **Silver and Gold.** Silver and gold from plated components, or from plated wiring, can also contaminate molten solder, and, in small solder baths particularly, contamination can be serious.

11.3.1 **Dross and Oxides.** All molten solder in contact with the atmosphere immediately forms a thin layer of oxide, and the rate at which it forms and grows depends on the extent to which the dross-forming impurities, zinc and cadmium, may be present in the solder, and also on whether or not the solder is being overheated. A constantly moving solder surface also causes more rapid oxidation and dross formation than a static surface, and the rate at which it forms depends on the solder wave form; high or cascading waves will produce more dross than low, smooth waves.

(a) There are no additives which can be directly mixed with solder for effective prevention, or reduction, of oxidation in a wave soldering machine, or in static baths; low impurity levels are the only effective way to reduce drossing. Certain anti-oxidant oils, or cover fluxes, are available which, when applied to the solder surface, help to reduce to a minimum the area which is exposed to the atmosphere. These oils are normally used in conjunction with those wave soldering machines which incorporate a special unit for either injecting oil through the solder and onto the surface of the wave, or applying a thin film of oil directly on to the top of the wave. In both cases the oil drains down the sides of the wave, and spreads out, so protecting the solder in the bath. For static solder baths, and for wave soldering machines which do not incorporate an oil injection unit, it is usual to apply a small quantity of cover flux to the surface of the solder.

12 SOLDER RESISTS These are organic coatings which are designed for use on both rigid and flexible printed circuits, to mask off those areas where soldering is not required. Some important advantages of the use of solder resists are as follows:—

(a) Elimination of bridging and icicling between closely spaced conductors and mountings.

(b) Protection is afforded against corrosion and contamination during storage, handling and subsequent life of the circuit.

(c) Flexibility of circuit patterns is maintained since a resist flexes with the conducting material.

(d) The surface resistance values of the circuit patterns are improved.

(e) Minimizing of solder contamination from large surfaces of copper and other plating materials, thereby maintaining a high level of solder purity and an extension of bath life.

(f) Heat distortion is minimized, since a resist acts as a heat barrier.

12.1 **Application.** Solder resists are applied by a silk screening process, in a manner similar to that used for circuit printing (see paragraph 7.1.1). The mesh size of the screen should be such as to permit adequate application of resist, so that after curing it will afford maximum resistance to the heat of soldering and to the solvency of fluxes. For some types of resist, their characteristics can be varied to suit particular applications, e.g. to achieve a better cure when curing facilities are limited in capability. A better cure may be achieved by adding to the resist the appropriate amount of catalyst specified by the manufacturer for the particular case.

12.2 **Curing.** The curing of resists is carried out by passing the circuits through ovens which incorporate both a conveyor system and exhaust blowers which will remove the fumes given off by the resists. The method of heating the ovens depends on the particular design, but generally it is either by infra-red radiant heaters or by normal convection heating. Infra-red radiant heating will normally cure the resist in 1 to 2 minutes, with the copper surface temperature raised between 132°C and 160°C. The curing time under convection heating is approximately 1 hour, with the copper surface temperature raised between 132°C and 143°C. In both cases, curing is followed by forced cooling, with air at room temperature for a period of 1½ to 2 minutes.

12.2.1 The effectiveness of the cure may be checked by applying a drop of toluene to the resist, and, after a period of 1 minute, removing the toluene, and checking that the resist is intact. Alternatively, cure effectiveness may be checked by applying a flux to the resist, and, after dipping the board in a solder bath for 8–10 seconds, observing that there is no solder adhering to the surface of the resist.

12.3 **Insulation Resistance.** After curing, the insulation resistance of the resist should be measured, since the resist becomes an integral part of the printed circuit. The resistance values vary with the actual circuit pattern, the type of base material, the type of resist, and on the cure.

12.4 **Storage.** Resists should be stored in closed containers in a cool, dry, place, and in accordance with any other conditions, appropriate to the storage limiting period, imposed by the manufacturers. Resists have a tendency to thicken during storage, but their normal flow characteristic can be restored by stirring.

**13** PLATING OF PRINTED WIRING CIRCUITS Plating finishes for printed wiring circuits are used as aids to the performance of circuits under specific conditions of use, and are not intended to be decorative. The choice of finish is, therefore, governed strictly by the functional and environmental conditions in which the circuit will be used. In many cases, different parts of a circuit may be subjected to different conditions of use, and provided there is clear demarcation between these parts, they can be plated with the appropriate finishes. A typical example of this differential plating method, is a circuit that is tin/lead plated for solderability over the component area, and nickel/gold plated for durability on edge-connector finger contacts.

13.1 **Plating Materials and Thicknesses.** The materials and thicknesses which are specified for a circuit, depend on a number of factors, of which the following are of importance: (a) the environmental conditions; (b) durability (in the case of edge-connector finger contacts); (c) contact resistance; (d) solderability; (e) metallic migration; (f) alloying, and (g) cost. To be considered, also, is the fact that with boards printed by the etching process (see paragraph 7.1), conductors increase in width as well as in thickness. In some metals (e.g. solder) these effects can be more pronounced than in others. The applications of the materials most commonly used for plating are given in the following paragraphs.

13.1.1 **Copper.** Copper plating is normally restricted to circuits with plated-through holes, since this is the means by which durability is given to the holes. The surface plating thickness of the circuit tracks is governed by the plating thickness required for the walls of the holes. Typical specified values are between the limits 0·001 in. and 0·004 in. Because of its poor resistance to climatic changes, copper plating is usually followed by a protective plating process.

13.1.2 **Solder.** This is the standard finish over copper for circuits requiring environmental protection coupled with good solderability. Plating thickness limits between 0·0003 in. and 0·002 in. are common. A disadvantage of solder plating, is that greater difficulty is experienced with growth in width of conductors during plating, than with any other finish.

13.1.3 **Nickel.** Nickel is usually applied as an undercoat for either rhodium or gold, not only to provide a hard base for edge-connector finger contacts and switching contact surfaces, but also to reduce the thickness of rhodium or gold needed to ensure minimum porosity. The plating thickness limits are generally between 0·000025 in. and 0·0004 in.

13.1.4 **Rhodium.** This is the hardest noble metal in common use as a plating material, and, because of its extremely good resistance to wear and corrosion, it is applied principally to switching contact surfaces. Two different plating processes may be adopted: (a) plating directly onto copper; the thickness of the rhodium deposit being generally between 0·00005 in. and 0·0002 in., (b) plating over a nickel undercoat 0·00025 in. thick, with the rhodium deposit thickness limited to 0·000015 in. The latter process is widely adopted, since it avoids the higher internal stress which is inevitable with thicker rhodium deposits.

13.1.5 **Silver.** Silver is particularly suitable for power switching where low contact resistance is important. Thicknesses of up to 0·0005 in. are frequently used to provide good solderability with reasonable corrosion resistance. Under some combinations of humidity and direct current potential, difficulty can be caused by the migration of silver between unconnected conductors.

13.1.6 **Gold.** Gold gives a durable, low-resistance, corrosion-resistant finish with a long service life, and it is commonly used for edge-connector finger contacts, even where other parts of the circuit are plated with a different finish. Its solderability is good, but there is a danger of formation of a brittle gold/tin alloy, which can cause 'dry joints' under extreme conditions of service. This embrittlement can be minimized by restricting the plating thickness to below 0·0001 in., but for non-porous surfaces, a thickness of about 0·0002 in. is usually regarded as the minimum.

13.1.7 **Palladium.** Of the noble metals recommended for plating, palladium exhibits the most useful combination of properties. It is the least costly, the deposit is comparatively free from internal stress, and it is completely impermeable at thicknesses of 0·0002 in. and above. It is applied principally to contacts and switching surfaces, the plating thickness limits being generally between 0·00005 in. and 0·00025 in.

13.2 **Through-hole Plating.** Through-hole plating is a process which is widely employed to provide a conducting surface in the holes of single-sided and double-sided boards, and also to provide a land or pad for the connection of components. This process is generally used with epoxy/glass laminates, since they can be plated more easily than those of the phenolic/paper type. When holes have been punched or drilled in the appropriate positions, the board is pre-treated, and a thin layer of copper (approximately 0·000020 in.) is deposited on its surfaces by an electroless copper plating process. The desired thickness of copper through the holes, and on the other surfaces of the board, is then built up by normal electrolytic deposition of copper pyrophosphate. Following this deposition, a photo-sensitive resist is applied, and the circuit pattern is exposed and etched. A typical sequence of the steps involved in the process is illustrated in Figure 9.

13.2.1 Boards should be inspected to ensure that the positions and sizes of the holes conform to the circuit design requirements. The plating of hole walls should also be visually inspected against a strong light, for signs of inclusions that may affect the insertion of component leads or their solderability. There should be no apparent failure of the plating, but pinholes are permissible provided that the total of their maximum dimensions, relative to hole diameter, does not exceed the specified limit. A typical value is 25% of the hole diameter.

14 ORGANIC PROTECTIVE COATINGS After printed wiring boards have been manufactured, organic coatings are applied to their surfaces, to protect them from oxidation and contamination. The coatings vary, depending on whether temporary protection is required, e.g. for maintaining clean copper surfaces during normal handling prior to soldering, or, whether permanent protection is to be applied after soldering for protecting the circuit and components from subsequent environmental contaminants. For temporary protection the coating is usually of a rosin-based type which does not require removal before soldering, since it also serves as a flux. Permanent protective coatings are usually epoxide- or polyurethane-based resin having exceptionally low oxygen absorption, high humidity resistance, and resistance to cracking and discoloration. The coatings for both types of protection may be applied with a brush, a spray, a roller, or by a dipping operation. The procedures to be adopted for each of these operations may vary with the type and proprietary brand of coating. Details of coating procedures are contained in the relevant data sheets, or technical bulletins, which are issued by the coating manufacturers; reference should, therefore, be made to such documents before coating operations are carried out.

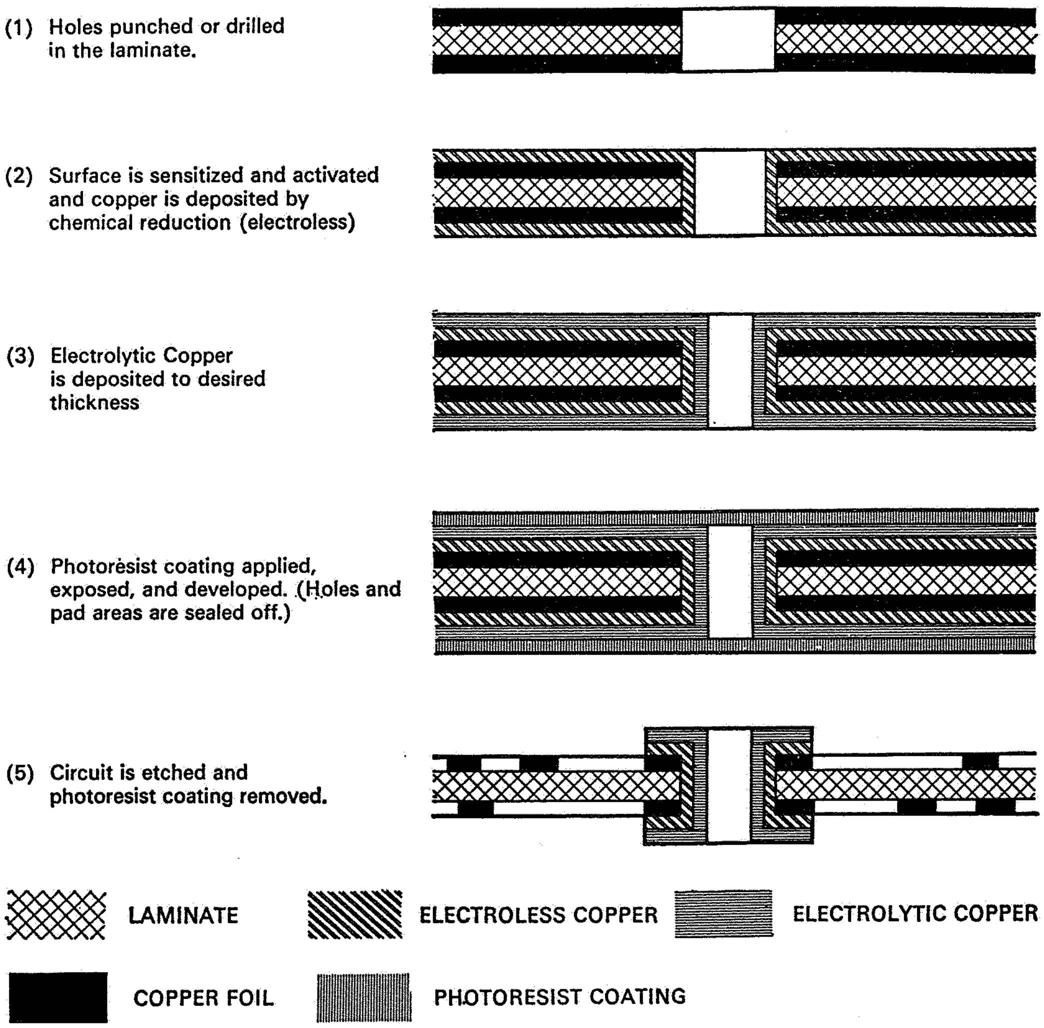



*Figure* 9 THROUGH-HOLE PLATING

**15** MULTI-LAYER CIRCUITS In order to save weight and space, and to provide for the interconnection of integrated circuits (which are a feature of a large majority of electronic equipment) the relevant circuits are assembled as a multi-layer moulded package, consisting of three or more single and/or double-sided printed boards and insulating layers of 'prepreg' material (see paragraph 2.1). The fundamentals of a typical moulding and curing operation are outlined in the following paragraphs.

15.1 **Registration Jig.** The individual boards and 'prepreg' material are first cleaned, to exclude all extraneous particles, and are then assembled in their appropriate sequence on the polished surface of a steel plate, which forms the bottom of a registration jig. The function of the jig is to permit accurate register of the positions of individual circuits, and for this purpose locating pins pass through holes around the periphery of the circuit boards and 'prepreg' material. The number and positioning of locating holes depend on the size and complexity of the circuit. When the complete assembly has been mounted onto the locating pins, a second steel plate of the registration jig is fixed in position, with its polished surface adjacent to the multi-layer assembly.

15.2 **Moulding and Curing.** The moulding and curing cycle of the multi-layer assembly is carried out by loading the registration jig into a hydraulically operated laminating press equipped with flat and parallel platens. The platens are designed to be heated (either by steam or electricity) up to a temperature of 175°C, and the hydraulic pressure on the area of the multi-layer assembly is selected and controlled within the range 10–500 lbf/in². Uniform distribution of heat and pressure is facilitated by placing several sheets of dry paper padding between the registration jig and the platens. If the press platens are electrically heated, the press is loaded hot at 170°–175°C; but, in the case of steam heating, which gives a faster temperature rise, the press may be loaded either hot or cold. A temperature gradient occurs across the surface of most hot press platens, the edges being up to 5°C cooler than the centre, depending on the platen size. To minimize the effect of this temperature variation on the curing of the multi-layer assembly, the dimensions of the platens are normally designed to be greater than those of the multi-layer assembly, so that the cooler areas of the platen surfaces are not in contact with the assembly.

15.2.1 The hydraulic pressure is controlled initially, at a specific value between 10 and 30 lbf/in² on the area of the multi-layer assembly. When the temperature within the assembly rises to 110°–120°C, the resin in the 'prepreg' layers begins to flow; this usually occurs after 3 to 7 minutes. The resin gels after a further 1 to 3 minutes, and, immediately before this occurs, the hydraulic pressure is increased to a specific value between 250 and 300 lbf/in². This pressure is maintained throughout the remainder of the cycle. The full laminating pressure is largely dependent on the width of the circuit conductors to be moulded, and while a high pressure is desirable, to ensure that the multi-layer assembly is completely void-free, if it is too high, narrow conductors in the circuit pattern are liable to become distorted. A pressure within the range 200–300 lbf/in² is generally recommended for conductors which are less than 0·020 in. wide. During pressing the temperature within the assembly continues to rise to a maximum of 160°–170°C, and this temperature is maintained for 35–40 minutes, to ensure that the resin in the 'prepreg' layers is fully cured (generally referred to as the 'C'-stage). The platens are then cooled (while under pressure) and the multi-layer assembly is removed from the press when the temperature within the assembly has fallen to below 50°C.

15.2.2 The exact point at which the resin gels, depends on the rate of temperature rise within the multi-layer assembly, which, in turn, depends on the rate of temperature rise in the press platens, and on the thickness and the nature of the padding between the registration jig and platens. Another factor is that although the 'prepreg' material is manufactured to have specific flow properties, there may be slight but significant variations in these properties between batches of material. This is particularly true where the material has been stored for several months prior to use, and, for this reason, the resin flow of a sample of each batch of material should be measured, not only on receipt, but also before use.

15.2.3 The stage at which full laminating pressure should be applied may be determined by either of two methods. In the first and simplest method, the resin which is exuded from the edges of the multi-layer assembly is probed as it progresses to a gelled state. The second method, which is the one preferred, requires control by temperature measurement. A thermocouple element is inserted into the middle layers of the assembly, in the trim or test area around the edges. The thermocouple is connected to an accurate temperature indicator, and, from the readings obtained, a temperature/time curve is plotted, from which an accurate forecast can be made of the point at which full laminating pressure should be applied. A curing cycle curve based on the moulding and curing of some typical circuit laminates and 'prepreg' materials is shown in Figure 10.

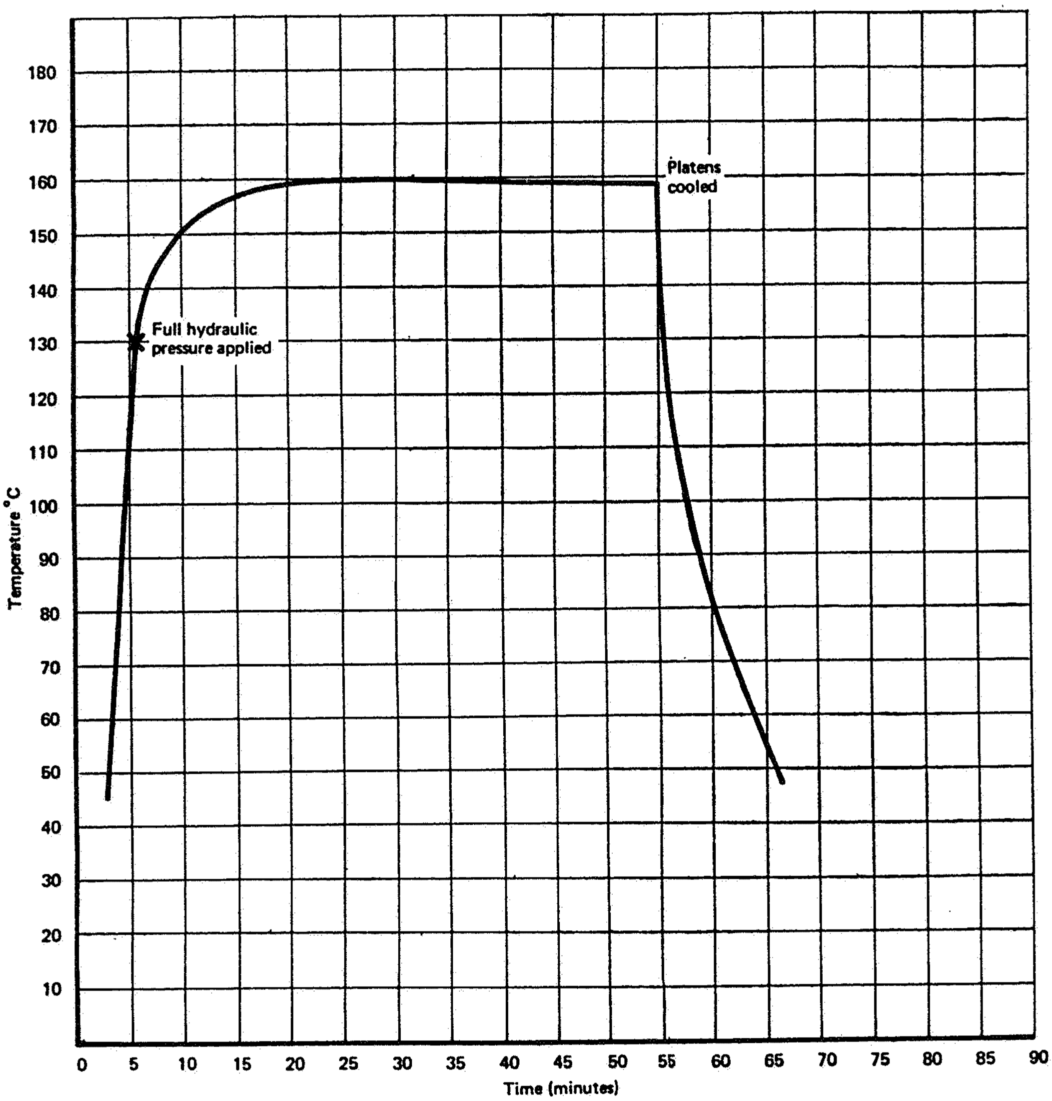



*Figure* 10 CURING CYCLE

15.3 **Thickness of Layers.** A multi-layer assembly can be made up from a number of different thicknesses of laminates, but a more economical design results when all layers are of the same thickness. The number and thicknesses of layers are limited by the following:—

(a) The required overall thickness.

(b) The minimum thickness of the boards in the assembly.

(c) The thickness that has to be allowed for 'prepreg' ('B'-stage) material.

(d) The smallest hole-diameter required.

Laminate manufacturers normally quote an overall laminate thickness and the increases in percentage thickness with increasing core thickness. These criteria are an important consideration when the final thickness of the multi-layer assembly is a critical factor; for example, edge-connectors, wrapped pins, etc., may necessitate a final thickness tolerance as small as ± 0·007 in.

15.3.1 The interconnection between layers is achieved by the connection of the through-hole plating to the thin rim of copper which is exposed where the hole passes through each copper layer. In some cases, interconnection is made by means of solid copper pillars which, unlike plated-through holes are not necessarily extended through the entire board; they can be routed around conductors of intermediate layers and brought to the surface at any convenient point.

15.3.2 The number and thickness of 'prepreg' material layers used is an important factor in the moulding and curing operation. Too few layers could result in an unreliable bond; but too many could limit the number of layers which could be designed into a given thickness, or result in an unacceptable overall thickness for a particular circuit configuration. Excessive 'prepreg' material can also cause inconsistent resin flow during the curing operation.

15.3.3 The overall thickness of a multi-layer assembly can be adjusted by adding or subtracting layers of 'prepreg' material, so long as the specified thickness limitations are not exceeded. Design requirements may require a spacing between copper foils that is thicker than the maximum allowable thickness of 'prepreg' material. In such cases, an unclad laminate can be used as an insulator between the facing foils. The thickness of this insulator should not exceed 0·020 in.

15.4 **Inspection of Circuits.** On completion of the moulding and curing cycle, multi-layer circuit assemblies should be inspected for the following:—

(a) Blistering, which can be caused by insufficient pressure, or by excessive moisture absorption.

(b) Air voids at the interfaces of individual circuits. Any voids which are found in the layers, particularly in areas immediately adjacent to copper conductors, are likely to have been caused either by excessive pressure, or by full laminating pressure which has been applied too late.

(c) Variations in thickness, which may be the result of non-uniform circuit configuration, or of the press platens not being parallel.

(d) Resin-starved areas, which have been caused by excessive resin flow or pressure.

(e) Resin bead around the edges of the multi-layer assembly; the absence of such a bead is an indication that the application of full laminating pressure had been delayed.

(f) Blotching of surfaces; this may be caused by low resin content of the 'prepreg' material, or by excessive laminating pressure.

(g) Register of circuit layers; in assemblies which use epoxy glass laminates, visual checks may be made, but the accuracy of this means of measurement is poor. In critical circuit applications, and for greater accuracy generally, the circuits should be inspected by X-ray techniques.

(h) Circuit continuity; if open circuits are found during continuity tests, this is usually the result of excessive laminating pressure having been applied before the resin in the 'prepreg' material layers had gelled.

16 FLEXIBLE PRINTED WIRING CIRCUITS Unlike rigid printed wiring boards, flexible circuits serve only as a means of interconnecting units, particularly those which require to be moved relative to each other, and those which may be mounted in different planes. Flexible circuits also permit easier assembly and higher density packaging of units. Flexible circuits are of laminated form, consisting of a flexible base insulation material (e.g. polyester, epoxy glass cloth and polyimide) copper foil, and an insulating coverlay of the same material as the base. Any one of three basic methods may be used in their production; die stamping, fusion bonding, and etched foil.

16.1 **Die Stamping.** In the die stamping method, the copper foil is coated with a heat-sensitive adhesive, and is brought into contact with the base material. A heated metal cutting die is used to cut the copper foil into the required conductor pattern, the stroke of the die being controlled to prevent damage to the base material. Heat from the die activates the adhesive, which then bonds the copper conductor pattern to the base material. The coverlay, which is adhesive coated and pre-punched, is laid over the exposed copper, and is thermally bonded to it. Finally, the circuit is blanked into its finished shape, and is completely encapsulated, except for exposed contacts and termination pads.

16.2 **Fusion Bonding.** In the fusion bonding method the base material is brought almost to its melting point, so that it fuses on to the copper foil. The conductor pattern is then etched in a similar manner to rigid printed wiring boards (see paragraph 7.1). A coverlay is then applied and the whole circuit is placed in a heated platen press. When the platen temperature approaches the melting point of the base material, pressure is applied, in order to effect a bond between the three layers of the circuit. When the assembly is cooled and removed from the press, the required pads and terminations, necessary for the soldering of connections, are provided by removing, by abrasion, the coverlay and the oxide coating on the copper. The circuit is then blanked into its final shape.

16.3 **Etched Foil.** In the etched foil method, the circuit pattern is produced in the same way as for rigid printed wiring boards (see paragraph 7.1), and the three layers are thermally bonded to each other by means of adhesive coatings. Holes are either drilled or pierced in the coverlay, prior to the bonding operation, in order to expose the connection and termination points on the circuit pattern.