BASIC

ENGINEERING PRACTICES AND PROCESSES

RESISTANCE WELDING—SPOT WELDING

1   INTRODUCTION   This Leaflet gives guidance on the application of the spot welding process to both ferrous and non-ferrous metals. It is not concerned with other resistance welding processes such as seam welding, which is the subject of Leaflet BL/6-16.

NOTE: Guidance is given on oxy-acetylene welding in Leaflet BL/6-4 and on arc welding in Leaflet BL/6-5.

1.1   Spot welding is a method of providing a joint between two or more metal sheets, but in modern designs is not used in any significant load-bearing applications. It is a pressure welding process in which a 'slug' of welded metal is produced at the interface (or interfaces) of the sheets; a heavy localised electric current is passed through the parts to be welded by means of two opposed water-cooled, copper-alloy electrodes, whilst these are subjected to mechanical pressure.

1.2   The fundamental requirements for a spot weld are ability to resist shear stress, freedom from internal cracks and cavities, correct penetration (i.e. the relationship of the thickness of the slug, to the total thickness joined), freedom from excessive surface indentation or burning, freedom from flash or 'spits' either on the surface or between sheets, and consistency of properties beween one weld and others made under the same conditions.

1.3   The strength of spot welded joints depends to a large extent on machine factors such as the accurate repeatability of the electrical and mechanical operating cycles, the stability of the electrical supply and the rigidity of the welding machine, which is of particular importance where heavy mechanical loads are concerned, since distortion under load can negate otherwise satisfactory conditions.

1.4   Accurate repeatability of the electrical and mechanical operating cycles usually necessitates the use of fully automatic control with electronic timing of the current flow, especially when welding stainless steels and heat-resisting alloys. Full strength welds cannot consistently be obtained in any material from non-automatic machines, and it is essential that special attention should be given to welds produced on such equipment.

1.5   Other factors which influence the strength of spot welded joints include adequate and uniform preparation of the surfaces to be welded, the method of presentation of the work to the machine, and the spacing and placing of the welds. Surface preparation is of particular importance with aluminium alloys, since the presence of an oxide film on the surfaces of these materials creates a high and variable resistance in comparison to the resistance of the parent metal which, apart from causing the generation of excessive heat at the electrode tips, results in welds of varying strength.

1.6   As the only certain method of testing the strength of spot welded joints would result in the destruction of the workpiece, acceptance of the joints must, therefore, depend on adequate inspection supervision of the whole process, backed up by a system of test sampling. A recommended test sampling procedure is described in paragraph 11.

2   DESCRIPTION OF PROCESS   Figure 1 illustrates the general arrangement of a typical air-operated spot welding machine. Machines of a similar type produced by various manufacturers will obviously vary in detail. Air-operated machines are usually manufactured in capacities up to 400 kVA. Further information on different types of equipment is given in paragraph 6.2.
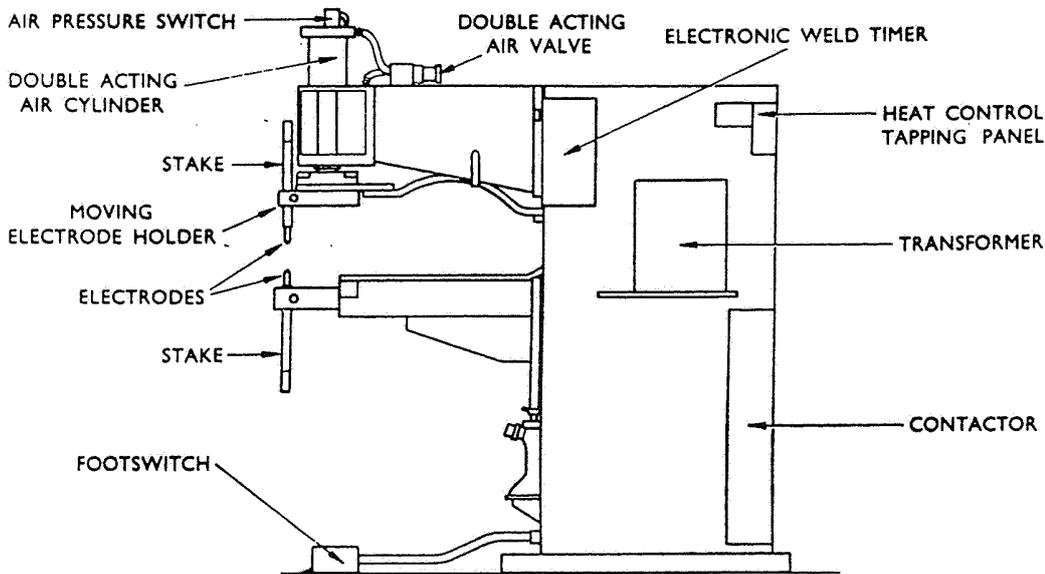

Figure 1   LAYOUT OF TYPICAL WELDING MACHINE

2.1   During the welding operation, the top electrode is brought down into contact with the workpiece by the depression of the foot switch. When pressure has built up on the workpiece, an electrical contactor closes, completing the circuit to the primary winding of the welding transformer and causing a secondary current of predetermined amperage to flow through the secondary circuit and through the workpiece.

2.2   The pressure on the workpiece of the water-cooled electrodes is maintained automatically for a predetermined period, during which the material is heated by the current flow through the resistance of the workpiece. At the conclusion of the pre-set period of current flow, the contactor opens and de-energises the welding transformer, but the electrode pressure is maintained for a further set period to permit the consolidation of the weld. At the end of this latter period, the top electrode pivots and the workpiece is freed for movement to the next welding position.

NOTE: It is essential that the electrodes should bed firmly upon the surfaces of the workpiece so that the axes of the electrodes are at right-angles to the plane of the surfaces, otherwise inconsistent and burnt welds may result. Supports may be necessary to ensure correct alignment where heavy or very long workpieces are being welded.

3 THE DESIGN OF SPOT WELDED JOINTS Considerable attention is given at the design stage to the various factors which can affect the strength, stiffness and suitability of spot-welded joints. In order that these factors may be more readily understood, they are discussed in general terms in paragraphs 3.1 to 3.6.

3.1 **Strength of Spot Welds.** Usually a minimum strength requirement per spot is assumed for design purposes, and whilst it is not possible actually to test the strength of production parts, indirect tests which give guidance on their strength are described in paragraph 11. The tensile strength of a spot weld is considerably lower than its shear strength; therefore, spot welding is not normally used for applications where loads acting out of the plane of the joint will occur. The stiffness of a spot welded joint is much greater than that of a comparable riveted joint. Factors which have a significant effect on the strength of the weld include the distance of the weld from the edge of the sheet, the pitch of the weld and the thickness ratio of the parts being joined.

3.2 **Edge Distance.** A minimum edge distance of 1·5D and a minimum overlap or flange width of 3D (D being the weld diameter) is generally recommended. Smaller values than these may lead to some loss of strength in the joint, an increase in the likelihood of splashing of metal from the interface, and an increase in the possibility of deformation during welding due to inadequate supporting material around the molten weld slug. The overlap, or flange width, is the width over which the materials being welded are in contact, and additional allowances must be made for any radiused corners which may be present on formed parts. Examples of good and bad design where radiused corners are concerned are shown in Figures 2(A) and 2(B), respectively, which illustrate the attachment of stringers to sheets.

Figure 2 ATTACHMENT OF STRINGERS TO SHEETS

3.3 **Pitch of Welds.** Weld spacing is associated with a definite minimum strength for the joint, since welds spaced closer than the predetermined optimum are reduced in strength due to current shunting (i.e. the passage of part of the welding current through the previously made weld). On the other hand, excessive spacing of the spot welds would result in the joint as a whole being weak. The effect of shunting is not of great importance where thin sheets are concerned, but becomes more pronounced with heavy gauge material, thus the weld pitch in these thicker materials is limited to dimensions which incur the least penalty in weld strength and joint strength. However, with titanium, which has a high electrical resistance, shunting is not a critical factor and weld strengths are not appreciably reduced until spacings are small enough to produce spot overlap. Figure 3 illustrates the action of shunting.
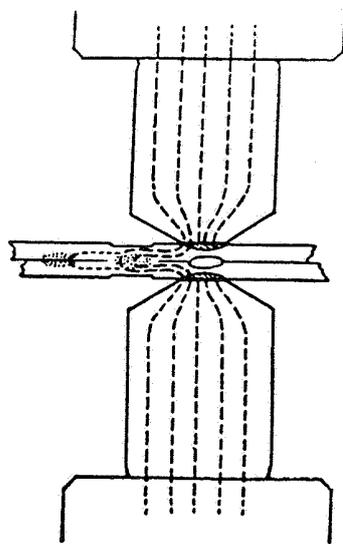
Figure 3 THE ACTION OF SHUNTING

3.4 **Material Thickness.** The total thickness of material which can successfully be joined by any one machine will obviously depend on the capacity of the machine and the nature of the material, but joint thickness of up to about 10 mm (0·4 in) in aluminium alloys and up to about 4 mm (0·16 in) in stainless steels are rarely exceeded. Excessive differences in the thickness of the sheets forming the joint tend to give inconsistent welds with little or no penetration of the thinner sheet. It is recommended that a thickness ratio of 2:1 to 2·5:1 should not be exceeded for any material. The joining of more than three sheets together is seldom attempted, since this results in the production of very weak welds.

3.5 **Surface Indentation.** The surface indentation of any sheet due to spot welding should normally not exceed 10% of the sheet thickness. Where indentation has to be avoided on one face of the workpiece, the tip diameter of the corresponding electrode can be increased up to three times the diameter normally recommended for the particular material thickness.

3.6 **Fitting of Surfaces.** It is important that the surfaces to be joined should be the best possible fit so that the electrode pressure is not required to overcome any stiffness of the sheets or sections, since this would result in a reduction of the pressure available for forging the weld. It is this factor which precludes the welding of contoured sections to flat sheets to form a contoured surface, or the placing of welds on radiused corners of sections and angles. Whenever necessary, a system of clamping should be used to hold the parts in correct register and to control the location of the weld. When welding assemblies containing numerous welds and, in particular, when welding heavy gauge material requiring large energy inputs, it is important to minimise distortion or deformation of the assembly caused by heat expansion; this can be done by commencing to weld at the centre of a seam and working outwards towards the ends or edges.

4   CLASSIFICATION OF MATERIALS   Table 1 lists the types of materials which are commonly joined by spot welding techniques, together with brief guidance on post-welding heat treatment and other relevant factors.   No attempt should be made to weld materials not listed, or to weld combinations of listed materials, unless this is specified by the drawing and a reliable technique has been developed.

TABLE 1

WELDABLE MATERIALS

Materials	Remarks
Aluminium and Aluminium Alloys	These materials do not require heat treatment after welding, as the speed of welding is so great that mechanical properties are not impaired.
Magnesium and Magnesium Alloys	The resistance welding of these materials must be controlled with special care, preferably under direct laboratory supervision.
Nickel Base Alloys	Nickel base precipitation-hardening alloys will require heat treatment after welding to improve their physical properties, but the solid solution alloys will only require to be stress-relieved after welding.
Austenitic Corrosion-Resisting Steels and Heat-Resisting Steels (Non-Magnetic)	Materials in this group generally require no heat treatment after welding.
Corrosion-Resisting and Heat-Resisting Ferritic Steels (Magnetic)	These materials may require heat treatment after welding due to embrittlement of the weld zone. Since the materials are magnetic, they should be welded on single-phase machines with constant current control or three-phase frequency conversion equipment.
Plain Carbon and Low Alloy Steels	These materials have a maximum carbon content of 0·26% and normally require no heat treatment after welding. Since the materials are magnetic, they should be welded on single-phase machines with constant current control or three-phase frequency conversion equipment.
Titanium Alloys	Generally require no heat treatment after welding.

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5   **SURFACE PREPARATION**   The success of resistance welding depends very largely on correct surface cleaning, since it is essential that the surfaces of the material should have a low and uniform contact resistance. Guidance on the surface preparation of various materials is given in paragraphs 5.1 to 5.6. It is difficult to lay down a standard mean period which can be permitted to elapse between surface preparation and welding, since this depends on such factors as the nature of the material, ambient conditions, etc., but the period should always be as short as possible. After surface treatment, the parts should be adequately washed and dried. DEF STAN 03/2 gives further details on the cleaning and preparation of metal surfaces.

NOTE: The use of cotton gloves when handling prepared surfaces is recommended.

5.1   **Aluminium Alloys.** The presence of a thin, tough, oxide surface film of high elec-
trical resistance is characteristic of the aluminium alloys, and its removal prior to welding is essential, otherwise discoloured, surface-burnt welds, and rapid electrode deterioration will result. Furthermore, since the oxide film is not uniform in thickness, its presence causes variations in the heat developed at the sheet interfaces, resulting in considerable variation in the size of the welds.

5.1.1   The variation in electrical resistance is further aggravated by the presence of extraneous matter such as dirt, grease or paint, and since no satisfactory method exists for the removal of the oxide film and the extraneous matter together, surface preparation must be considered in two stages.

5.1.2   Firstly, the surface must be efficiently degreased by, for example, a process such as that described in Leaflet **BL/6-8**, using trichloroethylene. The oxide film must then be removed by a chemical process such as the ones described in (a) and (b) or by a suitable proprietary process.

(a) **Chromo-Sulphuric Acid Pickle.** The solution should consist of de-mineralised water containing:—

Sulphuric acid (d=1·84)	150 ml/litre
Chromic acid (CrO_3)	50 g/litre

The solution should be contained in a lead-lined tank and should be maintained at 60°C. The treatment period should not exceed 30 minutes, after which the parts should be thoroughly washed.

(b) **Sulphuric Acid and Sodium Fluoride Bath.** The solution consists of de-mineralised water containing:—

Sulphuric acid (d=1·84)	100 ml/litre
Sodium fluoride	(NaF)	10 g/litre

The solution should be maintained at room temperature, and the parts should be immersed until uniformly clean (5 to 10 minutes). The parts should then be rinsed in cold water, dipped in an aqueous solution of 500 ml/litre nitric acid (d=1·84) for one minute and then thoroughly washed in clean water.

5.1.3   The cleaning of aluminium alloys of the type which are solution treated and naturally aged, should not be commenced until 24 hours after solution treatment. Great care should be taken to ensure the complete removal of all cleaning and pickling solutions, by efficient washing and rapid drying.

5.2   **Magnesium Alloys.** These materials should first be degreased and then carefully cleaned by a mechanical means. They should finally be air-blasted to ensure the removal of any particles left by the cleaning process.

5.3 **Corrosion-Resisting Steels.** The surfaces to be welded should be degreased and then prepared by cleaning with a brush having stainless steel bristles. Pickling is not necessary for these materials unless vapour-blasting or abrasive paper cleaning is employed, in which case contamination should be removed by pickling or swabbing in a 20% (by volume) nitric acid solution.

5.4 **Nickel Alloys.** The surfaces should first be degreased and then immersed in one of the following aqueous solutions:—

(a) Nitric acid (d = 1·42)   200 ml/litre
    Hydrofluoric acid   50 ml/litre
    The solution should be used at a temperature not exceeding 65°C.

(b) Hydrofluoric acid   125 ml/litre
    Ferric sulphate ($Fe_2(SO_4)_3$)   200 g/litre
    The solution should be used at a temperature of 65 to 70°C.

NOTE: Nickel alloys should be in the solution heat-treated condition prior to immersion in these liquids.

5.5 **Plain Carbon Steels.** After degreasing, plain carbon steels should be pickled in an aqueous solution containing 10% sulphuric acid (d = 1·84) by volume. The solution should be contained in a lead-lined or rubber-lined tank and should be used at room temperature. Welding should be carried out immediately after washing and drying the parts.

5.6 **Titanium Alloys.** The requirements for the surface preparation of titanium alloys are similar to those for other materials, i.e. the surface must be clean and free from grease. The surfaces may be cleaned by the use of any approved solvent which leaves no residue, but if the material has been heat treated for manipulation purposes prior to welding, a light oxide film will be present on the surfaces; this should be removed by an acid pickle (the solution described in paragraph 5.4 (a) is suitable) or by brushing with a wire brush.

6   SPOT WELDING OF ALUMINIUM ALLOYS   The successful spot welding of aluminium alloys necessitates careful control of the welding technique, with particular attention to surface preparation (see paragraph 5.1), electrode maintenance (see paragraph 14) and component design; otherwise even the best equipment will give poor results.

6.1   **General**

6.1.1 The welding of aluminium alloys is considerably more difficult than the welding of low carbon steels due to the inherent nature of the materials, their surface condition and their tendency to alloy with copper and copper-based electrodes. In general, the high-tensile, heat-treated alloys show greater consistency of weld strength than the low-tensile alloys, although variations due to cleaning procedures and machine settings may result in greater inconsistency than is likely to arise from differences between alloys. The heat-treated materials usually tend to show cracks and porosity in the weld more than non-heat-treated alloys, but shrinkage cracks in the weld metal are confined almost entirely to the copper-bearing alloys. There is a tendency for the weld strength of aluminium-clad alloys to be less, and the weld consistency poorer, due to the cladding, which has a higher melting point and a lower resistance than the core.

6.1.2 The above factors have necessitated the production of specialised high capacity machines giving close control of the heat/pressure cycle, so designed as to give rapid electrode follow-up (i.e. the ability of the electrodes to follow rapidly the contraction of the solidifying and cooling spot weld so that it is always subject to the effective weld pressure).

6.1.3 Aluminium alloys are materials of high thermal and electrical conductivity. The amount of heat developed by electrical resistance welding methods depends on the resistance offered to the welding current; thus, despite the relatively low fusion temperature of these materials (compared with low carbon steel) a considerably greater rate of energy input is required, necessitating the use of high currents and short welding times, the latter being necessary to minimise conduction losses. However, advantage cannot be taken of the highly resistant oxide film which forms on the surface of these materials, since, as indicated in paragraph 5.1, its inherent lack of uniformity results in variation in weld size and quality.

6.1.4 The temperature range between the liquid and solid states is very small, and because of this, very close control must be exercised over the energy input, since small variations in energy may produce relatively large variations in weld size. The high thermal conductivity of the aluminium alloys (which results in rapid dissipation of heat) causes the welds to solidify very quickly, increasing the tendency to form shrinkage cracks and porosity. In practice, this factor is overcome by various machine refinements, e.g. by rapid electrode follow-up, by the application of a relatively high pressure after welding (which serves to close up pores and eliminate the tendency to form shrinkage cracks) and by decreasing the rate of cooling during the solidification of the weld by passing a relatively small but long duration post-heating current after the main welding current has been switched off.

6.1.5 The tendency for aluminium alloys to alloy with copper or copper-based electrodes is known as electrode 'pick-up' and is caused by one or more of the following factors:—

(a) Insufficiently cooled electrodes.

(b) High contact resistance caused by incompletely cleaned materials.

(c) Low electrode pressure.

(d) Incorrectly contoured or misaligned electrodes.

(e) Relatively long duration welding currents.

(f) The use of unsuitable electrode material.

6.2 **Types of Equipment.** Fully automatic machines are universally used for the welding of aluminium alloys, so that the predetermined welding cycle can be reproduced indefinitely, independent of the operator. Compressed air is generally used as a means of applying the load to the electrodes.

6.2.1 'Stored energy' single impulse, uni-directional machines are generally used. These machines can be sub-divided into two groups, i.e. the 'induction storage' and the 'condenser storage' types. With the induction storage type, energy is stored in the electro-magnetic field of a large iron-cored inductor, whilst with the condenser type, energy is stored in the electrostatic charge of a large condenser. These machines are, however, gradually being replaced by three-phase frequency conversion machines.

6.2.2 Portable and semi-portable machines, known as 'gun' or 'pinch' welders, are also used, and are of value when used in conjunction with jigs for mass production work. Such machines are not normally used for aluminium alloys except, in certain circumstances, for tacking.

6.3 **Electrodes.** The main requirements for an electrode for spot welding aluminium alloys, are that it should possess the maximum conductivity compatible with high resistance to deformation and the minimum tendency to alloy with the material to be welded. The most careful adjustment of current and pressure settings will be invalidated if badly worn or deformed electrodes are used, since current and pressure per unit area of contact between the electrode and the workpiece is reduced, resulting in poor quality welds.

6.3.1 Because of its high electrical and thermal conductivity, copper is used as the base for all spot welding electrode materials. However, pure copper, even when hardened by cold working, would soon soften at the temperatures reached during welding. In practice, therefore, conductivity has to be sacrificed to some extent in order to obtain a material capable of withstanding, for economic periods, the pressures and temperatures to be applied.

6.3.2 Special alloy electrode materials are available (such as chromium-copper) which have an electrical conductivity of 80% of that of annealed copper, coupled with high resistance to wear and to softening at elevated temperatures. The relationship between the size of the machine and the workpiece is also important in these respects, since underpowered machines necessitate excessive welding time, which heats the electrodes beyond the critical temperature and rapidly reduces their physical properties.

6.3.3 Domed electrodes are normally used for the welding of aluminium alloys, the radius of the dome varying from 50 to 125 mm (2 to 5 in) according to the thickness of the workpiece. Truncated cone type electrodes, having an included angle of between 150 and 160° are often used with stored energy machines. The relevant sizes of both types of electrodes for various sheet thicknesses are indicated in Table 2.

TABLE 2

COMMON FACTORS FOR WELDING ALUMINIUM ALLOYS

Material Thickness		Flat Electrode Tip Diameter		Domed Electrode Dome Radius		Minimum Weld Diameter	
(mm)	(s.w.g.)	(mm)	(in)	(mm)	(in)	(mm)	(in)
0·37	28	3·175	0·125	50	2	2·78	0·100
0·45	26	3·175	0·125	50	2	2·87	0·113
0·55	24	3·969	0·156	50	2	3·18	0·125
0·70	22	3·969	0·156	50	2	3·37	0·133
0·90	20	4·762	0·1875	50	2	4·03	0·159
1·20	18	5·556	0·2187	50	2	4·47	0·176
1·60	16	6·350	0·250	100	4	5·08	0·200
2·00	14	7·144	0·281	100	4	5·71	0·225

6.3.4 Straight-thrust electrodes should be used wherever possible, but in some instances, e.g. when attaching angle sections with narrow flanges, the use of eccentric or offset electrodes is necessary. In such instances the minimum amount of eccentricity or offset should be used, so as to restrict eccentric loading and to provide maximum support to the tip.

6.3.5 In general, electrodes should not be permitted to touch adjacent structure, otherwise shunting (see paragraph 3.3) may occur through this structure, depending on the relative resistance of the direct and indirect current paths. However, where contact is unavoidable any tendency to shunting can usually be counteracted by adjustment to machine settings.

6.3.6 Information on the maintenance of electrodes is given in paragraph 14.

6.4 **Machine Settings.** Due to a number of factors, such as individual machine characteristics, the nature of the material, the method of surface preparation and the peculiarities of a particular job, it is not possible to recommend specific machine settings. These can only be determined by experience based on comprehensive tests. However, certain factors in the welding process can be considered to have common values and those for aluminium alloys are listed in Table 2. The tip diameters recommended in this table are based on the accepted formula of $D = t$, where D is the tip diameter, and t is the thickness of the workpiece. This formula may be used for determining the most suitable tip diameter for any material, but slight adjustment may be necessary when welding materials of unequal thicknesses. In general, the minimum weld pitch should not be less than three times the diameter of the electrode tip.

6.4.1 Optimum machine settings are those which give the best weld strength, consistency and metallurgical weld quality, compatible with good electrode life and simplicity of operation under production conditions. Close co-operation between production and design staff is essential in order that the strength value chosen can be readily obtained and maintained in production.

6.4.2 Machines should be set only by skilled and authorised persons, and once settings have been made, the control of the process must be such that the settings may be used indefinitely for a particular set of conditions, although it must be borne in mind that variations in material composition and surface condition may give rise to complications necessitating an alteration to the original setting.

6.4.3 The importance of electrode tip cleaning cannot be over-emphasised and should be rigidly enforced, since worn or dirty electrodes may not only affect the strength and uniformity of the welds but will invalidate the machine settings. It is not possible to recommend precisely how welds may be made before cleaning is necessary, because of the number of factors to be taken into account, but a good general rule is to clean electrodes immediately any sticking is detected. Information on electrode maintenance is given in paragraph 14.

6.4.4 The quality of spot welding should be controlled by means of control test pieces, and a recommended system is described in paragraph 11. Details regarding the inspection of spot welded joints are given in paragraph 12, and a list of typical weld defects and their causes is given in paragraph 13.

7   SPOT WELDING OF MAGNESIUM ALLOYS   Although magnesium alloys can be spot welded, the process is not recommended for stressed applications. The equipment used for spot welding aluminium alloy is suitable also for magnesium alloys, provided that positive control of the spot welding cycle can be achieved. Magnesium alloys have a rather lower electrical conductivity than aluminium alloys, consequently lower current values will be required for equivalent thicknesses. The recommendations given in Table 2 and paragraph 6.4 are equally applicable to magnesium alloys.

8 . SPOT WELDING OF PLAIN CARBON AND LOW ALLOY STEELS   The spot welding of the plain carbon and the low alloy steels is, in comparison with the aluminium alloys, a relatively simple operation because of the readily weldable nature of the materials and the absence of an interfering oxide film.   However, if the welds are to be of a consistent size and strength, cleanliness is essential and the surfaces should be prepared as indicated in paragraph 5.5.

NOTE: No attempt should be made to spot weld materials which are cadmium plated.   The plating should first be removed, the process described in Leaflet BL/7-2 being suitable.

8.1   With steels having a carbon content of up to about 0·2%, a high rate of cooling is generally desirable, since this improves the properties of the weld, particularly in respect of the avoidance of brittleness.   However, with steels having a higher carbon content and those having small additions of nickel, chromium, manganese, etc., considerable variations in properties may result from different rates of cooling, and there is a limit to which such variations can be tolerated.

8.2   So far as the higher carbon and low alloy steels are concerned, increases in the rate of cooling will result in proportional increases in the hardening effect, producing welds of relatively high tensile strength but with poor ductility.   In addition, the volumetric changes brought about by the formation of the hardened structure and the shrinkage during cooling of the weld, may result in the formation of quenching cracks in the surrounding metal.

8.3   Rapid rates of cooling can be obtained by employing very short welding times (i.e. by using high currents) which will limit the zone affected by the heat.   On the other hand, slow rates of cooling can be obtained by employing long welding times (i.e. by using low currents) which will give a gradual accumulation of welding heat, resulting in a comparatively large heat-affected zone.

TABLE 3

COMMON FACTORS FOR WELDING PLAIN CARBON AND LOW ALLOY STEELS

Material Thickness		Electrode Tip Diameter		Minimum Weld Diameter	
(mm)	(s.w.g.)	(mm)	(in)	(mm)	(in)
0·37	28	3·175	0·125	2·388	0·094
0·45	26	3·175	0·125	2·692	0·106
0·55	24	3·175	0·125	2·870	0·113
0·70	22	4·762	0·1875	3·581	0·141
0·90	20	4·762	0·1875	4·292	0·169
1·20	18	6·350	0·250	4·775	0·188
1·60	16	6·350	0·250	5·232	0·206
2·00	14	6·350	0·250	5·715	0·225
2·50	12	7·937	0·3125	6·096	0·240

8.4   Neither of the methods given in paragraph 8.3 is, on its own, capable of producing satisfactory welds in high carbon and low alloy steels, because of the greater hardenability of these materials, and a means has to be provided for improving the ductility of the weld and the adjacent metal.   Such a method consists of subjecting the whole component (including the test piece where applicable) to a tempering process after welding.

8.5   **Electrodes.**   The recommendations given in paragraph 6.3 are equally applicable to plain carbon and low alloy steels, but electrodes with an included tip angle of 120° should be used.

8.6   **Machine Settings.**   The remarks concerning machine settings given in paragraph 6.4 are equally applicable to plain carbon and low alloy steels, except that common factors should be as given in Table 3.

9   SPOT WELDING OF STAINLESS STEELS   Austenitic stainless steels have an electrical resistance approximately six times that of ordinary carbon steel, with a lower heat conductivity and melting range; therefore, considerably less heat input is required for spot welding these materials compared with plain carbon steels.

9.1   The welding of this type of material is made more difficult because of 'weld decay', which results from the precipitation of chromium carbide in metal near the weld when it is heated to a temperature within the range of 500 to 900°C.   The corrosion resistance of these materials is dependent on the retention of chromium in solid solution; therefore, the corrosion resistance is reduced if precipitation of chromium carbide occurs near the weld.

TABLE 4

COMMON FACTORS FOR WELDING STAINLESS AND HEAT
RESISTING STEELS

Material Thickness		Electrode Tip Diameter		Minimum Weld Diameter	
(mm)	(s.w.g.)	(mm)	(in)	(mm)	(in)
0·37	28	3·175	0·125	2·540	0·100
0·45	26	3·175	0·125	2·845	0·112
0·55	24	3·175	0·125	3·022	0·119
0·70	22	4·762	0·1875	3·810	0·150
0·90	20	4·762	C·1875	4·521	0·17°
1·20	18	6·350	0·250	5·080	0·200
1·60	16	6·350	0·250	5·562	0·219
2·00	14	6·350	0·250	6·045	0·238
2·50	12	7·937	0·3125	6·096	0·240

9.2   The extent of precipitation is directly related to welding times, so that short welding times are essential for these materials, since this not only reduces the heat affected zone, but permits a high rate of cooling after welding, which also reduces the tendency for precipitation.

9.3   Austenitic steels are available which contain small additions of titanium or niobium in amounts sufficient to combine with all the carbon present so that no chromium can be precipitated as carbide.

9.4   **Electrodes.** The recommendations given in paragraph 6.3 are equally applicable to stainless steels, but electrodes having an included tip angle of 120° should be used.

9.5   **Machine Settings.** The remarks concerning machine settings given in paragraph 6.4 are equally applicable to stainless steels except that the common factors should be as given in Table 4.

10   SPOT WELDING OF TITANIUM ALLOYS   Resistance spot welding character-istics of titanium are essentially similar to those of stainless steel and for this reason satisfactory welds can be made on a wide range of conventional machines and under a wide variety of conditions.   The requirements for producing satisfactory spot welds in titanium are less stringent than those required for welding aluminium and its alloys.

10.1   **Electrodes.** Electrodes should be made of heat-treated, copper-chromium alloy; several proprietary makes of electrode are available.   Either domed or truncated cone electrodes may be used, but experience has indicated that the use of domed electrodes with a dome radius of 63·5 to 100 mm (2·5 to 4 in), depending on sheet thickness, avoids the risk of excessive electrode indentation.

10.2   **Welding Conditions.** Sound welds can be obtained with conventional machines over a wide range of machine settings, but to secure the optimum mechanical properties, welding current should be adjusted so that for sheets of approximately equal thickness, the depth of the fusion zone is not less than 75 to 80% of the total thickness.

10.3   **Machine Settings.** The remarks concerning machine settings given in paragraph 6.4 are equally applicable to the spot welding of titanium alloys.

11   CONTROL OF SPOT WELDING   For design purposes a minimum strength per spot weld is assumed.   Since it is not possible actually to test the strength of welds in production parts, this aspect has to be controlled by the examination of results of tests conducted on separately welded test samples, which simulate the production parts in respect of the material specification and thickness, surface preparation, machine settings and weld pitch.   The test samples for the tests and examinations of paragraphs 11.4, 11.5 and 11.6 should be prepared at suitable intervals, an acceptable basis being one set of tests and examinations at the beginning and end of each shift, whenever a machine setting is changed, and after the replacement of electrodes.

NOTE: When spot welding is used for location purposes only and the loads on the joint are to be carried by other means of attachment, test samples are not normally required.

11.1 Production control test samples can only be used to determine whether the weld strength obtained with the samples exceeds the minimum strength per weld prescribed on the relevant drawings. It should be borne in mind that the strengths obtained with samples do not necessarily indicate that the individual weld strengths in the production assembly are acceptable, since it is not possible for such a test sample to be entirely representative of the production part as regards spacing and edge distance. Further, the sample cannot take into account the 'mass effect' in welding large panels. Minimum strength figures must be chosen with care, and should be determined by welding production assemblies and control test samples under the same conditions, breaking the welds in the assembly and comparing the results with the shear strength obtained with the test samples.
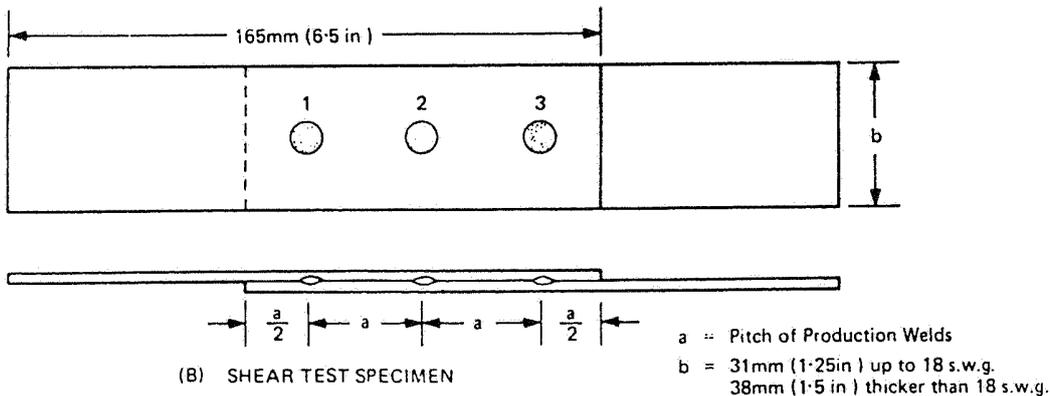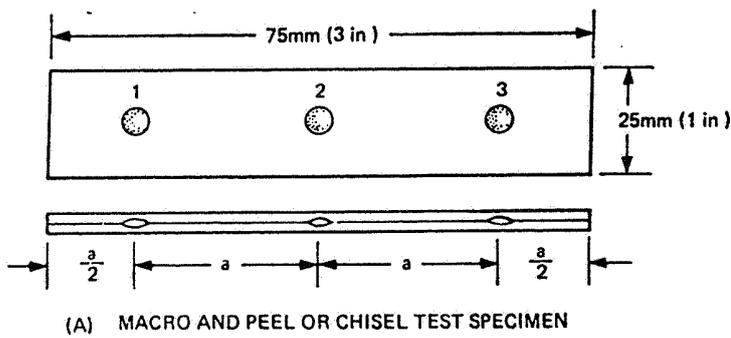

(A) MACRO AND PEEL OR CHISEL TEST SPECIMEN

(B) SHEAR TEST SPECIMEN

a = Pitch of Production Welds
b = 31mm (1·25in) up to 18 s.w.g.
       38mm (1·5 in) thicker than 18 s.w.g.

Figure 4 TEST SPECIMENS

14

11.2   Some work of particular importance may require 100% X-ray inspection or X-ray inspection of the first part produced. These requirements should be stated on the drawing and should also be the subject of an approved technique.

11.3   As a further check on the efficiency of a welding process, random samples may be selected from actual production work, to be tested by an appropriate method.

11.4   **Peel or Chisel Test.** This test has the advantage that it can be quickly performed. The test sample should be prepared as shown in Figure 4(A), and the two strips of metal should be torn apart or separated with a blunt chisel, working on each side of the weld. The first weld (which should be marked when welding the sample) should be ignored and the remaining spots should be examined. The weld nugget should be torn from one of the strips and remain in the other; it should not shear along the mating surfaces of the sheets.

11.5   **Shear Test.** Test samples should be made up to the dimensions shown in Figure 4(B), the spots being marked in the order of welding.

11.5.1   The first weld should then be removed by drilling.

11.5.2   The test sample should be held at one end and a load applied to the other end, so that a pull force is applied to the second and third welds in shear, no twisting action being exerted on the welds. Load should be applied at a controlled rate, and the load at failure should be noted.

11.5.3   The strength per spot is taken as half the load at failure and should be at least equal to the value quoted on the relevant drawing or associated documentation.

11.5.4   If a test sample fails at a load below the specified load, two further test samples should be made. If one or both of these additional samples fails the test, the material welded since the last satisfactory test should be subjected to closer examination and the entire welding process should be examined to identify the cause; if the technique has been closely controlled this should not prove difficult.

11.6   **Macroscopic Examination.** The samples for macroscopic examination should be prepared to the dimensions given in Figure 4(A), the spots being marked in order of welding.

11.6.1   The first weld should be ignored and the second and third welds should be carefully sectioned through the centreline and polished.

11.6.2   When examined through a lens of low magnification the welds should be well shaped and show freedom from overheating and from excessive cavitation and porosity. Slight cracks in the nugget may be permissible, but not if they extend into the parent metal.

11.6.3   Penetration should be adequate but not excessive, and for welds in sheets of approximately equal thickness the depth of the fusion zone should be 40 to 80% of the sheet thickness and at least 20% in any one sheet (but see paragraph 10.2 for titanium alloys). The fusion zone should not reach the surface of the sheet or, where clad materials are concerned, the cladding.

11.6.4   The minimum weld (nugget) diameter should be approximately that shown in Tables 2, 3 and 4, or as specified on the relevant drawing.

11.6.5   Pick-up (see paragraph 6.1.5) from the electrodes is not acceptable in aluminium alloys.

11.6.6   Electrode indentation should not exceed 10% of the thickness of the individual sheets.

11.7   **Identification of Test Samples.** All test samples should be marked with the machine number, the date and time of manufacture, the part number of the item represented, and the test serial number.

12   INSPECTION OF SPOT WELDED PARTS   In addition to indicating the examination to be afforded the parts after welding, this paragraph summarises the responsibilities for inspection for the process as a whole.

12.1   Inspection should verify that the period of pressure and heating, current values, etc., are as specified on the drawing and are in accordance with the results of experiments and past experience with the particular type of weld and machine used.

12.2   It should be ensured that the metal to be welded has been suitably cleaned and that the highest standard of cleanliness is observed throughout the process, that the welding technique is correct, that all drawing requirements are complied with, and that the electrodes used are of the correct form and size required by the drawing.

12.3   After welding, the surfaces of each weld should be examined to ensure that they show no obvious signs of overheating, and that both they and the adjacent metal are free from visible cracks.

12.4   The electrode indentation should be checked to ensure that it does not exceed 10% of the original thickness of the sheet being welded.   The indentation should be a well radiused impression without sharp edges.

12.5   The sheet separation at the weld should be checked to ensure that it is not greater than 10% of the combined thickness of the sheets being welded.

12.6   The inspections of 12.1 to 12.5 should be backed up by the evidence afforded by the shear, macroscopic and peel or chisel tests described in paragraph 11 and, where stressed parts are concerned, by the specified radiological examinations.

13   COMMON FAULTS IN SPOT WELDING   Table 6 indicates common faults which may occur in the spot welding process, together with the probable causes of such faults.   Figure 5 illustrates some of these faults.

TABLE 6

COMMON FAULTS IN SPOT WELDING

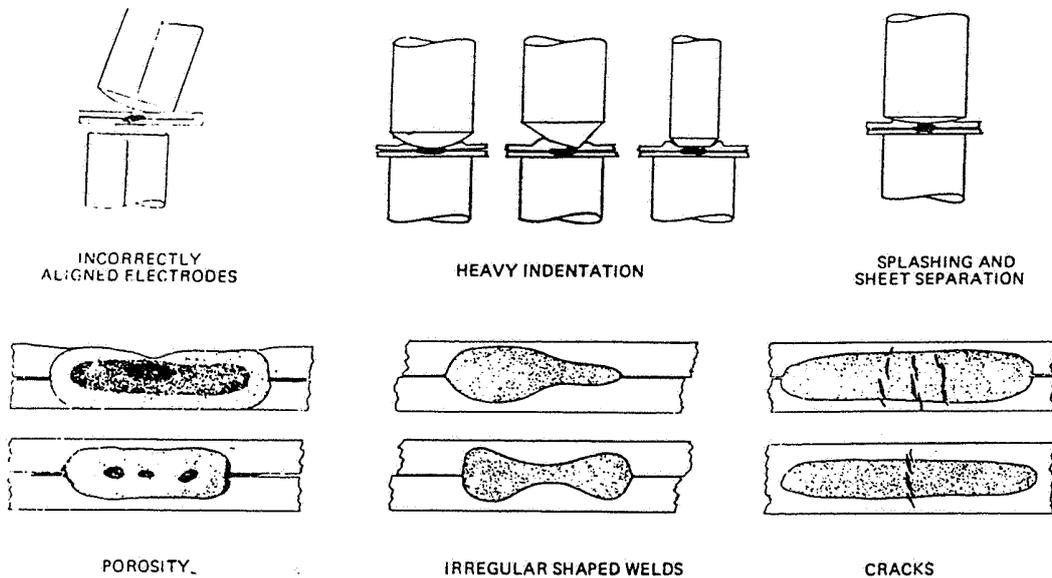| Fault	Probable Causes
Poor Strength Welds	This fault may result from a combination of various factors, the most important of which are insufficient current, weld pressure too high and misalignment of the electrode tips, producing irregular shaped welds.
Irregular Shaped Welds	Electrode tip misalignment. Incorrect surface preparation.
Surface Burning	Any factor which affects the energy input to the weld and the surface contact resistance may cause surface burning. The most important factors are incorrect surface preparation whereby the material has too high a contact resistance. Badly cleaned electrodes (e.g. electrodes from which 'pick up' has not been removed). Misaligned electrode tips, giving excessive local current concentration. High current.
Heavy Indentation	Sharp electrode contour (i.e. the use of electrodes of too small a radius or too small an included cone angle). Excessive energy input to weld with marked collapse surrounding the weld under pressure of the electrodes, and usually associated with interfacial splashes between the sheets (i.e. expulsion of weld metal at sheet separation). High electrode pressure.
Concave Shaped Nugget	Insufficient weld time. Insufficient current. Excessive electrode pressure.
Cracks in Nugget	Insufficient forging time. Insufficient electrode pressure. Excessive current. Insufficient overlap.
Unbalanced Nugget	Misalignment of electrodes. Component held at angle to electrodes.
Unequal Penetration of Equal Gauges	Electrodes of unequal sizes.
Surface Cracking	Excessive welding current. Insufficient forging time or pressure too low. Inadequate surface preparation leading to excessive heating and rapid cooling.

INCORRECTLY
ALIGNED ELECTRODES

HEAVY INDENTATION

SPLASHING AND
SHEET SEPARATION

POROSITY.

IRREGULAR SHAPED WELDS

CRACKS

Figure 5 TYPICAL WELD FAULTS

14   MAINTENANCE OF ELECTRODES   The electrodes fitted to some small machines are sometimes solid, but with most modern machines they are hollow, water-cooled and fitted with removable tips.

14.1   The cleanliness of electrode tips is of the utmost importance and the tips should be cleaned in accordance with a definite schedule and whenever evidence of 'sticking' is noted.   Light erosion may be blended out using a fine grade of emery paper, but deeper erosion should be blended out by machining.   Filing or other cleaning methods which would alter the shape of the electrodes must not be used.

14.2   Deformation of electrodes will occur during use.   An increase in diameter of the flat tip of a truncated cone electrode produces a corresponding reduction in current density, and weld strength will be affected accordingly; no definite rule can be given regarding the permissible extent of distortion, but in any case it should never exceed 10%.   Similarly the diameter of the flat which forms on domed electrodes should not be allowed to exceed the corresponding flat tip diameter by more than 10%.   Profile gauges are helpful in checking deformation.   Where deformation exceeds agreed limits, the electrode tip should be machined to the original diameter.

14.3   Before electrodes are inserted in the holders on the machine, they should be wiped with a clean rag to remove any dirt.   This ensures that the tapers of the electrode and the holder are maintained in good condition, facilitating the removal of electrodes and preventing water leakage.

15   MAINTENANCE OF WELDING EQUIPMENT   In general, the maintenance of the machines and equipment used for spot welding should be in accordance with the instructions prepared by the manufacturers of the machines or equipment. However, to ensure continued efficiency, the following points should receive regular attention.

15.1   Each week all machine bearings should be lubricated and the air line water traps should be drained.

15.2   Monthly maintenance should include the following:—

(a) A calibration check of all instruments and gauges.

(b) A check on the water cooling system to ensure an unrestricted flow and freedom from leaks.

(c) A check to ensure that all indicator lights on the control panel function correctly.

(d) A check to ensure that all relays on the control panel and on the machine are clean, in good condition, and are holding correctly.

(e) A check on thermionic valves for satisfactory operation.

(f) A check to ensure that the moving arm is completely free from side play and twist, and is free to fall under its own weight with the compressed air switched OFF.

(g) A check to ensure that the air pressure line from the reducing valve to the air pressure head is pressure tight and free from air leaks, and that the reducing valve is functioning correctly.

(h) A check to ensure the correct operation of the timing device on the control panel.

(j) A check to ensure cleanliness of the welding machine and its mechanical components.

BASIC

ENGINEERING PRACTICES AND PROCESSES

LOCKING AND RETAINING DEVICES

I   INTRODUCTION   This Leaflet gives guidance on the methods of locking screw-threaded components, and the retention or location of circular parts in various assemblies. Chapter **D4-1** of British Civil Airworthiness Requirements prescribes that an approved means of locking must be provided on all connecting elements in the primary structure, fluid systems, controls and other mechanical systems essential to the safe operation of an aircraft. Information on the assembly and locking of turnbuckles is given in Leaflet AL/3-7, on the assembly and inspection of critical bolted joints in Leaflet AL/7-8, and on stiffnuts in Leaflet BL/2-6.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet BL/5-1, Issue 3, 1st February 1967.

1.1   The purpose of a locking device is to prevent loosening or disengagement of mating components under varying conditions of stress, vibration and temperature, and its effectiveness may be of the utmost importance to the safety of an aircraft. Locking devices should be fitted in such a way as to prevent the possibility of fretting, distortion, displacement or uneven stressing of the locked parts.

1.2   During inspection of the assembly, it is necessary to ascertain that all locking or retaining devices are of the type and material specified in the relevant drawings or the appropriate publication, and that the locking or fitting operation has been correctly performed with the appropriate tools.

2   SPLIT PINS   Split pins are manufactured from corrosion resisting steel, and are used in conjunction with drilled bolts and slotted or castellated nuts. The pins should be a reasonably close fit in the nut and bolt/stud assembly. Table 1 indicates the diameters and length of pins normally used in conjunction with bolts/studs up to 1 inch diameter.

TABLE 1

SPLIT PIN SIZES

Bolt Diameter (inch)	Pin Diameter (inch)		Pin Length (inch)
	British (SP 90)	American (MS 24665)	
1/4 or 2 BA	1/16	1/16	3/4
5/16	1/16	1/16	1
3/8	1/16	3/32	1
7/16	3/32	3/32	1.1/4
1/2	3/32	3/32	1.1/4
9/16	1/8	1/8	1.1/2
5/8	1/8	1/8	1.1/2
3/4	5/32	1/8	1.3/4
7/8	5/32	1/8	2
1	3/16	1/8	2.1/4

NOTE: It will be seen that British and American practice differs with regard to split pin diameters for different thread sizes and care must be taken to ensure that the correct pin is selected for any particular drilled bolt. The size of the split pin hole in the bolt should be checked before fitting the nut.

2.1   The legs of split pins should be turned as indicated on the design drawings, but when the method is not specified it is recommended that one of the methods illustrated in Figure 1 should be used.   If necessary, pins should be cut to a suitable length to prevent pick-up in clothing, cleaning cloths, etc., and the surplus ends accounted for to prevent their becoming a loose article hazard.
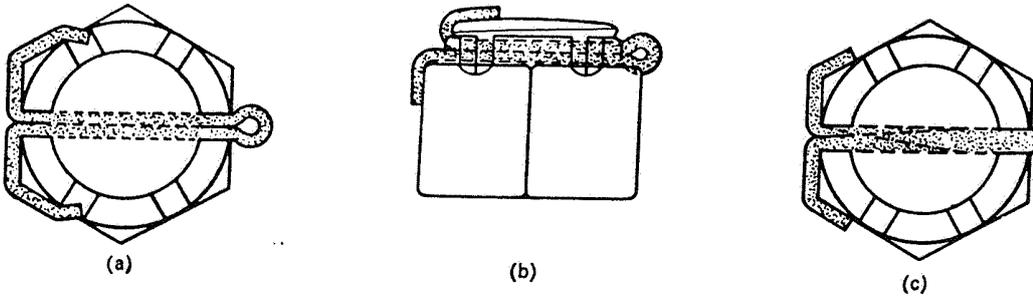

(a)   (b)   (c)

Figure 1 SPLIT PINNING

2.2   After turning and closing the legs to the nut faces, an inspection should be made to ensure that cracking or cutting has not occurred at the bends.   The most common methods of split pinning are illustrated by Figure 1 (a) and (b).   The method shown in Figure 1 (c) is used where clearances are critical.

2.3   For bolted joints, one pair of slots must be in alignment with the hole in the bolt when the specified degree of tightness has been obtained.   Undrilled bolts should be prepared for drilling by tightening the nut to the specified torque loading and marking the hole position.   The nut should be removed and the split pin hole drilled with the aid of a drilling jig.   Burrs should then be removed, the nut fitted and tightened to the required torque loading, and the correct size of split pin fitted.

2.4   In instances where torque loading is not specified, it may be permissible to tighten the nut slightly to achieve alignment, but in no circumstances should a nut be eased back from the normally tight position since this may result in slackness between the parts of the assembly.   Nuts must not be filed to facilitate the fitting of split pins. Alignment is more difficult with drilled bolts, and selective assembly of nuts and/or washers may be required.

2.5   Split pins should not be used more than once.   Split pin holes should not be enlarged, nor split pins filed to facilitate fitting.

3   LOCKING WASHERS   There are several types of locking washers in general use consisting of spring washers, cup washers, shakeproof washers, crinkle washers and tab washers (Figure 2).

3.1   **Spring Washers.**   These washers are available in two forms, i.e. as a single coil (SP 47) or as a double coil (SP 55 and 56).

3.1.1   In some instances, particularly with light alloy assemblies, spring washers are assembled with plain facing washers between the spring washer and the component, to prevent damage to the surface of the component or the protective treatment when the spring washer is compressed.   Often, however, particularly in steel assemblies, plain washers are not specified.

3.1.2   It is good practice to renew spring washers during overhaul or repair.   This is essential in engines and engine components, and units with reciprocating parts, such as compressors or pumps.

3.2   **Cup Washers.**   These washers (AS 8690 to 8699) are manufactured in spring steel and are dished to form a spring of high rating; assembly should be in accordance with the manufacturer's instructions.

3.3   **Shakeproof Washers.**   Flat washers of this type (AGS 2034 and 2035, steel; AGS 2037, phosphor bronze) are sometimes used instead of spring washers and, in certain circumstances, conical shakeproof washers (AGS 2036, steel) are used for locking countersunk screws.   Either the internal diameter (AGS 2035 and 2037) or external diameter (AGS 2034 and 2036) is serrated, the serrations being set to bite into the component and nut to prevent rotation.   Shakeproof washers should only be used once.

NOTE: These washers will not normally be specified in assemblies where anti-corrosion treatment of components has been carried out.

3.4   **Crinkle Washers.**   These washers (SP 134 to 138, copper alloy, and SP 139 to 140, corrosion resisting steel) are often used in lightly loaded applications in instrument and electrical installations.

3.5   **Tab Washers.**   Tab washers are manufactured from thin metallic sheet materials, to SP 41 to 46 or SP 107 to 112, or to proprietary specifications, and have two or more tabs projecting from the external diameter; they may also be designed for locking two or more nuts.   When the washer is fitted, one tab is bent against the component or fitted into a hole provided for that purpose, whilst a second tab is bent against a flat or flats of the nut, after the nut has been correctly tightened down.   The component tab should not be bent against a curved surface, since this would permit movement of the washer, and result in loosening of the nut.

3.5.1   Before bending the second tab, an examination should be made of the tab already fixed to ensure that it is not disturbed, sheared or distorted as a result of the washer turning with the nut.   When the second tab has been bent, this too should be examined for cracks.

3.5.2   In some assemblies, washers having a tab projecting from the inside diameter are used.   The tab fits into a slot machined in the bolt thread or the component hole, whilst an external tab is turned up as described in paragraph 3.5.

3.5.3   Tabs must not be bent more than once.   Multiple tab washers may be re-used after removing the used tab, dressing sharp edges, and carefully inspecting the remaining tabs for cracks or scoring.

4   LOCKNUTS   Generally, locknuts are thin plain nuts which are tightened against ordinary plain nuts or against components into which male threaded items are fitted, although proprietary locknuts are available which are formed from sheet material. Control rods, swaged-end cables and jack ram eye-end fittings are common examples of the use of locknuts, but in some instances wire locking is also specified.   To ensure efficient locking, the bearing surface of the nuts and the component must bed together evenly and the correct degree of tightness must be obtained by applying the stipulated torque loading.   It is emphasised that the locknut should not be over-tightened, since this will result in the stripping of the nut threads or over-stressing of the male component. In cases where rotation can occur, the plain nut must be held stationary whilst the locknut is tightened.
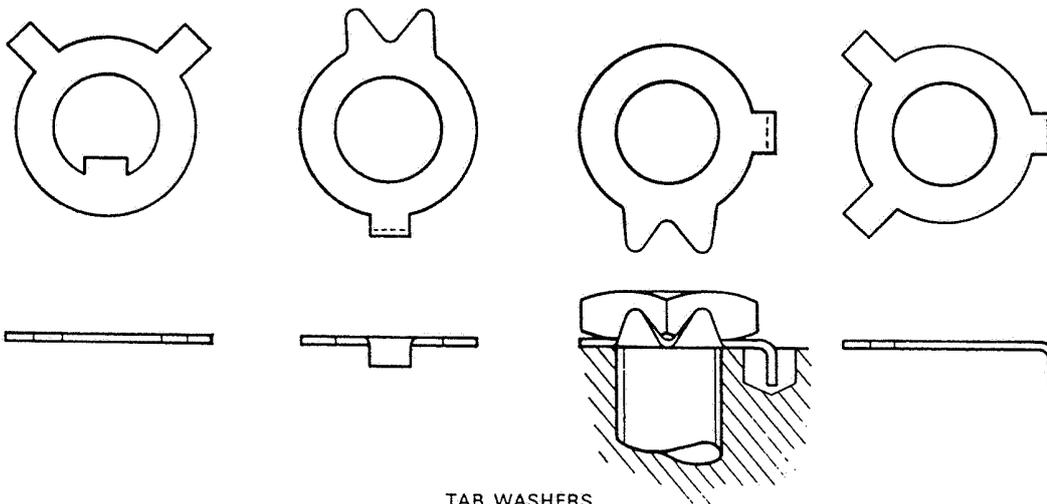
Single Coil   Double Coil   Crinkle   Cup
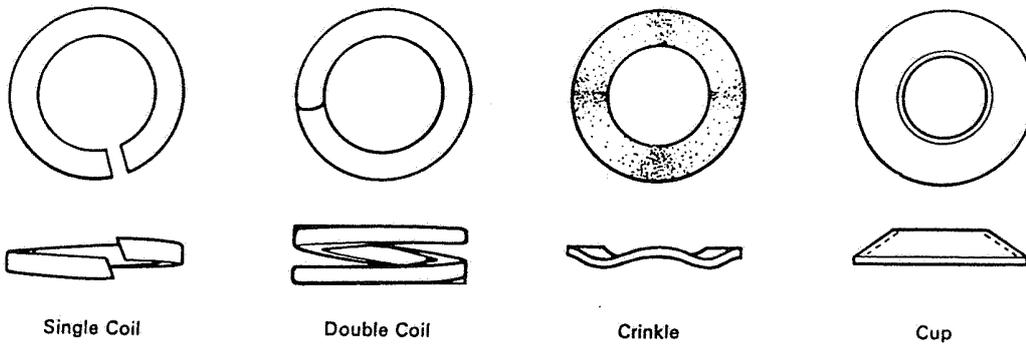
SPRING WASHERS
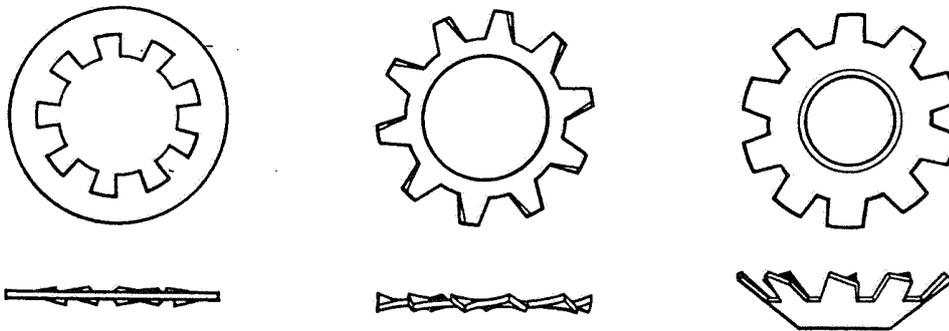
SHAKEPROOF WASHERS

TAB WASHERS

Figure 2 TYPES OF WASHERS

4

5   LOCKING PLATES   Locking plates are usually manufactured from steel. They are placed over hexagonal nuts or bolt heads after these items have been tightened down, and secured, usually by a screw, to an adjacent part of the structure. A typical application is shown in Figure 3.

5.1   Locking plates may be used repeatedly provided they remain a good fit around the hexagon of the nut or bolt head.
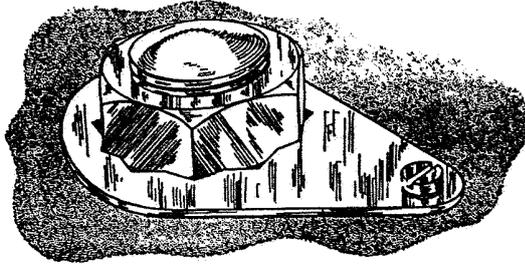
Figure 3 LOCKING PLATE

5.2   In certain instances, particularly where vibration is likely, locking plate screws are fitted with spring or shakeproof washers. Some plates may be located by counter-sunk screws, which may be locked by peening (see Figure 8). Plates may also be provided with a retaining screw slot which permits a limited amount of angular adjustment to suit the position of the nut.

6   CIRCLIPS AND LOCKING RINGS   Many of these locking devices (see Figure 4) are standard AGS parts manufactured from spring steel wire, sheet or plate, but they may also be specially designed for a particular application. All are hardened and tempered to give inward or outward spring for locking screwed parts together, for locking grub screws (paragraph 10), or for locating components within bores or housings.

6.1   Wire circlips have both ends bent whilst other types have drilled ends which facilitate expansion or contraction for fitting into position.

6.2   Generally, wire locking rings have one bent end which is inserted into a radial hole drilled through the outer or inner component, depending on whether it is an external or internal type. Locking rings of sheet or plate are seldom provided with a bent end, and the fitting of these entails the use of special expanding/contracting tools and protecting sleeves.

6.3   Grooves for circlips and locking rings are semi-circular for wire types and of rectangular section for others and, before fitting, precautions should be taken to ensure that these are free from deformation, burring or dirt.

6.4   Inspection should ensure that all of these devices are bedding correctly, and that the locking end of locking rings is correctly engaged.

6.5   Identification of these devices is difficult and every care should be taken to ensure that the correct items are fitted. Items should be obtained by part numbers and not identified by comparing the old and new, since the diameters of the old are likely to differ considerably from those of new items. Part numbers of the correct part to be fitted should be verified from the appropriate drawings, Overhaul or Repair Manuals or Parts Catalogue.

6.6 Some manufacturers stipulate that circlips and locking rings must not be used more than once. However, in some instances, it is specified that the gap between the ends of a circlip or locking ring should, after fitting, be within prescribed limits, and individual selection may be necessary. The radial position of the gap may also be specified.

7 WIRE LOCKING Corrosion resisting steel and heat resisting nickel alloy are the materials normally recommended for wire locking, except in the circumstances described in paragraph 7.6. Care should be taken to ensure that the wire used is to the correct specification and gauge required by the relevant drawing. In the normal twisting method of wire locking, a suitable length of wire should be cut from the coil and passed through the hole provided for the purpose in the component. The wire should be twisted over the length required to reach the locking point, through which one end of the wire should be passed, and then twisted for not less than a further ½ inch whilst being pulled taut. It is necessary to pull the wire taut to ensure that the final twists are close to the locking hole, but neither this nor the twisting should be too severe. After surplus wire has been removed, the twisted ends should be bent in such a manner as to prevent their catching in clothing, cleaning cloths, etc. There should be no untwisted lengths in excess of ⅜ inch, and lengths of unsupported wire should not normally exceed 3 inches.

INTERNAL - EXTERNAL   INTERNAL   EXTERNAL

CIRCLIPS

WIRE TYPES   SHEET/PLATE TYPES

LOCKING
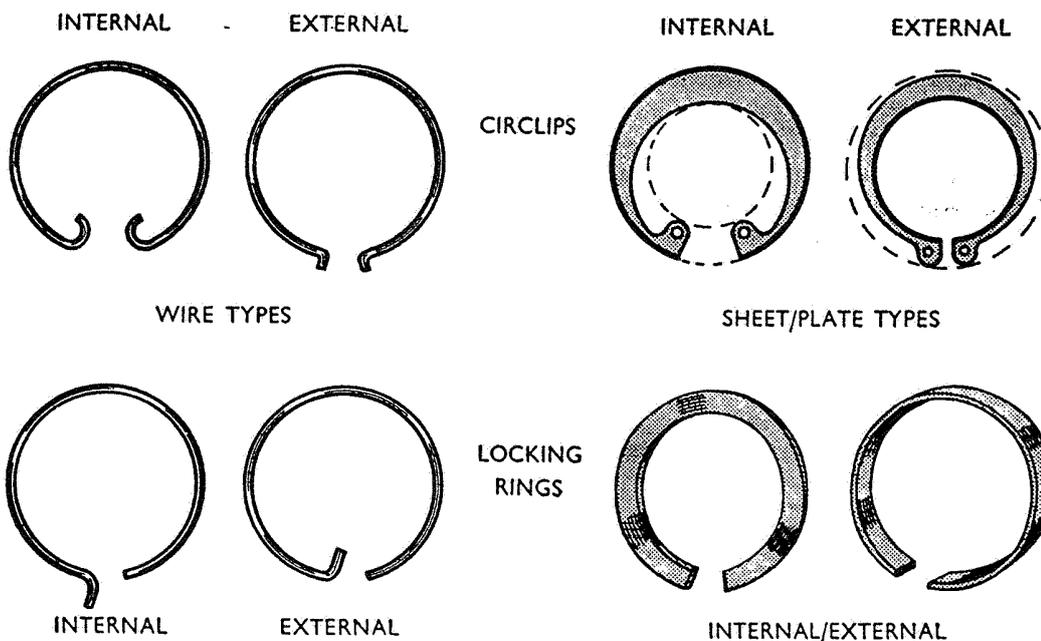RINGS

INTERNAL   EXTERNAL   INTERNAL/EXTERNAL

Figure 4 CIRCLIPS AND LOCKING RINGS

7.1 The angle of approach of the wire should not be less than 45° to the rotational axis of the component to be locked (see Figure 5), whilst the line of approach should be tangential to the parts being locked (see Figure 6). The lay of the wire must always be such as to resist any tendency of the locked part or parts to become loose, and for this reason it is essential to ascertain whether the parts have left or right hand threads before fitting the wire.
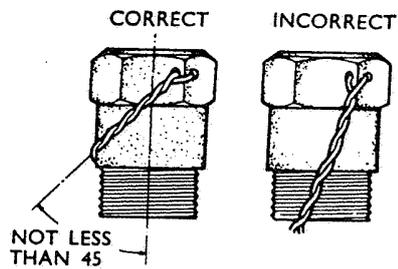
CORRECT   INCORRECT

NOT LESS
THAN 45

90°

90°

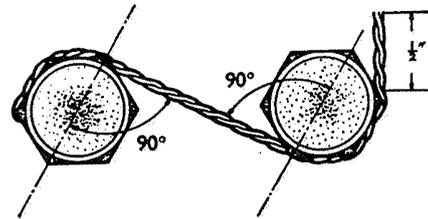*Figure 5* ANGLE OF APPROACH   *Figure 6* TANGENTIAL APPROACH

7.2   In instances where the method of wire locking is not indicated on the drawing, great care is necessary when deciding on a locking method to ensure that there is no possibility of the parts becoming loose.   For example, when adaptors are used in pipe joints, it is essential that the adaptor is secured to each union nut by separate locking wires to adjacent corners of the adaptor nut, with the approach angle shown in Figure 5.   It may be specified that the adaptor is locked additionally to some external point.

7.3   When locking tabs are used, they should be fitted in such a way that the tabs and the wire are in complete alignment.   Examples of correct and incorrect use of locking tabs are shown in Figure 7.   Whenever possible, the closed end of the wire should be in the tab and the open end at the component to be locked.
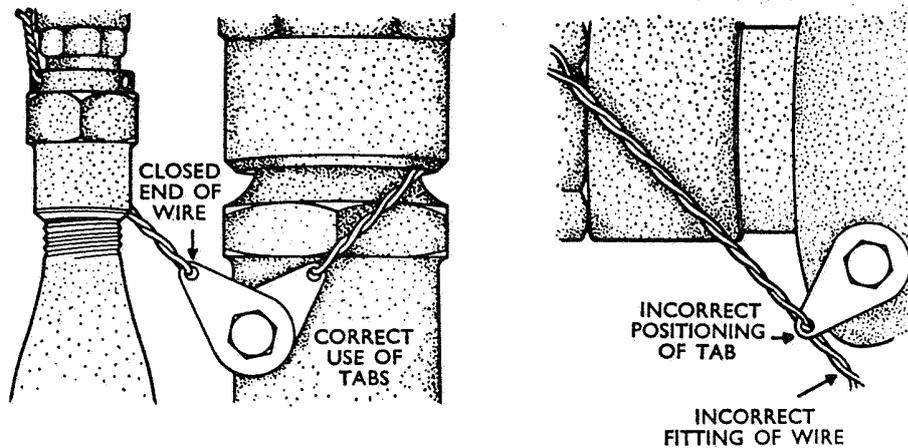
CLOSED
END OF
WIRE

CORRECT
USE OF
TABS

INCORRECT
POSITIONING
OF TAB

INCORRECT
FITTING OF WIRE

Figure 7 CORRECT AND INCORRECT USE OF LOCKING TABS

7.4   Some wire locking is done with a single strand of the specified wire, particularly in instances of complete ring or similar formations of nuts.   The wire is passed in sequence through the nut slots and bolt/stud holes around the formation until the wire ends meet. The ends are cut to suit and twisted together to tension the loop.   The wire direction through all nuts must be such that any loosening of a nut will further tension the wire.

7.5   Locking wire must not be used more than once. The wire must be adequately tensioned; over-tensioning may lead to fracture of the wire, or of the metal around the locking hole. Sharp edges of locking holes must be removed, and there must be no obstruction by the locking wire of any moving parts, controls, etc.

7.6   In some instances controls or switches are wire locked into their normal operating position, and selection of an emergency position necessitates physically breaking the wire. The use of stainless steel wire in these instances could prevent operation of an essential service, and thin copper wire is usually specified. The method of installing this type of locking (sometimes known as 'wire sealing') is normally detailed in the appropriate Maintenance Manual.

8   SELF-LOCKING FASTENERS   These fasteners include stiffnuts and screws, nuts or bolts in which an inset nylon patch or stud applies friction between the male and female components. To provide effective locking, the friction element in each device must be fully engaged with complete threads on the mating component; with stiffnuts this consideration requires that the male threads extend at least one full thread (not including the chamfer), through the friction element.

8.1   Fasteners with a fibre or nylon friction element should only be used once, and must not be used in locations where all-metal stiffnuts are specified. All-metal stiffnuts should not be re-used in locations vital to aircraft safety (e.g. control runs) but may be re-used in other locations provided the locking quality remains satisfactory.

8.1.1   Most aircraft manufacturers lay down the assembly conditions (e.g. dry or lubricated) and acceptable limits of in-built torque for the re-use of stiffnuts, and require that each nut should be checked with a torque wrench during assembly.

NOTE: The use of torque wrenches is discussed in Leaflet BL/6-30.

8.1.2   A recognised method of checking the friction elements of small stiffnuts which are not being used in locations vital to aircraft safety is to screw the nut on to the male thread, using finger pressure only. If it is possible to turn the nut far enough for the male thread to protrude through the friction element the locking is unsatisfactory. This test is suitable for small nuts where the torque applied by the fingers approximates to the in-built torque requirement of the nut specification, but is unrealistic for larger nuts.

8.1.3   Unsatisfactory locking may also result from a worn male thread, and if either of the above tests leads to rejection of a stiffnut the male thread should be closely inspected. If a new stiffnut fails to provide adequate friction then it may be necessary to replace the bolt or stud on which it is to be assembled.

9   PEENING   The peening of bolts for locking purposes should only be carried out when specified in the drawing, or the relevant manual, as the operation prevents re-use of the nut and bolt and may cause difficulty in dismantling. About 1½ threads of the bolt should be projecting and the peening carried down to the nut to prevent it slackening. Adequate support should be given to the bolt during the peening operation, and care taken to prevent damage to the part by misdirected blows with the hammer. Countersunk screws may be locked by the method illustrated in Figure 8 when the thread is inaccessible. Protective treatment damaged by the peening operation must be restored.
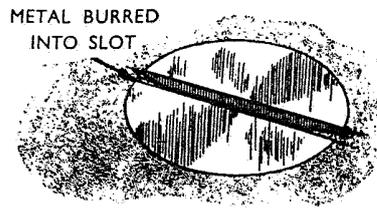
METAL BURRED
INTO SLOT

Figure 8 PEENING TO LOCK COUNTERSUNK SCREWS

10 GRUB SCREWS These are used as a method of locking two threaded components together. In one method the outer component only is drilled and threaded and the grub screw may be machined at the inner end to a tapered point or a parallel plain shank to fit either a conical recess or parallel hole in the inner component. Other grub screws may be fitted into a single hole drilled and threaded in both inner and outer components. Grub screws may be locked by peening using the method illustrated in Figure 8, by a wire type locking ring or by means of a nylon insert in either the male or female thread.

10.1 Grub screws are also used, with the variations already mentioned, in non-threaded assemblies to retain the parts and ensure correct alignment. They may be fitted as additional or precautionary locking devices in assemblies with interference fits or bonded joints, or, in some cases, they may be the only means of retention. In these cases, however, several grub screws may be fitted around the component and these may be locked by lock nuts or clamping type lock rings.

11 TAPER PINS AND PARALLEL PINS Taper pins, with taper of 1 in 48, and parallel pins, are used on both tubular and solid sections, to secure control levers to torque shafts and forked ends to control rods, etc. Some taper pins are bifurcated and the legs spread for locking, whilst other taper pins, and parallel pins, are locked by peening, or by forming reaction rivet heads. To avoid slackness, the pins are usually assembled in reamed holes, the head being supported during the locking process. Careful inspection is required after fitment of pins through hollow tubes, to ensure that undue force during the peening operation has not bent the pins, and thus impaired the security of the fittings.

12 LOCKING BY ADHESIVES

12.1 Many small components, particularly those in instruments, valves, switches, etc., may be locked by the application of Shellac, Araldite or similar materials to DTD 900 specifications. The adhesive is applied to the outside of the nut face and protruding screw thread, or the component and screw head, after tightening, and prevents movement between the two parts.

12.1.1 When using Araldite it is good practice to mix a separate sample under similar conditions, to check that it hardens within the specified time period.

12.2 Threaded metal fasteners may also be locked using a liquid sealant such as Loctite. This is an approved proprietary material (DTD 900 Approval No. 4588) which hardens in the screw threads after assembly, and is supplied in various grades to give a pre-determined locking torque in a variety of applications from stud locking to retaining bearings in housings. In using Loctite it is advisable to have the parts free from grease to achieve maximum strength. It is possible, however, to use Loctite on threaded parts which have not been degreased but retain the original lubrication applied by the manu-facturer. In these cases a 15 per cent decrease in the strength of locking usually occurs. Loctite should only be used when specified by the approved drawings or instructions, and applied in accordance with the manufacturer's instructions.

BASIC
ENGINEERING PRACTICES AND PROCESSES

BALL AND ROLLER BEARINGS

1   INTRODUCTION   This Leaflet gives information on the uses of the various types of ball and roller bearings, and general guidance on installation, maintenance and inspection. Methods of assessing wear are described, but the appropriate aircraft manual should be consulted for the amount of play or clearance permitted, in any installation in which rolling bearings are used.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet BL/5-2, Issue 1, dated 1st July 1957.

2   TYPES OF BEARINGS AND THEIR USES   Bearings are broadly classified by the type of rolling element used in their construction. Ball bearings employ steel balls which rotate in grooved raceways, whilst roller bearings utilise cylindrical, tapered or spherical rollers, running in suitably shaped raceways. Both types of bearings are designed for operation under continuous rotary or oscillatory conditions, but, whilst ball bearings and tapered roller bearings accept both radial and axial loads, other types of roller bearings accept mainly radial loads. The following paragraphs amplify the uses of the various types of bearings, and examples are shown in Figure 1.
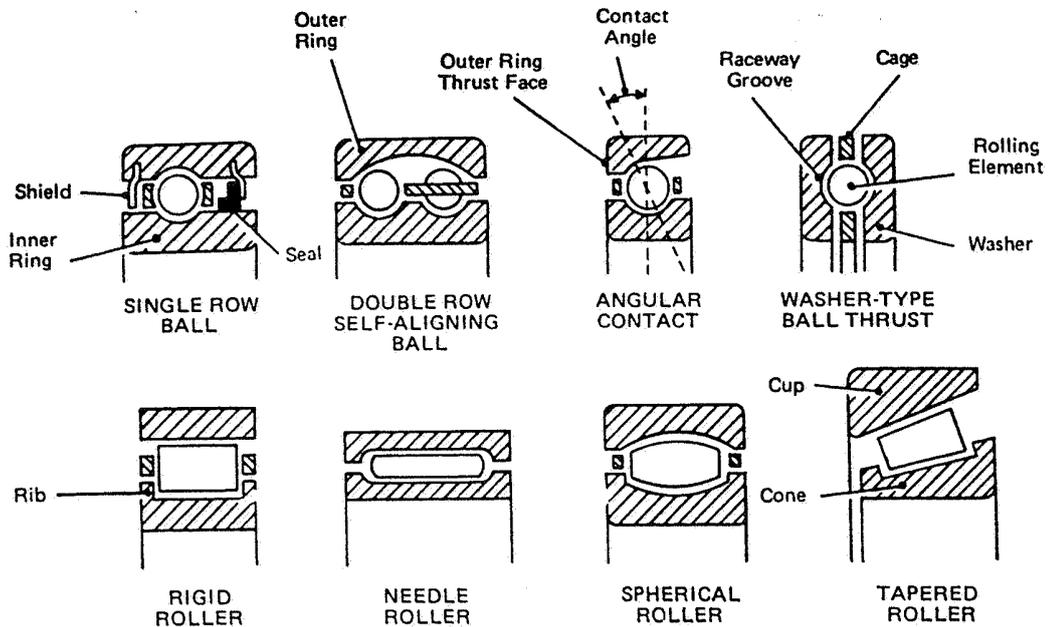

Figure 1   EXAMPLES OF BALL AND ROLLER BEARINGS

2.1   Caged bearings are in general use for engine applications and in equipment with rotational speeds in excess of approximately 100 rev/ min.   Most other bearings on an aircraft are intended for oscillating or slow rotation conditions and do not have a cage; they are generally shielded or sealed and pre-packed with grease, but some have re-lubrication facilities.

2.2   **Ball Bearings.**   These bearings may be divided into four main groups, namely radial, angular contact, thrust and instrument precision bearings.

2.2.1   **Radial Bearings.**   This is the most common type of rolling bearing and is found in all forms of transmission assemblies such as shafts, gears and control-rod end fittings. The bearings are manufactured with the balls in either single or double rows, rigid for normal applications, or self-aligning for positions where accurate alignment cannot be maintained.   Such bearings may also be provided with metal shields or synthetic rubber seals to prevent the ingress of foreign matter and retain the lubricant, and with a circlip groove or flange for retention purposes.   The balls are often retained in a cage, but in some cases filling slots in the inner and outer rings permit individual insertion of the balls, thus allowing a larger number of balls to be used and giving the bearing a greater radial load capacity; however, axial loads are limited due to the presence of the raceway interruptions.

2.2.2   **Angular Contact Bearings.**   These bearings are capable of accepting radial loads, and axial loads in one direction.   The outer ring is recessed on one side to allow the ball and cage assembly to be fitted, thus enabling more balls to be used and the cage to be in one piece.   The axial loading capacity of an angular contact bearing depends to a large extent on the contact angle.   To achieve the contact angle large radial internal clearances are usually employed; the standards of clearance specified for radial bearings (paragraph 3) do not normally apply.

(i)   In applications where axial loads will always be in one direction, a single angular contact bearing may be used, but where axial loads vary in direction an opposed pair of bearings is often used, and adjusted to maintain the required axial clearance.

(ii)   A particular type of angular contact bearing, known as a duplex bearing, is fitted with a split inner or outer ring, and is designed to take axial loads in either direction.   The balls make contact with two separate raceways in each ring, and one essential condition of operation is that the bearing should never run unloaded. The bearings are not adjustable, and radial loads should always be lighter than axial loads.   This is a most efficient form of thrust bearing and is not speed-limited as is the washer type described below.

2.2.3   **Thrust Bearings.**   Thrust bearings are designed for axial loading only, and are normally used in conjunction with a roller bearing or radial ball bearing.   The balls are retained in a cage and run between washers having either flat or grooved raceways. Centrifugal loading on the balls has an adverse effect on the bearings and they are, therefore, most suitable for carrying heavy loads at low speeds.

2.2.4   **Instrument Precision Bearings.**   These bearings are used mainly in instrument and communication equipment, and are manufactured to a high degree of accuracy and finish.   They are generally of the radial bearing type without filling slots, although other types are obtainable.   Tolerances quoted in BS 3469 for instrument precision bearings are closer than those quoted in BS 292 for standard ball and roller bearings, and only three classes of radial internal clearance are specified.   BS 3469 also contains details of test procedures for instrument precision bearings.

NOTE: Neither BS 3469 nor BS 292 quotes tolerances for axial clearance

2.3 **Roller Bearings.** Roller bearings may be divided into three main groups, according to whether they have cylindrical, spherical or tapered rollers.

2.3.1 **Cylindrical Roller Bearings.** These bearings are capable of carrying greater radial loads than ball bearings of similar external dimensions, due to the greater contact area of the rolling elements. Bearings with ribs on both rings will also carry light, intermittent, axial loads.

(i) The type of cylindrical roller bearing most commonly used is that in which the diameter and length of the rollers are equal, and standard sizes within this type are listed in BS 292. Bearings having rollers of a length greater than their diameter are also used for special applications.

(ii) A different kind of bearing in this category is the needle roller bearing, in which the length of the rollers is several times greater than their diameter. These bearings are designed for pure radial loads and are often used in locations where the movement is oscillatory rather than rotary, such as universal couplings and control-rod ends. Needle bearings are particularly useful in locations where space is limited, and are often supplied as a cage and roller assembly, the shaft of the components acting as the inner ring. The dimensions and surface finish of the shaft must be closely controlled to the standards specified by the bearing manufacturer. These bearings are particularly susceptible to the effects of misalignment and lack of lubricant, and may also be subject to brinelling, due to the lack of rotational movement.

NOTE: "Brinelling" is indentation of the surface of a material, resembling the indentations formed during a Brinell hardness test (Leaflet BL/10-3).

2.3.2 **Tapered Roller Bearings.** These bearings are designed so that the axes of the rollers form an angle with the shaft axis. They are capable of accepting simultaneous radial loads and axial loads in one direction, the proportions of the loads determining the taper angle. Tapered roller bearings are often mounted back to back in pairs, and adjusted against each other to obtain a working clearance. Because the axial load on the rollers results in rubbing contact on the cone rib, careful lubrication is essential, particularly at high speeds.

2.3.3 **Spherical Roller Bearings.** A spherical roller bearing may have one or two rows of rollers which run in a spherical raceway in the outer ring, thus enabling the bearing to accept a minor degree of misalignment between opposite bearings. The bearing is capable of withstanding heavy radial loads, and moderate axial loads from either direction.

3 RADIAL INTERNAL CLEARANCE Radial ball bearings and cylindrical roller bearings are manufactured with various amounts of radial internal clearance. Standard bearings are available in four grades of fit, namely Group 2, Normal Group, Group 3 and Group 4, while instrument precision bearings are supplied in the first three groups only. Bearings are usually marked in some way to indicate the class of fit, a system of dots, circles or letters often being used. It is important that replacement bearings are of the same standard.

3.1 Group 2 bearings have the smallest radial internal clearance and are normally used in precision work where minimum axial and radial movement is required. These bearings should not be used where operating conditions, such as high temperatures, could reduce internal clearances, and are not suitable for use as thrust bearings or for high speed

3.2   Normal Group bearings are used for most general applications where only one ring is an interference fit and where no appreciable transfer of heat to the bearing is likely to occur.

3.3   Group 3 bearings have a greater radial internal clearance than Normal Group bearings and are used where both rings are an interference fit, or where one ring is an interference fit and some transfer of heat must be accepted.   They are also used for high speeds and where axial loading predominates.

3.4   Group 4 bearings have the largest radial internal clearance; they are used where both rings are an interference fit, and the transfer of heat reduces internal clearances.

4   LUBRICATION   Adequate lubrication is essential for all types of rolling bearings. The purposes of the lubricant are to lubricate the areas of rubbing contact, e.g. between the rolling elements and the cage, to protect the bearing from corrosion, and to dissipate heat. For low rotational speeds, or for oscillating functions such as are found in a number of airframe applications, grease is a suitable lubricant; at higher rotational speeds grease would generate excessive temperatures because of churning, and oil is more suitable. Because of the variety of uses to which rolling bearings are put, and the varying require-ments of different locations, it is important that only those lubricants recommended in the approved Maintenance Manual should be used.

4.1   External bearings on aircraft are often of the pre-packed, shielded or sealed types, and are usually packed with anti-freeze grease because of the low temperatures en-countered; these bearings cannot normally be re-packed with grease, and when un-serviceable must be rejected.   Wheel bearings are normally tapered roller bearings, and should be re-packed with the correct grease when refitting the wheel (see Leaflet AL/3—19).

4.2   Bearings fitted in engines and gearboxes are generally lubricated by oil spray, splash, mist, drip feed, or controlled level oil bath, and loss of lubricant is prevented by the use of oil retaining devices such as labyrinth seals, felt or rubber washers, and oil throwers.

5   INSTALLATION OF BEARINGS   The majority of bearing failures are caused by faulty installation, unsatisfactory lubrication, or inadequate protection against the entry of liquids, dirt or grit.   To obtain the maximum life from a bearing, therefore, great care must be exercised during installation and maintenance, and strict cleanliness must be maintained at all times.

5.1   Where bearings carry axial loads only, the rings need only be a push fit in the housing or on the shaft, as appropriate, but bearings which carry radial loads must be installed with an interference fit between the revolving ring and its housing or shaft, otherwise creep or spin may take place and result in damage to both components.   In instances where light alloy housings are used, the bearing may appear to be a loose fit during installation owing to the need to control bearing fit in the housing at the low tempera-tures experienced at high altitude.
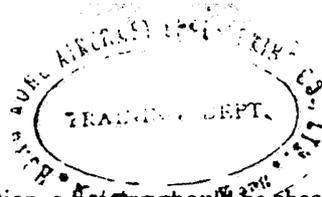
5.2 Before installation, a bearing should be checked to ensure that it is free from damage and corrosion, and that it rotates freely. In some cases bearings are packed with storage grease, which is unsuitable for service use and must be removed by washing in a suitable solvent as specified in paragraph 8.1. All open bearings should be lubricated with the specified oil or grease before installation.

5.3 Bearings must be assembled the right way round, i.e. as specified in the appropriate drawing or manual, and should be seated squarely against the shoulders on shafts or housings so that raceways are at right angles to the shaft axis. Damage to the shoulders or bearing rings, or the presence of dirt, could prevent correct seating, impose uneven stress on the bearing and promote rapid wear. It is important, therefore, to ensure that there is no damage likely to prevent correct seating of the bearing rings, and that all mating surfaces are scrupulously clean.

NOTE: Some bearings are supplied as matched pairs, and it is important that they are mounted correctly.

5.4 Bearings may often be installed using finger pressure only, but where one ring is an interference fit (usually the rotating inner ring), an assembly tool or press should be used; in some instances it may also be necessary to freeze the shaft or heat the bearing in hot oil, depending on the degree of interference specified. If these tools are not available, the use of a soft steel or brass tube drift may be permitted in some instances; any force necessary must be applied only to the ring concerned, since force applied to the companion ring may result in damage to the rolling elements, or brinelling of the raceways.

NOTE: If a drift is used, the tube must be a close fit over the shaft and must not transmit force to the ring ribs. Light taps from a hammer should be distributed evenly round the top of the drift, to prevent misalignment. On no account should a copper drift be used, as work-hardening could result in chips of copper entering the bearing.

5.5 Retaining devices are used to prevent axial movements of the inner and outer rings of a bearing. Stationary outer rings are normally held in place by circlips or retaining plates, and shims are often used in conjunction with the latter to adjust the clearances in thrust or location bearings. All bearings capable of clearance adjustment must be adjusted to the correct clearance or preload specified in the relevant Maintenance or Overhaul Manual, otherwise damage or excessive wear may result. Rotating inner rings are usually firmly held by means of a washer and nut on the shaft and, although the thread may be handed to prevent loosening during operation, care should be taken to ensure that the nut is securely locked to the shaft.

NOTE: In the case of rod end bearings, the outer races may be retained in their housings by indentations at the entry faces of the housings, or by use of an epoxy sealer.

5.6 On completion of assembly, the bearing housing should, where applicable, be lightly packed with grease to provide an adequate reserve of lubricant, and oil-lubricated bearings should be lightly lubricated with the appropriate oil. Excessive greasing should be avoided, however, since grease is expelled from the bearing as soon as it begins to rotate, and, if insufficient space is left, churning and overheating may occur, causing the grease to run out and the bearing to fail; as a rough guide, the bearing should be approximately one third full.

6 MAINTENANCE OF BEARINGS Ball and roller bearings, if properly lubricated and installed, have a long life and require little attention. Bearing failures may have serious results, however, and aircraft Maintenance Manuals and approved Maintenance Schedules include inspections and, where applicable, lubrication instructions for all types of rolling bearings.

9.1   Slight corrosion on the outer surface of the rings is usually acceptable, provided that it does not prevent proper fit of the rings in housings or on shafts. Staining on the raceways or rolling elements may be acceptable on non-critical bearings, but deep pitting or scaling of the surface would not be acceptable on any types of bearings. Fracture, chips or damage to the rings, balls, rollers or cage, would necessitate rejecting the bearing.

9.2   If the rings show signs of creep or spinning, the outside and inside diameters of the bearing should be checked with a micrometer and plug gauge respectively. The shaft and housing should also be inspected for damage and wear, to ensure that a proper fit will be obtained when the bearing is replaced.

9.3   The running smoothness of a bearing may be determined by mounting it on a shaft which is mechanically rotated at 500 to 1000 rev/min. With the shaft running and the bearing oiled, the outer ring should be held, and the smoothness and resistance should be determined by applying alternate axial and radial loads in either direction. The outer ring must be square to the shaft, or a false impression of roughness may result.

9.4   Excessive wear in a bearing will result in large internal clearances, and a badly worn bearing will normally have been rejected following the initial inspection in situ. Axial clearance in a bearing is seldom quoted since it depends on the internal design of the particular bearing, but, where necessary, a rough guide to the radial internal clearance may be determined by mounting the inner ring on a shaft and measuring, with a dial test indicator, the average radial movement obtained at various angular positions of the outer ring. It is important that the outer ring is moved in the same plane as the inner ring, or an incorrect reading will result.

10   PROTECTION AGAINST CORROSION Bearings which have been found satisfactory and are to be re-used immediately, should be lubricated with oil or grease as appropriate, and reinstalled; bearings which are to be stored should be dipped in rust preventive oil, wrapped in greaseproof paper and suitably boxed and labelled. Bearings should be stored horizontally, in a clean, dry atmosphere, and it is recommended that, after one year in storage, the bearings should be inspected for corrosion and re-protected.

BL/6-15

Issue 2.

1st April, 1973.

BASIC

ENGINEERING PRACTICES AND PROCESSES

MANUFACTURE OF RIGID PIPES

1   INTRODUCTION This Leaflet gives guidance on the manufacture, testing and inspection of rigid pipes. Where applicable, it should be read in conjunction with Leaflet AL/3-14, 'Installation of Rigid Pipes', and with the relevant manuals for the aircraft concerned.

NOTE: The term 'manufacture' is used in this Leaflet to describe the actual production of a pipe complete with its end fittings, and not to describe the manufacture of the tubular material from which it is made.

1.1   The efficiency and safety of an aircraft depend to a large extent on the integrity of its pipe systems.   It is essential, therefore, to ensure that the manufacture and inspection of individual pipes are performed with care and attention, and in accordance with the requirements of the drawings.

1.2   Guidance on flexible pipes is given in Leaflet AL/3-13, on hydraulic systems in Leaflet AL/4-1, on pneumatic systems in Leaflet AL/5-1, on pressurisation systems in Leaflet AL/3-23, on fuel systems in Leaflet AL/3-17, and on pitot-static systems in Leaflet AL/10-1.

2   GENERAL Pipe assemblies are usually formed and flared in accordance with a particular drawing but, since interchangeability is a very important consideration, each completed assembly is usually checked in a checking fixture or compared with a master pipe assembly.   This practice is necessary to prevent stress at end fittings, and to avoid contact with adjacent parts during service.

2.1   Certain pipes which convey liquids or gases are required to be protected internally, and only the process specified on the relevant drawing should be used.

2.2   The method of working metal tubes for use on aircraft is dependent upon the type of material from which they are manufactured and the system in which they are to be used; the characteristics and heat treated condition of the material must be known before bending or flaring operations are carried out.   Some of the most commonly used pipe materials are described in subsequent paragraphs.

3   MATERIALS Metal tubing for aircraft pipe lines is available in various materials, and in a variety of sizes, conforming to either British Standards, DTD Specifications or, in some instances, to approved proprietary specifications.   The method of marking tubes after manufacture is given in Leaflet BL/2-2.

NOTE: These markings are for material identification of the tubes only, and bear no relation to the identification scheme for aircraft installations described in paragraph 15.

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3.1 When stored, the tubes must be adequately supported to prevent bending.

NOTE: Storage procedures are described in Leaflet BL/1-6.

3.2 **Copper and Copper Alloy Tubes.** Seamless copper tubes complying with BS T7 are available in a range of sizes up to 2½ inch outside diameter. The material can be flared, brazed or silver soldered. Tubes up to 1 inch outside diameter are supplied in the fully softened condition, but above 1 inch outside diameter the tubes are supplied in the half-hard condition.

3.2.1 High pressure seamless copper tubes complying with BS T51 are widely used in aircraft high pressure air and oxygen systems. The material can be flared, brazed or silver soldered, and is available in sizes up to ⅝ inch outside diameter.

3.2.2 If care is taken during flaring or bending copper tubes the slight hardening unavoidably induced should not prove harmful to the service life of the pipes.

3.2.3 Copper tubes supplied in the half-hard condition, or tubes which may be subjected to severe bending operations, may be annealed by heating to between 600°C and 700°C and either quenching in water or cooling in air.

3.2.4 **Aluminium-Nickel-Silicon Brass Tubes.** Aluminium-Nickel-Silicon Brass material, often known as 'Tungum', is widely used for the manufacture of tubing used in hydraulic systems (DTD 253, low pressure tubes and DTD 5019, high pressure tubes) and can be flared, brazed or silver soldered. The tubes are supplied in the annealed condition, and should be worked at room temperature. When the tubing hardens due to working, stresses can be relieved by heating to a carefully controlled temperature of 400°C for a period of one hour, and then cooling by any convenient method.

3.2.5 **High Nickel Copper Alloy Tubes.** Tubes complying with specification DTD 477 are used for high, medium and low pressure pipe lines, according to size and gauge, and can be flared readily.

3.3 **Steel Tubes.** Steel tubes are available in various grades, and are often supplied in the half-hard condition, but may normally be softened for working purposes. However, softened tubes must be subsequently re-heat-treated to restore the specified strength. Tubes complying with BS T26 or DTD 503 are used extensively for high pressure systems in aircraft.

3.3.1 Corrosion-resistant steel tubes, such as 35-ton chromium-nickel non-corrodible steel tubes to BS T55, are widely used for cabin-heating and fuel pipes, and for exhaust manifolds.

3.3.2 Solder and fusible alloys must not be allowed to come into contact with high-tensile steel tubing (i.e. tubing with a tensile strength greater than 50 tons/in^2) due to the possibility of intercrystalline penetration. A suitable method of preventing contact during bending is described in paragraph 4.4.7.

3.3.3 40-ton chromium non-corrodible steel tubes to DTD 5016 are suitable for high pressure systems where flaring is required.

3.4 **Aluminium Alloy Tubes.** The working and heat treatment of aluminium alloy tubes vary according to the chemical composition and condition of the alloy. It is essential, therefore, to ensure that all manufacturing operations comply with the instructions on the relevant drawing.

NOTE: For information on the heat treatment of aluminium alloys, see Leaflet BL/9-1.

4   PIPE BENDING

4.1   The preferred method of bending aircraft system pipes is by use of a mandrel-type bending machine (paragraph 5.4) but, because of the tooling required, the method is generally used only for repetitive work. In some instances, where complicated shapes cannot be produced by this method, a proprietary wax filler is used and the pipe bent on a normal bending machine.

4.2   For small quantity work it is generally possible, depending on the nature of the pipe material, to make large radius bends by hand in pipes up to ½ inch outside diameter. For pipes larger than ½ inch outside diameter, or where considered necessary due to the type of material or radius of bend, it is usual to fill the pipe with fusible alloy of low melting temperature and to bend the pipe either by hand or in a bending machine. Sand is generally used as a filler when bending oxygen pipes, so that contamination with oil is avoided.

4.3   Cleaning.   It is essential that pipes are properly cleaned before any heat treatment, as the introduction of carbon could lead to weld decay problems with certain materials. Paraffin at high pressure may be used for initial cleaning, but should be followed by trichloroethylene de-greasing and drying in warm dry air.

4.4   Fusible Alloys.   Fusible alloys used for tube bending usually contain lead, tin, bismuth, and cadmium. The material must be ductile, have a low melting point and should tend to expand on solidifying. Resin, lead or bituminous fillers should not be used when bending pipes which are intended for use on aircraft systems because of the difficulty of ensuring that every trace of the filler has been removed.

4.4.1   Fusible alloy of the type recommended for use on aircraft pipes has a melting point below 100°C. Boiling water can, therefore, be used to melt the alloy for loading and unloading. Since the alloy must not be subjected to a temperature above 100°C, the alloy containers should be completely surrounded by water maintained at 85°C to 95°C. Under no circumstances must a flame be used in conjunction with fusible filler alloys. If a tube requires heat treatment, this must be carried out before filling operations are started.

NOTE: Black iron or stainless steel tanks are generally used as fusible alloy containers. All joints should be welded or riveted, and containers having soldered joints must not be used. Fusible alloys in the molten state are corrosive and should not be left for long periods in contact with lead, aluminium, zinc or copper.

4.4.2   Low tensile steel tubes complying with BS T26, T55 and DTD 97, are often bent by using a higher melting point filler alloy than that described in paragraph 4.4.1. Alloys of the lead-tin variety may be used provided the loading and unloading operations are carried out at a temperature not exceeding 400°C.

4.4.3   With high tensile tubes complying with BS T2, T50, T57, T58, T59, T60 and specification DTD 203, fusible filler alloys may only be used if direct contact is avoided. (See paragraph 4.4.7.)

4.4.4   For aluminium alloy tubes subject to precipitation treatment, the following precautions must be taken:—

(i)   When pre-heating the tube prior to filling with fusible alloy, it should only be immersed in boiling water for the time necessary for the tube to acquire the temperature of the water.

(ii)   The bending operation must take place as soon as the fusible alloy has solidified.

(iii)   Unless the pipes are annealed, the loading, unloading and bending operations must be completed within two hours after solution treatment.

4.4.5 **Loading.** Before filling the tube, the bore of the tube must be thoroughly clean and dry; it should then be coated with a continuous film of lubricating oil, or lubricating oil and paraffin, as may be prescribed by the makers of the fusible alloy. Oiling should be done either by completely filling the tube or immersing the tube in an oil bath; an oily wad drawn through the tube is not satisfactory. It is essential that only clean oil is used for this purpose. A straight mineral lubricating oil of viscosity equivalent to SAE 10 is usually recommended, as detergent additives in engine oils tend to cause sticking of the alloy on emptying the tube.

(i) When the tube has been lubricated it should be plugged at one end and immersed in hot water to within a few inches of the open end.

(ii) When the tube has acquired the temperature of the water and while still immersed, the fusible alloy should be poured gently into the open end of the tube. It is essential not to damage the oil film or to create air pockets during this filling operation.

(iii) Immediately after filling, the whole tube should be cooled by immersion in cold water. To prevent the formation of cavities the cooling should take place progressively from the plugged end.

(iv) The ductility of filler alloys depends on rapid, efficient quenching. After quenching, the loaded tubes should be allowed to attain room temperature before bending commences.

4.4.6 **Unloading.** After a tube has been bent to the desired shape, it should be unloaded by completely immersing it in boiling water to melt the filler alloy. The hot water enters the tube at this stage and care must be taken to preserve the protective oil film. Violent agitation of the tube and contents should be avoided. Breaking of the oil film will cause the fusible alloy to adhere to the bore either as beads or in the form of tinning which, once formed on a tube, may be impossible to remove.

(i) Even without breaking the oil film, beads of fusible alloy may form around particles of dirt. These beads can be removed only when they are in the solid condition, and any attempt to remove them in the molten condition may cause tinning.

(ii) A stiff, rotating wire brush may be used for cleaning some tubes, but must be of a type which will not damage the bore. Alternatively a steam jet may be used, but it is important to ensure that the steam is not superheated. As a final cleaning operation, and where neither of these methods is considered advisable, a tight-fitting felt pull-through should be passed through the pipe in both directions.

4.4.7 As an alternative to oiling, a thin plastics sheathing can be used to prevent contact of the filler alloy with the interior of the tube, thereby eliminating the possibility of tinning. The plastics sheath is passed through the tube and is secured by expanding it over the end of the tube. Sheathing should not exceed 0·010 inch wall thickness, otherwise the rate of quench will be retarded, adversely affecting the ductility of the filler alloy. Plastics sheathing should be examined after removal to ensure that it is still intact and that no leakage of filler has occurred which may adhere to the inside of the pipe.

4.4.8 As visual examination of the bores of bent pipes is impracticable, if contamination is suspected, radiographic inspection techniques should be used. If contamination is found the manufacturer of the fusible alloy should be consulted.

5   PIPE BENDING MACHINES These are normally either compression or mandrel machines and may be hand operated, power assisted or fully automatic.

5.1   Compression bending machines are provided with circular formers in various diameters, grooved around their circumferences to fit a particular diameter pipe. The pipe is bent by rolling a similarly grooved guide round the former, the semi-circular grooves exactly fitting the outside diameter of the tube and preventing distortion from taking place. When the mean radius of the bend is larger than four times the outside diameter of the pipe, bending is possible on a compression bender without using a filler but the insertion of a close-fitting spring may be recommended. A compression bender can also be used when the mean radius is less than four times the outside diameter provided that a fusible filler alloy is used to maintain full bore.

5.2   When springs are used internally for pipe bending they must be of the correct size and form, have a high standard of finish and be free from deformation. They should be examined prior to insertion to ensure that they are thoroughly clean and that no foreign matter is trapped between the coils. Immediately upon removal from a pipe the springs should again be examined for signs of 'pick-up' or flaking of the pipe bore.

NOTE: The formation or ripples at pipe bends can be caused by the use of incorrectly designed or deformed springs.

5.3   When a filler alloy is used, the setting expansion of the alloy causes the tubes to become oversize. This must be allowed for when manufacturing formers and usually amounts to approximately 0·002 inch per inch diameter. Bending machines are available which have been specially designed to accommodate loaded tubes.

5.4   When it is required to produce full bore bends without the use of a filler on mean radii less than four times the outside diameter of the pipe, mandrel benders are used. These machines are also provided with interchangeable formers grooved to receive any particular size of tube but, in addition, plain or articulated mandrels are used which are machined to closely fit the inside diameter of the tube and support it at the bend. The method of bending called for on the drawing will, however, depend largely on the material from which the tube is made, its diameter and the wall thickness.

5.5   According to the tube material, heat treatment may be required before or after bending, but in all cases the actual bending operation is carried out at room temperature.

6   PIPE FLARING Flaring is necessary to fit certain standard types of pipe couplings. The flared end of the pipe must seat on the coned face of an adaptor nipple or externally coned adaptor. By means of a collar and union nut, the flared end and coned face are joined together, forming a connection capable of holding considerable fluid pressure. It is important that tools used for flaring are periodically examined for damage likely to cause scoring of the flared ends and thus prevent proper seating of the mating components.

6.1   AGS Pipe Flaring Tools. These tools are made in two sizes; the small tool for expanding the ends of pipes ¹⁄₁₆ inch to ½ inch outside diameter and the large tool for pipes from ⅝ inch to 1½ inch outside diameter. Both tools are provided with sets of half bushes, in pairs, to cover the range of pipe sizes to be flared.

NOTE: The cones on AGS unions and adaptors have an included angle of 32°, the pipe flaring machines being shaped accordingly. American AN couplings, however, have a 74° included angle, and special tools are required to flare pipes to fit these couplings.

6.2 **Flaring Operation.** Before a pipe is flared, it must be ascertained that it is of the specified material and in the correct heat treatment condition for this operation. It is advisable that the pipe should be bent to shape before flaring.

6.2.1 The pipe end should be square, smoothly finished and clean; a rough or burred edge may cause the pipe to split when flared.

6.2.2 The sleeve or union nut, and collar, should be assembled on the pipe, then the appropriate half bushes fitted to the pipe end and clamped in the flaring tool with the pipe end level with the faces of the bushes. It is most important that the half bushes used are dimensionally accurate and carefully maintained. If a gap exists between the bushes when they are fitted to the pipe, diametrically opposed flash lines may be formed on the pipe flare, representing a potential source of failure.

6.2.3 For all materials except stainless steel (paragraph 6.2.7), the expanding cone of the flaring tool should then be screwed in until it starts to expand the end of the pipe. At this stage the expanding cone should be rotated by the handle provided and gently fed inwards until the pipe end is expanded to the limit imposed by the counter-sunk half bushes.

6.2.4 When the flare is formed the pipe should be freed from the half bushes and inspected for cracks, splits, thinning, eccentricity, or other visible faults.

6.2.5 To check the flaring it is recommended that each coupling is connected to a coned adaptor test fitting and then dismantled. If the test fitting is made from steel, this will allow it to withstand repeated use, but over-tightening is to be avoided. When assembled, the flare should pass through the union nut thread with not more than $\frac{1}{64}$ inch clearance.

6.2.6 With the collar as far as it will go towards the flared end of the pipe, the projection of the pipe beyond the collar face must be measured. The tolerances given in Table 1 are permissible.

TABLE 1

Tube Outside Diameter (inches)	Projection Tolerance (inches)
$\frac{3}{16}$ to $\frac{1}{4}$	0 to 0·010
$\frac{5}{16}$ to $\frac{3}{8}$	$\frac{1}{64}$ to $\frac{1}{32}$
$\frac{7}{16}$ to $1\frac{1}{2}$	$\frac{1}{32}$ to $\frac{1}{16}$

6.2.7 **Stainless Steel.** Under no circumstances should the expanding cone be used with stainless steel, since 'pick-up' and subsequent damage to the flare may occur. For this material, a single operating tool and a special buffer lubricant (e.g. Trilac Lacquer) are recommended.

7 PIPE BEADING· Pipe beading is used to assist in the efficient coupling of hoses to rigid pipes in low pressure connections.

7.1 Pipe beading is usually formed by means of a beading machine, the rollers of which may be changed to suit the size of beading required.
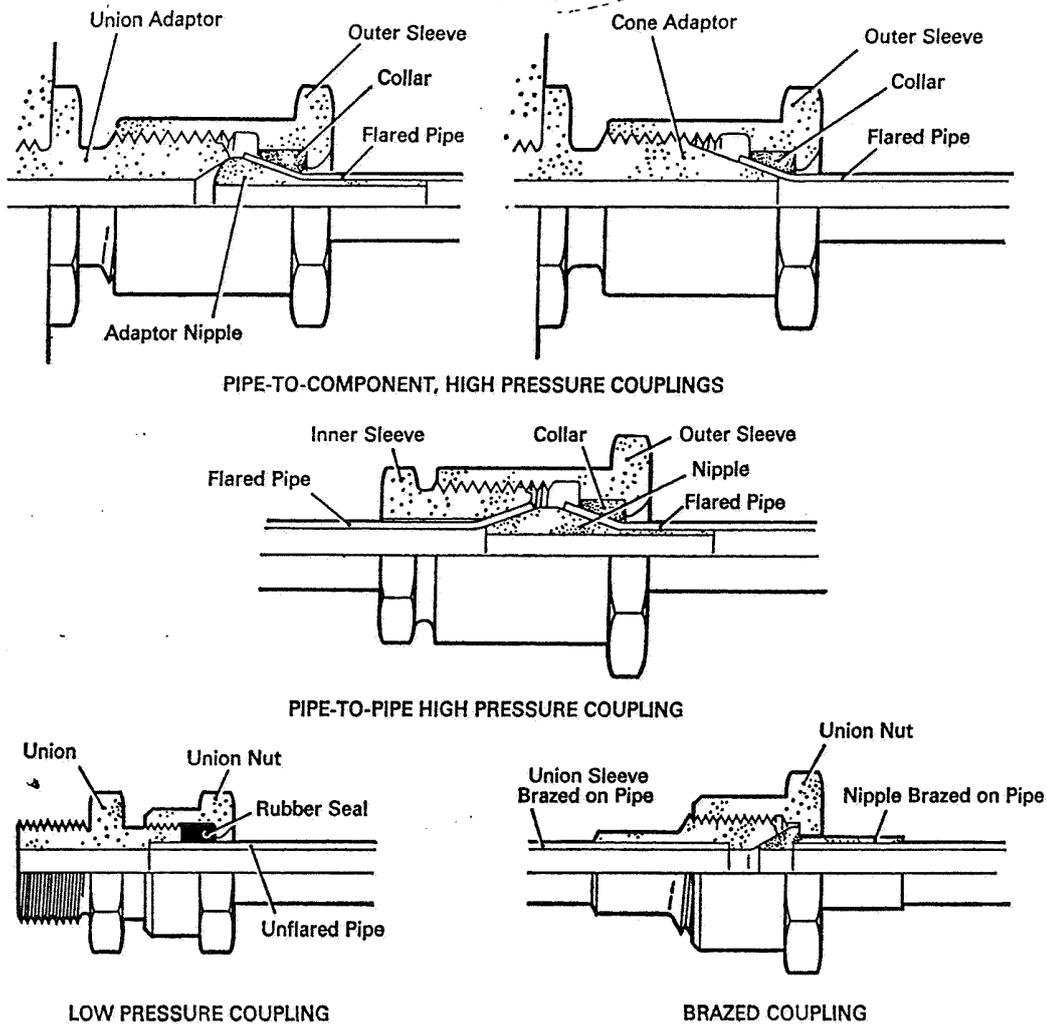
Union Adaptor
Outer Sleeve
Collar
Flared Pipe
Adaptor Nipple

Cone Adaptor
Outer Sleeve
Collar
Flared Pipe

PIPE-TO-COMPONENT, HIGH PRESSURE COUPLINGS

Inner Sleeve
Collar
Outer Sleeve
Nipple
Flared Pipe
Flared Pipe

PIPE-TO-PIPE HIGH PRESSURE COUPLING

Union
Union Nut
Rubber Seal
Unflared Pipe

Union Nut
Union Sleeve Brazed on Pipe
Nipple Brazed on Pipe

LOW PRESSURE COUPLING   **BRAZED COUPLING**

Figure 1   TYPICAL AGS PIPE COUPLINGS

7.2   The pipe is usually expanded approximately $\frac{1}{4}$ inch in diameter at a distance of $\frac{1}{4}$ inch from the end of the tube, but reference should be made to the relevant drawing or manufacturer's instructions for details, as the bead will vary according to tube size and type of hose used.

8   'AGS' AND 'AS' COUPLINGS A wide range of pipe couplings, adaptors, bulk-head unions and banjo unions are covered by AGS and AS specifications. Some typical couplings are shown in Figure 1 in which the main parts are annotated.

8.1   **High Pressure Coupling.** All couplings now use a similar method of assembly, a flared pipe, adaptor nipple, collar, outer sleeve and inner sleeve being the basic components in the high pressure joint. Nipples which do not have a parallel extension may still be found in use, but these have been replaced by the type shown in Figure 1 to prevent incorrect assembly. The parallel extension should always be inserted into the flared pipe which is fitted with a collar and outer sleeve.

8.2 Cone adaptors have an included angle of 32° to match the pipe flaring, and union adaptors have a 60° countersunk end to match the spherical end of an adaptor nipple.

8.3 Pipe coupling nipples must only be used in pipe to pipe joints since the outer conical face of the nipple has a 32° included angle to match the bore of an inner sleeve and will not form a proper joint with a 60° countersunk face.

8.4 Standard pipe couplings are made from a variety of materials, including aluminium alloy, brass, mild steel and stainless steel, and generally have a working pressure, depending on size, of between 200 and 3000 lbf/in².

8.5 After a pipe coupling has been assembled for the first time, it should be disassembled and the extension of the flared end beyond the collar checked as described in paragraph 6.2.6.

8.6 **Low Pressure Couplings.** This type of coupling is used in certain low pressure pipe lines and vents. It consists of a rubber ring which is compressed around the pipe when the union nut is tightened. The end of the pipe, which is not flared, butts against a shoulder in the body of the union.

8.7 **Brazed Nipple Couplings.** A conical nipple is brazed or silver-soldered to the end of the pipe and held in position by a union nut, which butts against a shoulder on the nipple. The conical face of the nipple mates with a countersunk adaptor, which may also be brazed or silver-soldered in position.
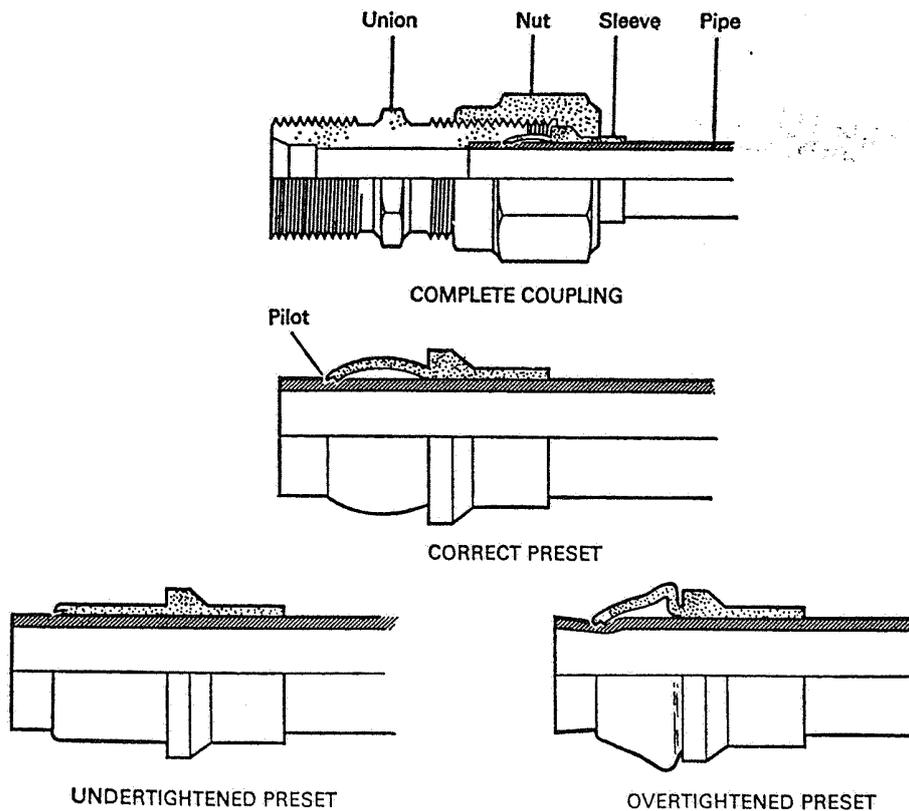

Figure 2 FLARELESS PIPE COUPLING

9   FLARELESS COUPLINGS The flaring operation leaves the tube end in a stressed condition and, since it is the flare which carries the load in a fitting, vibration may eventually result in fatigue failure. To prevent pipe couplings from failing in this way a different type of coupling known as the 'flareless' coupling was devised and is in common use on civil aircraft. The individual parts of the coupling are assembled as shown in Figure 2 and the nut screwed on to its fitting until it is finger tight. The nut is then turned a further full turn with a spanner, this action bowing the sleeve and causing it to bite into the tube at its forward end. When the nut is slackened the sleeve remains permanently bowed and attached to the pipe.

9.1   This pre-setting operation may be carried out using the fitting which is to be used in service, but a special hardened steel fitting is often used for pre-setting purposes.

9.2   After pre-setting, the pipe should be inspected to ensure that the sleeve is correctly bowed and that the sleeve end has bitten into the pipe (Figure 2). The pilot should be close to or touching the pipe, and end play should be less than 0·010 inch. It is permissible for the sleeve to rotate on the pipe.

9.3   In service, the nut should be tightened until a distinct increase in torque is felt, then turned a further one to two hexagon flats. If the joint leaks, the nut should be unscrewed and the mating parts inspected for foreign matter, scratches or similar damage; excessive tightening will permanently damage the tube end and sleeve, and result in further leakage.

10   BRAZED COUPLINGS Screwed couplings will always be a potential source of leaks and add considerable weight to an aircraft system. It is obvious that a complete piping system cannot be installed in an aircraft in one piece, but a method has recently been devised of brazing pipes together after positioning in the aircraft. Pipe ends meet in a butt joint and a connecting sleeve is brazed on to the outside, by induction heating, to form a permanent joint.

10.1   To ensure that molten brazing alloy flows easily through the joint by capillary action, the gap between the pipe and the sleeve is carefully controlled. The sleeve is manufactured to close tolerances and the pipe ends are expanded slightly over nominal diameter, so that tube manufacturing tolerances are prevented from affecting the fit.

10.2   Thorough cleanliness is essential to a brazed joint and all parts are cleaned by acid pickling prior to assembly; to prevent oxidation, brazing is carried out within a portable chamber through which inert gas (e.g. argon) is passed during the brazing operation.

11   AVIMO COUPLINGS This type of coupling is used for connecting pipe lines in a semi-flexible manner. It is mostly used in engine service pipes carrying coolant or oil at pressures up to 60 lbf/in² and at temperatures up to 130°C.

11.1   The coupling consists of:—

(i) Two specially corrugated sleeves, made of material similar to that of the tubes to be coupled, into which the ends of the tubes are welded or brazed.

(ii) A neoprene (synthetic rubber) collar which fits over the adjacent ends of the sleeves and beds into their corrugations.

(iii) Two semi-circular flanged packings of steel, specially designed to compress the collar uniformly.

(iv) A screw-action hose clip of the AGS 605 type which encircles the joint and clamps the packing pieces together.

11.2 Couplings embodying an attachment flange are also available for fitting through bulkheads.

11.3 A fireproof version of the above type of coupling is available, but is restricted to internal pressures of 50 lbf/in².

12 **SELF-SEALING COUPLINGS** Self-sealing couplings are used in hydraulic, fuel, oil and other pipeline systems. They eliminate the necessity of draining a system when a connection is broken to change a component, e.g. a fuel or hydraulic pump. Bleeding and priming operations for the complete system are often unnecessary after the parts concerned are re-connected.

12.1 With the exception of couplings which have a bayonet and socket action, when the two halves of a self-sealing coupling are brought together by screwing home the coupling nut, a spring in each half is compressed and associated valves slide back simultaneously. Full bore is obtained when the flange of the male half is brought into contact with the face of the female portion.

12.2 When making or breaking the joint of a self-sealing coupling, care must be taken to avoid turning between the two halves, otherwise the seating for the valve in the union half of the coupling may damage the seat in the fixed half of the coupling and prevent a fluid-tight joint being made.

12.3 When the two halves of a self-sealing coupling have been disconnected, blanking caps should be fitted to each half coupling. The caps will protect the threads and the valves, prevent the ingress of dirt, and form an independent pressure seal.

12.4 When self-sealing couplings are fitted to pipe assemblies, they must be pressure tested with the pipe, special attention being given to signs of leakage from the valve seats.

13 **BORE TEST** Pipes should be tested to ensure that the bore is clear and dimensionally correct after forming. One method of satisfying this requirement is to pass a steel ball, with a diameter of 80 per cent of the internal diameter of the pipe, through the pipe in both directions. When, owing to the design of the pipe or the size of the end fittings, this test is impracticable, or when a more searching test is required, the drawing will normally require a flow test to be performed. In this test it must be demonstrated that the pipe is capable of passing a specified quantity of fluid, in the time, and under the conditions stipulated on the drawing.

14 **PRESSURE TESTS** Before pressure testing it is necessary to verify that: (i) the test equipment and instruments are adequate for the tests specified on the drawing, (ii) the test fluid is clean and suitably safeguarded by filters against the ingress of dirt, and (iii) the test equipment and instruments are checked at regular intervals. A record should be kept of the checks and the results.

14.1 The component parts of a flared coupling require bedding-in to ensure freedom from leaks, and the following procedure should be adopted when fitting flared pipe assemblies to a test rig:—

(i) Assemble the component parts of the coupling and run up the union nut by hand.

(ii) Using a suitable spanner to prevent rotation of the union, tighten the union nut to the specified torque value.

(iii) Slacken the nut a half to one turn then retighten to specified torque value.

14.1.1 Should the connection fail to seal properly the coupling should be critically examined for likely causes such as scratches or dirt. The specified torque should never be exceeded as this may damage the joint.

NOTE: The assembly of flareless couplings is described in paragraph 9.3.

14.2 **Hydraulic Pressure Testing.** After coupling to the appropriate pressure delivery point on the test rig, the pipe to be tested must be checked for full bore flow by pumping fluid through it and checking the flow at the open end. If satisfactory, the open end should be suitably blanked. The pressure should then be built up to that prescribed on the drawing, which is usually $1\frac{1}{2}$ times the maximum working pressure of the pipe in service. The pressure should be maintained long enough to ascertain that no leaks occur, or for such a period of time as may be specified on the drawing.

NOTE: The fluid used for hydraulic pressure testing may be either oil, paraffin or water. It is, however, recommended that, whenever possible, the fluid should be the same as that used in the completed system.

14.3 **Testing Pneumatic and Oxygen Pipes.** Pneumatic and oxygen pipes are normally given a hydraulic pressure test using water as the test medium, followed by a compressed air test which is limited to maximum system pressure. Using high pressure air can be extremely dangerous and the pipes should be located behind a heavy plastics screen and submerged in water during the test.

14.3.1 The pneumatic test rig should include a pressure regulator, pressure gauge, relief valve, oil and water trap, and adequate filters to ensure that the air supplied during test is not contaminated. All of these components should be inspected at frequent intervals and every precaution taken to prevent the entry of dirt or grease into the pipe being tested.

14.3.2 When conducting the test the relief valve and regulator should be set at test pressure, and air slowly introduced into the pipe. Test pressure should normally be maintained for a period of five minutes and the pipe examined for leakage, indicated by bubbles.

14.4 **Cleaning After Test.** After a pipe has been tested it should normally be flushed through with white spirit or other similar solvent, dried with a jet of clean, dry air and securely blanked.

14.4.1 Special care must be exercised when cleaning pipes used in high pressure air and gaseous or liquid oxygen systems; these pipes must be scrupulously clean and free from any possible contamination by oil or grease. It is usually recommended that pipes for use in these systems are flushed with trichloroethylene, blown through with double filtered air, and blanked-off immediately.

14.4.2 Nipple plugs, cone plugs and sealing caps to AGS specifications are often used for sealing the end connections of pipe assemblies but, if these components are unsuitable, special blanking devices should be provided. These blanks must be so designed that it is impossible to leave them in position when the pipe is connected into the aircraft system. Pipes should never be blanked with adhesive tape or rag.

14.5 **Marking.** Pipe assemblies should be marked to indicate that they have passed the prescribed pressure test. The marking should conform to the method specified for the identification of pipes by the aircraft manufacturer, and will usually be by rubber stamp on the pipe itself or by metal stamping on a label attached to the pipe.

14.5.1 Where the drawing requires identification labels to be attached by soldering, the solder must be continuous round the whole label. Serious corrosion may occur if spot soldering is employed or if gaps are present in the solder fillet.

15   IDENTIFICATION SCHEME All pipe line systems in aircraft are marked at convenient intervals throughout their runs, so that the particular system can be traced without the possibility of confusion with other systems.

15.1 The requirement for the identification of pipe lines is specified in Chapter **D4-1** of British Civil Airworthiness Requirements.

15.2 A suitable scheme for identification marking is described in British Standards M23. This method provides clear identification of pipes on a code basis. The marking consists of a written description of the main function of the system, together with a geometrical symbol and a colour scheme.

16   INSPECTION When all stages of manufacture of a pipe assembly are completed, the following points should be verified:—

(i) The material and dimensions are in accordance with the relevant drawing.

(ii) The material has received the correct heat treatment both during manufacture and as a finished pipe.

(iii) When fusible alloy has been used during pipe bending, all the necessary precautions have been taken for the removal of the alloy (see paragraph 4.3.6).

(iv) Bends are not made too near the pipe ends, thereby preventing the union nut from being withdrawn its entire length.

(v) The pipes are correct in respect of form and length after bending, and there is no evidence of ovality, ripples, flakes, kinks, bulges, splits, scores, flaking of bores or thinning of gauge in excess of specified limits.

(vi) The end fittings are in accordance with the drawing.

(vii) Flares are free from cracks, splits or thinning and are concentric to the pipe.

(viii) The pipe has successfully withstood the specified pressure test.

(ix) The pipe is clean internally and externally and has received the correct protective treatment.

(x) The pipe is correctly part numbered and, where applicable, has the correct code marking (for part marking see Leaflet **BL/2-1** and for code marking BS M23).

NOTE: Identification labels on pipelines should be affixed sufficiently far from the end fittings to prevent interference with the union nut or pick-up of the label when the fitting is assembled. It is recommended that this distance should not be less than nine inches.

(xi) The pipe is properly blanked by an approved method.

BASIC

ENGINEERING PRACTICES AND PROCESSES

RESISTANCE WELDING – SEAM WELDING PROCEDURE

1   **INTRODUCTION** This Leaflet gives guidance on the application of the seam welding process to both ferrous and non-ferrous materials. It should be noted that, in the paragraphs dealing with the description and operation of seam welding machines, imperial measurements have been retained in this Leaflet; the figures for metric sized material and machines calibrated in accordance with the metric system, should be obtained by experiment. Other forms of resistance welding are the subjects of separate Leaflets.

1.1   Seam welding is a method of producing a load-carrying and/or pressure-tight joint between two or more (usually only two) parts manufactured in sheet metal. The seam weld is produced by feeding the parts between two rotatable copper alloy electrode wheels, passing a high intensity pulsating current through the parts whilst the electrode wheels are being rotated, and applying a steady pressure to the wheels sufficient to forge the local areas heated by the welding current into a series of spaced or overlapping spot welds.

1.2   'Seam' welding is the term usually employed to describe the process in which the electrode wheels rotate during the flow of the pulsed welding current and is usually employed on light gauge (up to 1·5 mm) material where the current ON and OFF times do not exceed 7 or 8 cycles (0·14 to 0·16 seconds). 'Roller spot' welding is the term usually employed to describe the process in which the electrode wheels are halted at the commencement of each current pulse, and rotate only during the OFF period between welds. Each weld is therefore completed with the electrodes stationary, allowing each weld to be forged, i.e. to cool from welding temperature whilst under pressure. Roller spot welding is normally employed on thick materials and on heat-resisting alloys where the current ON time for each welding pulse exceeds 6 cycles (0·12 seconds).

NOTE: The term 'cycles' refers to the normal electrical mains supply of 50 Hz, i.e. cycles/second.

1.3   Seam welding is the fastest method of making pressure-tight joints on thin gauge materials and can produce 1500 overlapping spot welds per minute at a setting of 1 cycle ON, 1 cycle OFF. The welding speed obtainable is determined by the weld ON and OFF time settings, and the number of welds required per inch using the equation:–

$$\text{Welding Speed (ins/min)} = \frac{\text{Number of cycles/minutes}}{\text{Sum of ON and OFF times x required number of spots/inch}}$$

EXAMPLE:-

Assuming a required weld spacing of 10 per inch and a machine setting of 2 cycles ON, 3 cycles OFF:-

$$\text{Welding Speed} = \frac{50 \times 60}{(2+3) \times 10} = 60 \text{ inches/minute}$$

1.4   As with spot welding, the strength of a seam welded joint depends largely on machine factors such as the track width of the electrode wheels, the welding force applied, the value of the welding current flowing during each weld and the speed or rotation of the electrode wheels. These must be set to values appropriate to the gauge and type of material to be welded, and the weld quality checked by test samples before production welding is commenced, at suitable intervals during the production period, and whenever any change is made to the machine settings or electrodes are replaced. The standard test samples and methods of testing are described in paragraph 14.

1.5   The weld quality is also affected by the condition of the workpiece and appropriate steps should be taken to ensure that the material specification, gauge thickness and surface condition are maintained within acceptable limits during the period of production.

2   WELDING EQUIPMENT   Seam welding machines vary widely in design and construction but can be broadly categorised as described in 2.1 to 2.4.

2.1   **Circumferential Machines (Figure 1).**   These, as the name implies, are used for welding around the girth or the ends of cylindrical workpieces, which either project into the machine to partially enclose the lower (or upper) arm or project away from the machine toward the operator.

2.2   **Longitudinal Machines (Figure 2).**   These are designed to produce straight welds on flat components, or the side welds on roll-formed cylindrical components. Welding is accomplished by movement of the workpiece into the throat of the machine, or out of the machine throat towards the operator, the maximum length of weld in one uninterrupted run being limited to the depth of the throat of the machine.

2.3   **Universal Machines (Figure 3).**   These can carry out longitudinal or circumferential welding by swivelling the upper weld head through 90° and using the appropriate circumferential or longitudinal lower arm extension supplied with the machine.

2.4   **Travelling Head of Travelling Table Machines.**   These are usually designed specifically for one particular application and employ one electrode wheel only, which is attached to the upper head of the machine. The lower wheel and its supporting arm are replaced by a bar-type lower electrode to which the overlapping workpieces are clamped and which is connected to the welding transformer to complete the welding circuit. The upper welding electrode, which is always allowed to rotate, is then traversed along the weld joint of the stationary workpiece to form a travelling head machine, or in some cases, the workpieces and their supporting bar electrode are moved under the stationary upper machine head to form a travelling table machine.
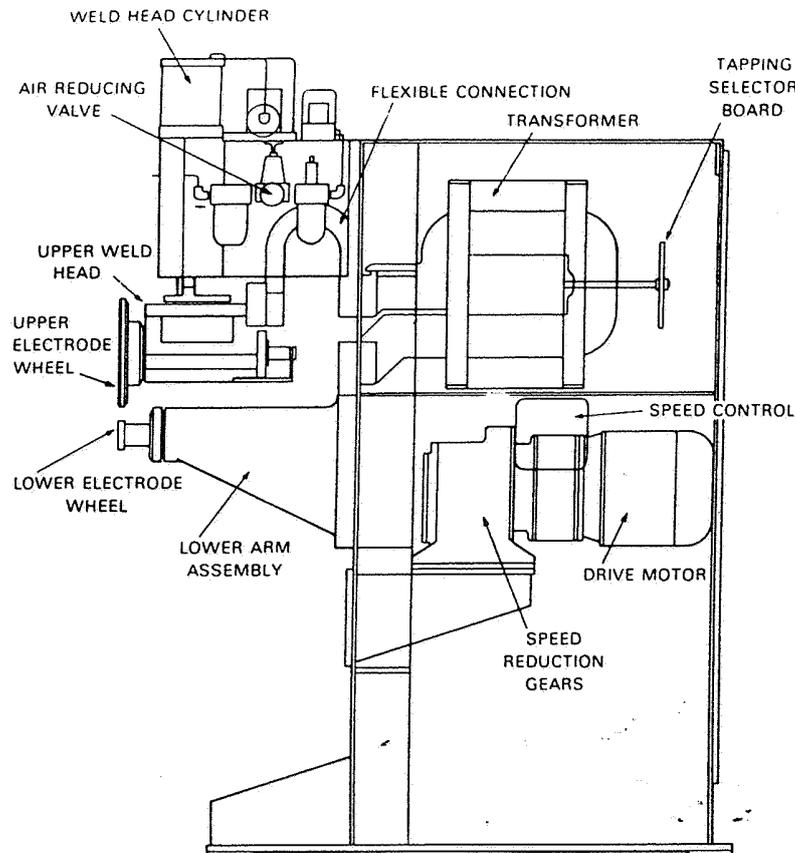
WELD HEAD CYLINDER

AIR REDUCING VALVE

FLEXIBLE CONNECTION

TRANSFORMER

TAPPING SELECTOR BOARD

UPPER WELD HEAD

UPPER ELECTRODE WHEEL

LOWER ELECTRODE WHEEL

LOWER ARM ASSEMBLY

SPEED CONTROL

DRIVE MOTOR

SPEED REDUCTION GEARS

Figure 1   CIRCUMFERENTIAL SEAM WELDER
LOWER WHEEL SPINDLE DRIVE

3   ELECTRODE DRIVES   A variety of methods are employed to rotate the electrode wheels during the welding sequence. These fall into two basic categories, as described in 3.1 and 3.2.

3.1   **Shaft or Spindle Drive.**   In this method either or both electrode wheels are rotated by means of an electric motor connected through suitable gearing to the spindle to which the electrode(s) is (are) attached (see Figure 1). The surface of the electrodes is smooth and should produce a good surface finish to the weld, but the electrode surface spreads progressively during use, and the wheels must be removed periodically and re-machined to restore the original track width. As the welding speed varies with any change in wheel diameter the motor speed must be adjusted whenever an electrode wheel is machined or replaced so as to maintain a constant welding speed.

BL/6-16

3.1.1   Roller spot welding is nearly always associated with shaft or spindle driven machines and the intermittent rotation of the electrode wheel necessary to this method of welding is produced either by repeated stopping and starting the wheel drive motor, or by the repeated operation of a clutch and brake inserted in between the drive motor and the electrode wheel shaft. As the clutch and brake system allows the drive motor to run continuously, this system is capable of higher welding rates than the motor stop/start system. In both cases, the flow of current is synchronised with the wheel dwell periods so that the weld current flow time (weld or heat time) and the subsequent forge or cool period take place while the wheels are stationary. The electrode wheels then rotate for a timed 'run' or 'index' period to move on to the next weld position, and the sequence is repeated for as long as required.
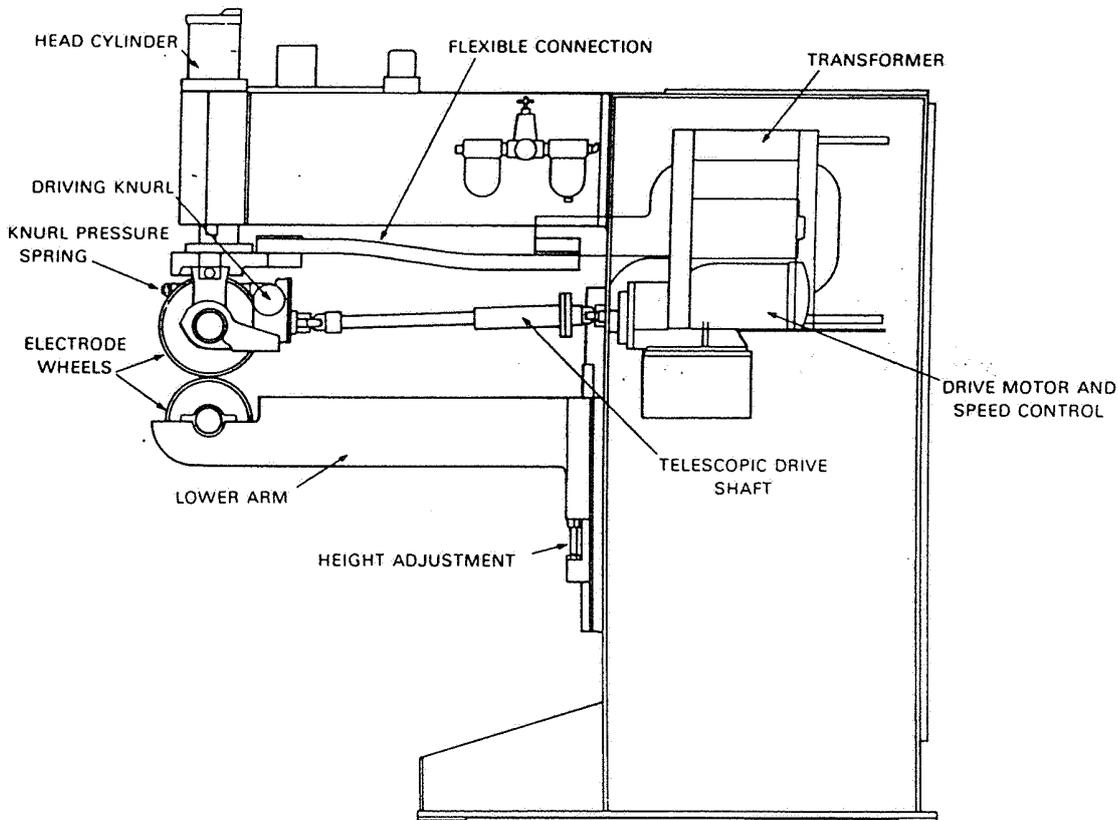

Figure 2   LONGITUDINAL SEAM WELDER
UPPER WHEEL KNURL DRIVE

4

WELD HEAD CYLINDER

PRESSURE
CONTROL

VERTICAL HEAD
SLIDE

TAPPING SELECTOR
BOARD

SPEED REDUCTION GEAR

FLEXIBLE
CONNECTION

DRIVING KNURL

ADJUSTABLE UPPER
HEAD ASSY

TRANSFORMER

LONGITUDINAL ARM EXTENSION

DRIVE MOTOR

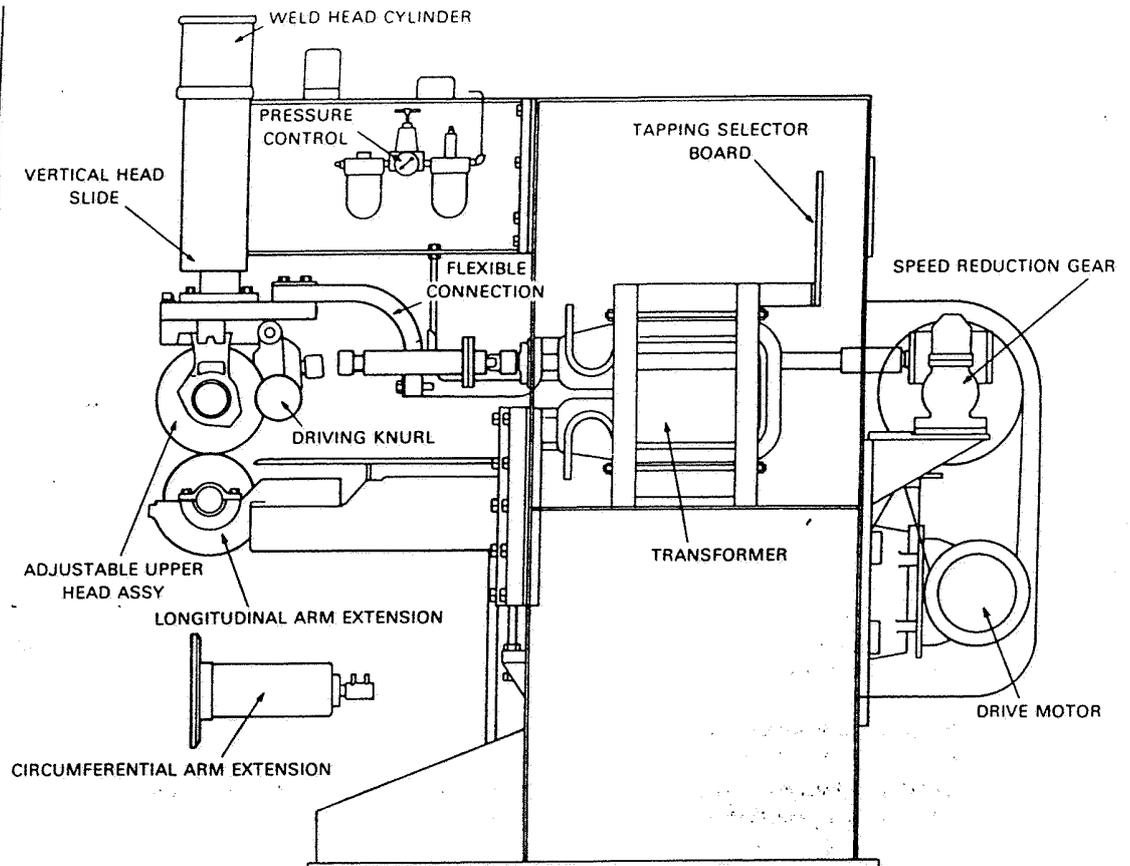CIRCUMFERENTIAL ARM EXTENSION

Figure 3   UNIVERSAL SEAM WELDER
UPPER WHEEL KNURL DRIVE

3.2 **Knurl Drive.** In this method either or both electrode wheels are rotated by means of a serrated knurl wheel, spring or air loaded on to the welding wheel rim and driven by a suitable electric motor (see Figures 2 and 3). As the knurl wheel is rotating at a constant speed and is relatively free from wear, the welding speed is virtually independent of the diameter of the electrode wheels and does not require adjustment as the electrodes wear.

3.2.1 The knurl wheel has a cutting action as it rotates against the flanks of the elec..ode wheel, and except unde: severe conditions, maintains a constant track width for the full life of the electrode. It is common practice in circumferential welding to drive both electrode wheels from a single electric motor to eliminate the 'slip' which can occur between the workpiece and an undriven electrode wheel, and knurl driving allows precise speed matching of the upper and lower wheels even when these have widely differing diameters.

3.2.2   One disadvantage of the knurl drive is that the pattern of the driving knurl is reproduced on the surface of the electrode wheel, and is then 'printed' on to the surface of the workpiece, producing a serrated finish which can precipitate the formation of cracks in alloy and heat resisting steels. For this reason, knurl drive seam welders should not be used for the welding of low alloy medium carbon steels, nickel, inconel or nimonic alloys, or for the welding of aluminium or magnesium alloys where the serrated surface of the electrodes could promote the dispersion of copper on to the surface of the weld seam and the transfer of workpiece material on to the surface of the electrode wheel.

4   **WELDING TRANSFORMER**   The current which flows through the electrodes to heat and weld the workpieces is usually produced by a single phase transformer mounted inside the frame of the welding machine and connected to two phases of the incoming three phase mains supply by a special thyristor power switch. This enables the transformer to be switched ON and OFF with extreme rapidity and absolute accuracy over timing intervals ranging from 1 to 99 cycles, adjustable in 1 cycle steps. The welding transformer usually incorporates two or three parallel-connected single-turn secondary windings of water cooled cast copper construction, interleaved with multi-turn primary coils to transform the incoming supply (nominally 400/440 V) down to a low voltage level (typically 5 to 10 V) to produce 2000 to 25,000 amperes or more, dependent on the rating of the machine. The secondary windings are connected to the upper and lower electrode wheels via rotatable current-carrying bearings with flexible links to permit vertical movement of the upper sliding head assembly.

4.1   One leg of the secondary winding is solidly earthed to the machine frame, which is itself connected to earth by a heavy copper cable. A primary tapping selector on the welding transformer is used to provide coarse adjustment of the welding current by altering the secondary voltage applied to the electrode wheels. The mains voltage supply must always be disconnected before adjusting any tapping selector.

5   **WELDING FORCE**   The pressure applied by the electrode wheels to the workpiece is an important factor in the production of satisfactory welds and must be carefully controlled during the welding process. This force is usually produced by compressed air applied to a double-acting pneumatic actuator to control the movement of the upper welding head, with a reducing valve and a pressure gauge to control and indicate the air pressure applied to the actuator. Actuators vary widely in design and allow accurate settings of weld force over a wide range of values.

5.1   Balanced pressure systems in which the downward force applied by the upper chamber of the actuator is partially counterbalanced by a separate controlled air pressure applied at the same time to the lower chamber is sometimes used to extend the available force range, and this technique, together with the use of two tandem coupled pistons or diaphragms can be used to provide a force range from 200 to 4000 lb on machines currently used in gas turbine engine manufacture.

5.2   Careful control of the welding force is essential and it should be borne in mind that fluctuations in the supply pressure may affect the welding force, and hence the quality of the weld. A stable pressure supply is therefore desirable, together with a pressure switch in the supply line, set to prevent the machine from operating if the supply pressure falls to a level at which the weld quality will be affected.

6   **ELECTRODE WHEELS** The design, choice of material and maintenance of adequate cooling of the electrode wheels, are of prime importance if efficient welding is to be achieved. With 'tracked' wheels the track width will depend on the thickness of the components being welded in the approximate ratio of 2 x t (where t is the thickness in mm of the material in contact with the electrode wheel, i.e. the upper or the lower workpiece). The welding track should not be more than half the thickness of the electrode wheel (except in special 'thin-wheel' machines) and the flanks either side of the wheel track should have an included angle of 120° (see Figure 4). Radiused wheels are sometimes employed in preference to tracked wheels, and in these cases the width of the wheel rim is machined to a radius usually between 1 and 2 inches.

7   **TIMING CONTROLS** Electronic timing controls of various types are employed to operate the weld force cylinder, initiate the rotation of the electrode wheels, and control the welding sequence. Roller spot welding requires additional controls in the form of an adjustable OFF or RUN time after each cool period, to rotate the electrode wheels for the preset time before the commencement of the next current flow period.

8   **CURRENT CONTROL** The heat developed in each of the overlapping welds is controlled mainly by the welding current, and this must be adjusted to the maximum value which can be obtained without 'splashing', or the expulsion of metal from the workpiece.

8.1 The primary means of current adjustment is by means of the transformer tapping selector referred to in paragraph 4 but this will only alter the current to a number of fixed values corresponding to the number of taps available. Stepless adjustment of the current between the tapping levels is provided by phase shift heat control in which the start of the conduction periods is delayed by an accurately controlled period of time. This prevents the flow of mains voltage supply in the primary windings of the transformer for part of each conduction period, and therefore reduces the heating effect of the secondary current produced.
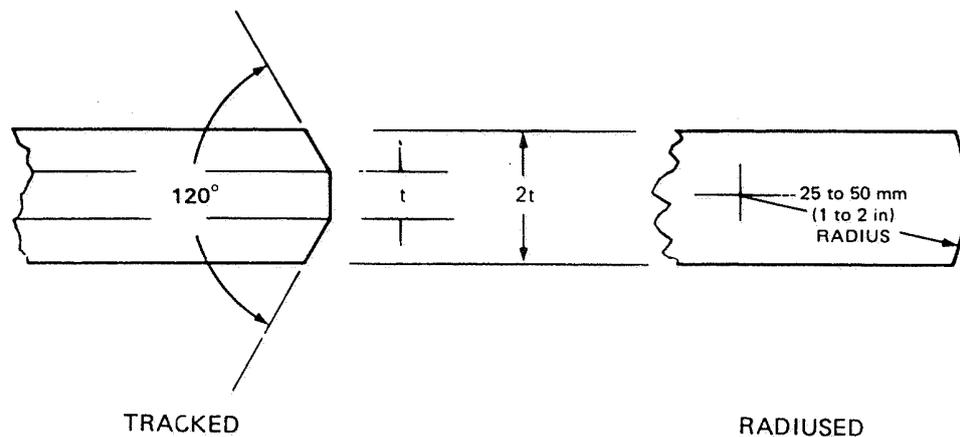

TRACKED   RADIUSED

Figure 4   TYPES OF ELECTRODE WHEELS

BL/6-16

8.2   The heat control potentiometers are usually included in the timing control Panel, and provide a range of adjustment at each tapping level.

9   **VOLTAGE COMPENSATION**   Seam welding machines are commonly equipped with special controls to minimise the variation of welding current which normally accompanies any fluctuation in the supply voltage. These controls continuously compare the incoming supply voltage with a non-varying reference source and automatically adjusts the internal phase shift setting to maintain the preset secondary voltage constant to $\pm 2\%$ against mains voltage variations of up to $\pm 15\%$.

10   **CONSTANT CURRENT**   Seam welding machines used extensively on highly stressed heat resisting alloy workpieces are usually provided with an additional control facility called 'Constant Current Control'.

10.1 This system monitors the current flowing in the transformer primary (primary feedback) or through the electrode wheels (secondary feedback) and compares the current to a reference corresponding to the setting of the tapping switch and phase shift potentiometers. Any variation of current due to the insertion of ferrous material into the throat of the machine, variation of the mains voltage supply, or any other cause, can be detected and automatically corrected to leave sufficient power in hand to allow the appropriate compensation to take place.

11   **THE WELDING OPERATION**

11.1 **Procedure.**   The metal sheets to be welded are placed between the rollers with a predetermined overlap; the rollers then clamp the joint to a predetermined and preset welding pressure. A current is applied through the rollers which heats the joint sufficiently to form a weld with the aid of the pressure imparted by the rollers. At the same time that the current is applied to the rollers, they start rotating, and the work is passed steadily between them at a carefully controlled speed. Each weld spot is completed in a fraction of a second and the OFF period occurs before the pulse of current makes the next weld; as this cycle is continued, a seam weld is produced. Accurate control and repeatability of machine settings is essential. This is accomplished by the use of welding schedules.

11.2 **Welding Conditions.**   The precise welding conditions and machine settings depend upon the particular work in hand, and it would be misleading to generalise.

11.2.1   The electrode roller pressure, weld time and current value should be based on test welds made with increasing current values until 'splashing' or expulsion of the metal occurs between the sheets. The current should then be reduced until 'splashing' ceases, when the weld strength should approach maximum. A correct combination of pressure, timing and current is essential if excessive indentation is to be avoided.

11.2.2 When sample welds to represent large sheets are made in small strips, some adjustment will have to be made, especially where a substantial amount of metal will be in the throat of the machine. Small variations in the quality of the material will also affect the machine settings and any table of machine settings must be considered as a rough guide only; sample welds will have to be taken to achieve optimum welds.

11.3 **Seam Weld Design.** In designing seam welds, the following factors are taken into consideration:–

(a) The seam must be accessible to the rollers of the welding machine, and care taken to ensure that, if external water cooling is used, the water is not trapped in the vessel or component being welded.

(b) If the machine is not provided with self-cleaning rollers there will be a danger of pick-up from the sheet being welded, and this pick-up, usually in the form of oxide, should be removed frequently otherwise there will be a danger of indentation and pitting in the sheet.

11.4 Considerable attention is given at the design stage to the various factors which can affect the strength, stiffness and suitability of welded joints. In order that these factors may be more readily understood they are described, in general terms, in paragraphs 11.4.1 to 11.4.5.

11.4.1 **Strength of Welds.** Usually a minimum strength requirement is assumed for design purposes, and whilst it is not possible actually to test the strength of production parts, indirect tests which give guidance on their strength are described in paragraph 14. Factors which have a significant effect on the strength of the weld include the distance of the weld from the edge of the sheet, and the thickness ratio of the parts being joined.

11.4.2 **Edge Distance.** A minimum edge distance of 1.75 D and a minimum overlap or flange width of 3.5 D (D being the weld diameter) is generally recommended. Smaller values than these may lead to some loss of strength in the joint, an increase in the likelihood of splashing of metal from the interface, and an increase in the possibility of deformation during welding due to inadequate supporting material around the molten weld slug. The overlap or flange width, is the width over which the materials being welded are in contact, and additional allowance must be made for any radiused corners which may be present on formed parts. Edge distance should be measured from the centre line of the weld to the edge of the material.

11.4.3 **Material Thickness.** The total thickness of material which can successfully be joined by one machine will depend on the capacity of the machine and the nature of the material, but joint thickness of up to about 10 mm (0.4 in) in aluminium alloys and up to about 4 mm (0.16 in) in stainless steels are rarely exceeded. Excessive differences in the thickness of the sheets forming the joint tend to give inconsistent welds with little or no penetration of the thinner sheet; it is recommended that a thickness ratio of $2:1$ to $2.5:1$ should not be exceeded for any material. The joining of more than three sheets together is seldom attempted since this results in the production of very weak joints.

11.4.4 **Surface Indentation.** The surface indentation of any sheet due to welding should normally not exceed 10% of the sheet thickness. Where indentation must be avoided on one face of the workpiece, the tip diameter of the corresponding electrode can be increased up to three times the diameter normally recommended for the particular material thickness.

11.4.5 **Fitting of Surfaces.** It is important that the surfaces to be joined should be the best possible fit so that the electrode pressure is not required to overcome any stiffness of the sheets or sections, since this would result in a reduction of the pressure available for forging the weld. It is this factor which precludes the welding of contoured surfaces, or the placing of welds on radiused corners of sections and angles. Whenever necessary, a system of clamping should be used to hold the parts in correct register and to control the location of the weld. When welding assemblies containing numerous welds and, in particular, when welding heavy gauge material which requires large energy inputs, it is important to minimise distortion or deformation of the assembly caused by heat expansion; this can be done by commencing to weld at the centre of the seam and working outwards to the ends or edges.

12   **SURFACE PREPARATION**   The success of resistance welding depends very largely on correct surface cleaning, since it is essential that the surfaces of the material should have a low and uniform contact resistance. Guidance on the preparation of various materials is given in paragraphs 12.1 to 12.6. It is difficult to lay down a standard mean period which can be permitted to elapse between surface preparation and welding, since this depends on such factors as the nature of the material, ambient conditions, etc., but the period should always be as short as possible. After surface treatment the parts should be adequately washed and dried. DEF STAN 03-2 gives details on the cleaning and preparation of various metal surfaces.

NOTE: The use of cotton gloves when handling prepared surfaces is recommended.

12.1 **Aluminium Alloys.** The presence of a thin, tough, oxide surface film of high electrical resistance is characteristic of the aluminium alloys, and its removal prior to welding is essential, otherwise discoloured, surface-burnt welds, and rapid electrode deterioration will result. Furthermore, since the oxide film is not uniform in thickness, its presence causes variations in the heat developed at the sheet interface, resulting in considerable variation in the size of the welds. The variation in electrical resistance is further aggravated by the presence of extraneous matter such as dirt, grease or paint and since no satisfactory method exists for the removal of the oxide film and the extraneous matter together, surface preparation must be considered in two stages.

12.1.1 Firstly, the surface must be efficiently degreased by, for example, a process such as that described in Leaflet **BL/6-8**, using trichlorethylene. The oxide film must be removed by a chemical process such as the ones described in (a) and (b) below, or by a suitable proprietary process.

(a)   **Chromo-Sulphuric Acid Pickle.**   The solution should consist of de-mineralised water containing:–

Sulphuric Acid (d = 1·84)   150 ml/litre
Chromic Acid (CrO₃)   50 g/litre

The solution should be contained in a lead-lined tank and should be maintained at 60°C. The treatment period should not exceed 30 minutes, after which the parts should be thoroughly washed.

(b)   **Sulphuric Acid and Sodium Fluoride Bath.**   The solution consists of de-mineralised water containing:–

Sulphuric Acid (d = 1·84)   100 ml/litre
Sodium Fluoride (NaF)   10 g/litre

The solution should be maintained at room temperature, and the parts should be immersed until uniformly clean (5 to 10 minutes). The parts should then be rinsed in cold water, dipped in an aqueous solution of 500 ml/litre nitric acid (d = 1·42) for one minute and then thoroughly washed in clean water.

12.1.2 The cleaning of aluminium alloys of the type which are solution treated and naturally aged, should not be commenced until 24 hours after solution treatment. Great care should be taken to ensure the complete removal of all cleaning and pickling solutions, by efficient washing and rapid drying.

12.2 **Magnesium Alloys.** These materials should first be degreased and then carefully cleaned by a mechanical means. They should finally be air-blasted to ensure the removal of any particles left by the cleaning process.

12.3 **Corrosion-Resisting Steels.** The surfaces to be welded should be degreased and then prepared by cleaning with a brush having stainless steel bristles. Pickling is not necessary for these materials unless vapour-blasting or abrasive paper cleaning is employed, in which case contamination should be removed by pickling or swabbing in a 20% (by volume) nitric acid solution.

12.4 **Nickel Alloys.** The surfaces should first be degreased and then immersed in one of the following aqueous solutions:–

(a)   Nitric Acid (d = 1·42)   200 ml/litre
       Hydrofluoric Acid   50 ml/litre

       The solution should be used at a room temperature not exceeding 65°C

(b)   Hydrofluoric Acid   200 g/litre
       Ferric Sulphate ($Fe_2(SO_4)3$) 200 g/litre

       The solution should be used at a temperature of 65° to 70°C

NOTE: Nickel alloys should be in the solution heat-treated condition prior to immersion in these liquids.

12.5 **Plain Carbon Steels.** After degreasing, plain carbon steels should be pickled in an aqueous solution containing 10% sulphuric acid (d = 1·84) by volume. The solution should be contained in a lead-lined or rubber-lined tank and should be used at room temperature. Welding should be carried out immediately after washing and drying the parts.

12.6 **Titanium Alloys.** The requirements for the surface preparation of titanium alloys are similar to those for other materials, i.e. the surface must be clean and free from grease. The surfaces may be cleaned by the use of any approved solvent which leaves no residue, but if the material has been heat treated for manipulation purposes prior to welding, a light oxide film will be present on the surfaces; this should be removed by an acid pickle (the solution described in paragraph 12.1.2(a) is suitable) or by brushing with a wire brush.

13   MATERIALS   Table 1 of Leaflet **BL/6-12** lists the types of material suitable for seam welding, together with brief details of heat treatment and other relevant factors. No attempt should be made to weld materials not listed or to weld combinations of listed materials. unless this is specified on the drawing and a proven technique is available.

13.1 **Low Carbon Steels.** Low carbon or mild steel has a carbon content in the range of 0·01% to 0·26% and a manganese content of below 0·7%. The advantage of this material is that it is not heat-treatable and is, therefore, very suitable for all forms of welding. Table 1 gives general guidance on suitable machine settings.

TABLE 1
TYPICAL SETTINGS FOR SEAM WELDING MILD STEEL

SWG	Tread Width (Inches)	Pressure (lb)	Timing Cycles On Off		Inches Per Minute	Spots Per Inch
24	$\frac{5}{32}$	550	1	1	120	$12\frac{1}{2}$
22	$\frac{3}{16}$	660	1	1	120	$12\frac{1}{2}$
20	$\frac{3}{16}$	660	1	1	120	$12\frac{1}{2}$
			2	2	75	10
18	$\frac{7}{32}$	770	2	2	75	10
			3	3	60	10
16	$\frac{1}{4}$	880	3	2	60	10
			3	3	50	10
14	$\frac{9}{32}$	990	4	3	45	$9\frac{1}{2}$
			4	4	40	$9\frac{1}{2}$

13.2 **Low Alloy Steels.** The low alloy steels contain one or more elements such as nickel, chromium, molybdenum, vanadium, etc, which improve the heat treatable qualities of the steel. These steels are easily seam welded, but will generally require heat treatment after welding to restore the properties of the steel.

13.3 **Medium Carbon Steel.** To obtain satisfactory mechanical properties, it is necessary to temper the welds. This tempering can be carried out by passing a current through the welds but it is more satisfactory, where possible, to temper the work in a furnace.

NOTE: With both low alloy steels and medium carbon steel cracking in the weld area may occur, especially at the higher end of the carbon range, unless careful attention has been paid to the heat treatment schedule specified for the material concerned.

13.4 **Nickel and its Alloys.** The need for cleanliness of the surfaces cannot be over-emphasised. Oxide films greatly increase the electrical resistance and will seriously affect the weld quality. Mechanical methods of removing the film, e.g. by the use of abrasives, are best. Pickling alone is satisfactory on nickel and monel, but for the other high-nickel alloys this should be followed by abrasive cleaning. Such treatments should be applied immediately before welding.

13.4.1   Table 2 gives recommended settings for seam welding high nickel alloys, and provides a starting point from which optimum settings for the equipment available can be determined. Very often however, the precise welding conditions depend upon the particular component.

TABLE 2
TYPICAL SETTINGS FOR SEAM WELDING NICKEL ALLOYS

Material	SWG	Tread Width (Inches)	Pressure (lb)	Timing Cycles On Off	Inches Per Minute	Spots Per Inch
Monel	20	$\frac{3}{16}$	700	4 12	19	10
	16	$\frac{3}{8}$	2500	8 12	20	$5\frac{1}{4}$
Nimonic 75	20	$\frac{3}{16}$	1850	4 8	24	$10\frac{1}{2}$
	16	$\frac{1}{4}$	2500	12 16	12	9
Nimonic 80	20	$\frac{3}{16}$	2300	4 8	30	$8\frac{1}{4}$
	16	$\frac{3}{16}$	4000	8 16	12	$10\frac{1}{2}$

13.4.2   Inconel and Nimonic alloys are characterised by their high mechanical strength at elevated temperatures and high electrode pressures are, therefore, needed to ensure satisfactory forging of the weld. Electrode roller pressure should be at least one third higher than that for mild steel. These alloys also have high electrical resistivity, which enables them to be welded with shorter welding times than those required for mild steel.

13.5 **Corrosion and Heat Resisting Steels.** Many of these steels are easily weldable provided care is taken with the joint preparation. The electrical resistance is approximately six times greater than that of ordinary mild steel, with a lower heat conductivity and melting range, so that considerably less heat input is required for seam welding these materials as compared with mild steel.

13.5.1 Some difficulty has been experienced in the welding of austenitic steels due to 'weld decay' being caused by the precipitation of chromium carbide in metal near a weld which has been heated to a temperature within the range of 500°C to 900°C. The corrosion resistance of these materials is dependent on the retention of chromium in solid solution, so that the corrosion resistance is reduced if precipitation of chromium carbide occurs near the weld.

13.5.2 The extent of precipitation increases with increased welding times, so that short welding times are essential for those materials, since this not only reduces the heat affected zones, but permits a high rate of cooling after welding, which also reduces the tendency to precipitation. However, the majority of specifications for austenitic steels now require that small additions of titanium or niobium be added in amounts sufficient to combine with all the carbon present so that no chromium can be precipitated as carbide.

13.6 **Aluminium and Aluminium Alloys.** Aluminium alloys are materials of inherently low resistance and of high thermal conductivity. The amount of heat developed by electrical resistance welding methods depends on the resistance offered to the welding current thus, despite the relatively low fusion temperature of these materials (as compared with low carbon steel) a considerably greater rate of energy input is required, necessitating the use of high currents and short welding times, the latter being necessary to minimise conduction losses. However, advantage cannot be taken of the highly resistant oxide film which forms on the surface of these materials, since, as indicated in paragraph 12.1 its inherent lack of uniformity results in variation of weld size and quality.

13.6.1 The majority of the aluminium alloys can be satisfactorily welded but special machines and carefully controlled surface cleaning are necessary. Pure aluminium is the most difficult material in this group to weld, being extremely soft and easily indented by the roller; in addition, its oxide film is difficult to remove and it has high conductivity. The seam welding of aluminium alloys presents more difficulty than seam welding low carbon steels, due to the inherent nature of the material, its surface condition and its tendency to alloy with the copper-based welding rollers. In general the high tensile heat-treated alloys show greater consistency of weld strength than the low tensile alloys.

13.6.2 Because of the high thermal and electrical conductivity of these materials, high welding currents and short welding currents and short welding times are needed. Special stored energy machines are employed to reduce the sudden surge of demand on the electrical supply system. These machines are currently being replaced with the phase frequency conversion machines.

NOTE: When seam welding aluminium and its alloys the welding rollers require frequent trimming and must be cleaned continuously to avoid 'pick-up' which damages the welded surfaces.

13.7 **Magnesium Alloys.** The seam welding of magnesium alloys presents rather more difficulties than the seam welding of aluminium alloys and is not recommended.

13.8 **Titanium Alloys.** The requirements for the surface preparation of titanium alloys are similar to those for other materials, i.e. the surface must be clean and free from grease. The surfaces may be cleaned by the use of any approved solvent which leaves no residue, but if the material has been heat treated for manipulation purposes prior to welding, a light oxide film will be present on the surfaces; this should be removed by an acid pickle (the solution described in paragraph 12.1.2 is suitable) or by brushing with a wire brush.

14 CONTROL OF WELDING For design purposes a minimum strength per inch is assumed. Since it is not possible actually to test the strength of the welds in production parts, weld efficiency must be controlled by examination of the results of tests conducted on separately welded test pieces, these test pieces simulating the production parts in respect to material specification and thickness, including surface preparation, machine settings and speeds of welding, with all other parameters and data affecting welds put on schedules. Test pieces should be prepared at appropriate intervals, a suitable basis being one test piece before a day's run and another at the end, with an additional test whenever a fresh machine setting is made or after the replacement of rollers.

14.1 Production control test pieces can only be used to determine whether the weld strength obtained with the specimen exceeds the minimum strength per inch weld prescribed in the relevant drawings. It should be borne in mind that the strength obtained with test pieces does not necessarily indicate the weld strength in the production assembly, since it is not possible for such an assembly to be entirely representative of the production part. Further, the specimen cannot take into account the 'Mass effect' in welding large panels.

14.2 Minimum strength figures should be chosen with care, and should be determined by welding production assemblies and control test pieces under the same conditions, destructively breaking the welds in the assembly and comparing the results with the shear strength obtained with the test pieces (paragraph 14.5), and by microscopic examination of cross-sections (paragraph 14.6). If the number of test pieces selected on the basis given above is large, and satisfactory results are obtained, the number of sections submitted for microscopic examination may be reduced to 10% of the total number of test pieces.

14.3 As a further check on the efficiency of welding, the Chief Inspector may, at his discretion, select samples from actual production to be tested by an appropriate method. Where engine parts are concerned, and particularly those used in gas turbines, the manner in which the weld will withstand heat stressing and vibration may be of more importance than static strength. Whilst a shear strength test provides a useful guide in this respect, a 'prising' test is additionally informative, and has the advantage that it can be quickly performed on the workshop floor, giving a positive indication as to the validity of information written into schedules and subsequently used on test pieces.

14.4 **Prising Tests.** The test specimen should be placed in a vice and plates prised apart with a chisel. A good weld does not shear at the weld interface, but will break away along the edge of the weld leaving the weld complete with both sheet thicknesses included.

14.4.1 Schedule sheets with all parameters appertaining to the particular weld should accompany the test specimen through inspection/radiography/NDT and destructive metallurgical tests, receiving necessary stamps and signatures to final acceptance.

14.4.2 Radiographs of the test pieces should be used as final comparison with radiographs of the workpiece.

14.5 **Shear Test.** The test samples for shear tests should be made as indicated in Figure 5, curved or flat as required by the controlling authority.

14.5.1   The sample should be cut so that the first 50 mm (2 in) of the weld is discarded, as indicated, leaving a test piece similar in type to that used for spot welding tests. The test piece should then be pulled in a similar manner as for spot welding tests (see Leaflet **BL/6-12**).

14.5.2   If it is desired to employ a testing machine with pin grips for this test, the width of the ends of the test piece should be increased accordingly to compensate for the presence of the locating holes. In no instance should the length of the portion of the weld to be tested be less than 25 mm (1 in).

14.6 **Microscopic Examination.**   The furthest portion of the sample on the side of the test piece remote from the discarded piece should be used for examination. Seam welds should be sectioned centrally and longitudinally for the purpose of examination.

14.6.1   After sectioning and polishing, the sample should be examined microscopically, in both the unetched and etched conditions, first at low magnification (x 10) and at higher magnification (x 100). At low magnification the welds should show freedom from cavitation and from excessive porosity. A slight amount of cracking is generally permissible in the weld itself but no cracks should appear outside the weld area. There should be adequate but not excessive penetration. For welds in sheets of approximately equal thickness, the depth of the fusion zone should be 40 to 80% of the sheet thickness, but should not reach the surface of the sheet or for clad materials, the coating.
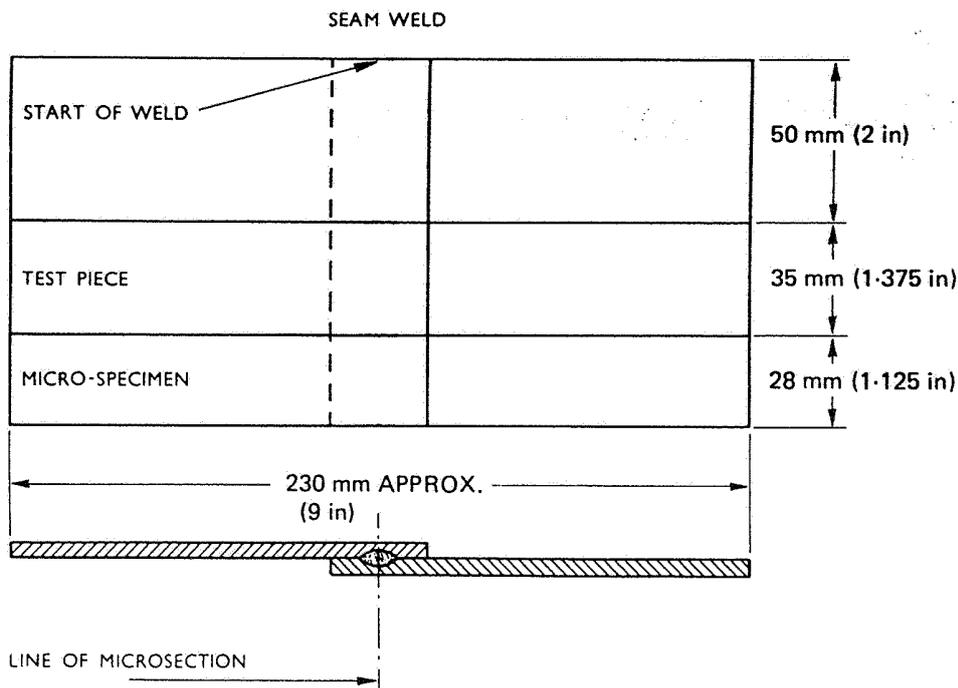
SEAM WELD

Figure 5   SHEAR TEST SPECIMEN

14.6.2 Pick-up from the electrode rollers is not permissible on aluminium alloys, as experience has shown that this defect seriously reduces the resistance to corrosion (this is often indicated on visual examination by a roughening of the surface).

14.6.3 The examination at higher magnification should be made to check and confirm the observations made at low magnification. Information on suitable etching reagents is given in paragraph 12.

15 **INSPECTION** In addition to indicating the examination to be afforded the parts after welding, this paragraph summarises the inspectional responsibilities for the process as a whole.

15.1 Inspection should verify that pressure and heating, current values, etc., are as specified in the drawing, welding schedule or other document and are in accordance with the results of experiments and past experience with the particular type of weld and machine used.

15.2 It should be ensured that the metal has been suitably cleaned and that the highest degree of cleanliness is observed throughout the process, that the welding technique is correct, that all drawing and other requirements are complied with, that electrode rollers used are correct in form and size and that the weld size is in accordance with that produced on the pre-production test piece.

15.3 After welding, the surface of the weld should be examined to ensure it shows no obvious signs of overheating, that the weld and adjacent metal is free from visible cracks and pitting, and that the distance between the centre line of the weld and the edge of the material being welded is not less than the minimum specified on the drawing.

NOTE: Slight cracks in the seam weld are generally permissible provided they do not extend into the parent sheet. However, in some cases of primary structure, such cracks may not be acceptable.

15.4 The roller indentation should be checked to ensure that it does not exceed 5% of the combined thickness of the sheets being welded.

15.5 The sheet separation at the weld should be checked to ensure that it is not greater than 10% of the combined thickness of the sheets being welded.

15.6 The above inspections should be backed up by evidence afforded by the mechanical, microscopical and prising tests described in paragraph 14, and where stressed parts are concerned, by suitable radiological examination to approved techniques. In addition, the use of a penetrant dye process will facilitate the inspection. An application of dye on one side and examination on the reverse side will reveal the presence of burning, cracks and, in the case of edge welding, lack of fusion.
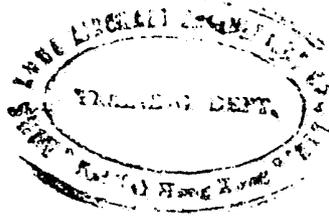
BL/6-18

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BASIC

ENGINEERING PRACTICES AND PROCESSES

MACHINING OF TITANIUM AND TITANIUM ALLOYS

1   INTRODUCTION This Leaflet gives guidance on the machining of titanium and titanium alloys, and discusses some of the problems which may be encountered when working this material. Non-mechanical machining methods such as chemical milling, electrical discharge milling or electrochemical metal removal are sometimes used with titanium and its alloys but, provided that adequate care is taken, the material may be satisfactorily machined using normal mechanical methods.

2   MATERIAL Titanium alloys have a very high strength/weight ratio, and their physical properties and resistance to corrosion at elevated temperatures show marked advantages over other materials of comparable weight. As a result, titanium alloys may be used to replace both stainless and non-stainless steel, thereby effecting a substantial saving in weight. Increasing use is being made of titanium alloys for the manufacture of both turbine engine and airframe parts, examples of which are compressor blades, firewalls, heat shields and structural parts subject to elevated temperatures.

2.1 The machining characteristics of the various titanium alloys differ considerably. This Leaflet is, therefore, confined to general machining conditions, and should be related to information supplied by the material manufacturer and experience gained from the use of various machines and equipment with particular materials.

2.2 The factors which cause difficulties in the machining of titanium and its alloys are listed below, but these can be reduced to acceptable proportions if the correct techniques are used for each specific machining operation.

    (i) The formation, during machining, of long thin chips with extremely abrasive qualities.

    (ii) Chip welding and fusion welding characteristics.

    (iii) Extreme work hardening properties.

    (iv) The chemical affinity of titanium for tool materials.

    (v) Difficulty in removing scale and skin.

    (vi) High notch sensitivity, requiring a good surface finish.

    (vii) Low thermal conductivity resulting in extremely high temperatures at work/tool interface; the reduction of cutting edge temperature is one of the basic problems in machining titanium, but can be solved to some extent by low cutting speeds, heavy feeds and copious supplies of cutting fluids.

3   GENERAL It will be seen from the above that titanium places greater demands on tools than other materials used in aircraft. It is necessary, therefore, to use tools which are more rigid and powerful than would be required for a similar operation on material such as high tensile alloy steel. Tools must be properly designed for the work and the cutting edge kept sharp.

3.1   A characteristic of titanium is its tendency to "gall" or "smear" when in contact with other metals. As a result, it is necessary to avoid sliding contact, and to use roller steadies and running centres whenever possible.

3.2   High rates of feed are essential; intermittent feeding or dwelling produces rapid work hardening and may result in early breakdown of the tool.

3.3   The importance of rigidity cannot be over-emphasised and should be considered when deciding on the technique to use with a particular component. Cutting loads are considerably higher than those for other materials of comparable tensile strength and adequate support must be provided.

3.4   A good surface finish can frequently be obtained with coarse feeds by using suitably shaped tools with a large nose radius. This radius will, however, be limited by the rigidity of the work, as the larger the nose radius, the greater the load and hence work deflection. It should also be noted that, because of the lower elastic modulus of titanium, work deflection is greater than would normally occur when machining, for instance, high tensile alloy steel.

3.5   **Cutting Fluids.** High quality soluble fluids, used in the diluted form recommended by the manufacturers, or chlorinated or sulphurised oils, should be used in generous quantities for all machining operations. Titanium materials are generally not susceptible to normal corrosion attack, but it has been established that stress corrosion cracking can take place in some welded structures which are exposed to trichloroethylene and other chlorinated hydro-carbons, the alloys most affected in practice being the titanium-aluminium-tin family. When it is necessary to machine a welded titanium structure, or doubt exists regarding the use of cutting fluids with a particular titanium alloy, the material manufacturer should be consulted. Chlorinated solvents should be removed, after machining, by use of a solvent such as methyl ethyl ketone.

3.6   Titanium and titanium alloys are usually machined in the annealed condition as this gives improved dimensional stability and facilitates machining. The annealing temperature depends on the actual material, but is usually between 650°C and 900°C and is followed by quenching. Age hardening, which increases the strength of the material, is carried out after annealing, by heating to a slightly lower temperature for a specified period. A stress relieving treatment may also be applied before the final machining operation by heating to a temperature below that required for age hardening. Details of the heating times and temperatures applicable to each particular alloy should be obtained from the material manufacturer.

3.6.1   Titanium has a high affinity for oxygen, nitrogen, hydrogen and carbon, particularly at temperatures above 650°C. These elements diffuse into the metal and, if present in sufficient quantities, can cause embrittlement of the metal surface. To reduce contamination to a minimum, the furnace atmosphere should be slightly oxidising and low in moisture content, and heating times should be kept to a minimum, within the recommendations of the material manufacturer.

3.7 **Anti-Seizing Compound.** To avoid seizing when using gauges such as plug gauges, ring gauges or thread gauges in tapped holes, it is important that the gauge is lubricated with an anti-seizing compound. However, chlorinated compounds could cause surface cracking if the component is subsequently heat treated, and must be removed after use. A solvent such as methyl ethyl ketone should be used for this purpose.

4   TURNING AND BORING   Cutting speeds should be low and feeds as coarse as practical, depending on the robustness of the components, machine conditions and the surface finish required. The tool must be well supported and the front and side clearance angles carefully chosen. Large clearance angles could weaken the cutting edge, but small clearance angles could result in the tool rubbing on the work and causing work hardening.

4.1   **Feeds.** Feeds within the range of 0·1 mm to 0·3 mm (0·005 inch to 0·015 inch) per revolution should be used, and feeds of 0·2 mm (0·101 inch) per revolution, or more are desirable; generally the feed should be as large as work deflection will allow. For a given metal removal rate, the use of heavy feeds and slow speeds will give longer tool life than light feeds and fast speeds.

4.1.1   Light finishing cuts, particularly those less than 0·1 mm (0·005 inch) deep, should be avoided whenever possible as the rate of tool wear will be excessive and work hardening may occur.

4.1.2   With tungsten carbide tools, roughing cuts of 2·5 mm to 7·5 mm (0·1 inch to 0·3 inch) deep may be used, but with high speed tool steel, cuts of 1·25 mm to 2·5 mm (0·05 inch to 0·1 inch) deep should not be exceeded.

NOTE: When finish cutting, a surface finish of up to one micron is obtainable.

4.2   **Speeds.** The speeds given in Table 1 are recommended.

TABLE 1

Material	*Type of Tool*	*Recommended Surface Speed*	
		metres/min	*feet/min*
Commercially pure titanium	High speed steel Stellite Carbide	50 to 60 60 to 70 100 to 110	150 to 180 180 to 200 300 to 330
High strength titanium alloys	High speed steel Stellite Carbide	10 to 20 20 to 30 40 to 50	30 to 60 60 to 90 120 to 150

4.3   Successful tool shapes vary considerably with the work, but generally the plan shape is relatively unimportant. As a rough guide, top rakes for tungsten carbide tools should be between 6° positive angle to 5° negative angle, depending on the severity of the operation. High speed steel tools may have up to 15° positive rake. In all cases a relief angle of approximately 7° is recommended.

NOTE: Definitions of the various angles mentioned in cutting tool geometry are given in Leaflet BL/6-11, together with others which are relevant although not specifically mentioned in the text.

4.4 To avoid excessive heating of work/tool interface (see paragraph 2.2 (vii)), a tool of proportionally heavy section should be used with a nose radius as large as possible, 6 mm (¼ inch) radius roughing and 3 mm (⅛ inch) radius finishing, to help dissipate heat. It is also important to use a copious supply of extreme-pressure soluble oil, unless very slow speeds can be tolerated.

4.5 **Turning with Tungsten Carbide Tools.** For continuous turning, tungsten carbide tools are generally used with a standard tool geometry except for the nose radius which, as previously stated, should be as large as possible. Usually, the grade of tool recommended for turning cast iron is suitable for titanium and titanium alloys. Tungsten carbide tools may be necessary for heavy work on some of the harder titanium alloys even for intermittent cutting, but in general, their use is confined to light continuous cuts. For efficient use of carbide tools, it is essential to regrind as soon as wear is apparent.

4.6 **Turning with High-Speed Steel Tools.** For rough turning, and for turning where the depth of cut is not constant and where interrupted cuts may be present, the use of tungsten-cobalt high-speed steel cutting tools is recommended.

4.6.1 With high-speed steels, the tool geometry is important and the angles given in Table 2 are recommended:

TABLE 2

Description	Recommended Angle
Top side rake	6° to 8° (approx)
Top back rake	7° to 8° (approx)
Plan approach angle	15° to 20° (approx)
Trail angle	7° to 10°
Front clearance	7° to 10°

4.6.2 For parting-off tools, side clearance should be rather greater than the 8° angle normally used for steel, to avoid rubbing and consequent work hardening.

5   MILLING High speed steel cutters having a coarse tooth spacing are suitable for general milling work. Milling cutters should be set true on the machine arbor and given maximum support. Spindle accuracy and the rigid mounting of jigs, fixtures and work-pieces are equally important.

5.1 For general work, and as a general guide, a radial rake of 5° with a helical angle of 55° and radial land of 0·1 mm (0·005 inch) may be used on slab mills.

5.2 In milling titanium, chips tend to weld to the cutter teeth and get carried round with the miller, resulting in cutters chipping and breaking. To minimise this, it is useful to employ "climb" milling, in which the cutter blades move in the same direction as the workpiece. However, the hard skin formed on the surface of forgings and rolled plate will quickly dull the cutter blades, and should be removed before climb milling commences.

5.3 **Speeds.** Depending on the work and milling conditions, the speeds will vary considerably, but for plain milling, surface speeds are usually between 25 and 35 metres (80 and 100 feet) per minute. For form milling, the speed is usually about half the speed for plain milling. Positive forward speed should be maintained to avoid the possibility of friction, with consequent work hardening.

5.4   Feed. Rates giving a feed of approximately 0·2 mm (0·010 inch) per tooth are recommended. For small cuts, the depth of cut should always be sufficient for the cutter to "bite" positively and thus obviate rubbing. It is not desirable to employ rates which would result in a feed of less than 0·1 mm (0·005 inch) per tooth. The cutter should always be allowed to complete the cut once it has started.

5.5   Care must be taken with the resharpening of cutters to ensure correctness of angle, since insufficient clearances cause rubbing and work hardening, and excessive clearances cause chatter. 8° to 10° top relief or clearance is recommended.

6   DRILLING   Rigidity is essential when drilling titanium and titanium alloys. A high-speed steel drill having a point angle of 105° to 120°, with a helix angle of 38° and a thickened web is recommended. It is important that a stub (i.e. short) drill should be used. For holes of more than 6 mm (¼ inch) diameter, a 90° or "double-angled" point is better.

6.1   Drills must be precision ground and special care must be taken to ensure that the drill tip is completely central, as any off-set of the tip will cause work hardening as a result of friction of the non-cutting edge.

6.2   Speed. For satisfactory drill life, drill surface speeds should be within 3 to 13 metres (10 to 40 feet) per minute. If speeds below 3 surface metres per minute are used, work hardening is likely to result.

6.3   Feed. A continuous feed of 0·05 to 0·1 mm (0·002 to 0·005 inch) per revolution for holes below 6 mm. (0·25 inch) diameter, and of 0·1 to 0·2 mm (0·005 to 0·010 inch per revolution for larger holes is recommended. Positive power feed must be employed whenever possible.

6.4   Cutting Fluid. Flood lubrication with a heavily chlorinated cutting oil of low viscosity helps to reduce frictional troubles.

6.5   Centre Drilling. Centre drilling should always be used instead of centre punching, as the local work hardening caused by centre punching will cause difficulty in starting the drill and will also tend to make the drill wander as well as blunt the drill point.

6.6   Work-Hardening. Many of the difficulties which may be encountered in subsequent operations, such as tapping and reaming, are often the result of work hardening of the walls of the hole during drilling. It is therefore essential that careful attention is given to correct procedure during the drilling operation.

6.7   Lathe Drilling. When drilling in a lathe, where the drill is stationary and the work-piece rotating, some difficulties may arise due to the fact that with a stationary drill in the horizontal position there is more restriction on the free clearance of chips from the flutes of the drill. For this reason, peripheral speeds should be in the region of 3 to 8 metres (10 to 25 feet) per minute.

6.8   General. It is essential that the cutting edges of drills should be kept sharp and they should be re-ground as soon as wear is evident. Wear is indicated by a change in chip formation, and the drill should not be allowed to deteriorate to the point of screeching. With a sharp drill, the chip is smooth and curled, but as soon as the drill becomes blunt the chip folds back on itself, generating excessive heat which quickly burns the drill point.

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7 REAMING Satisfactory reaming of titanium and titanium alloys depends largely on the procedure adopted during the drilling operation (see paragraph 6.6).

7.1 High-speed steel reamers with spiral flutes and standard cutting angles are satisfactory for reaming titanium and titanium alloys. To help chip removal, honing of the cutting edges and polishing of the flutes will be found helpful. The relieving of the outside diameter at some distance back from the cutting edge to reduce the bearing surface is often considered beneficial. The actual finish of the reamer, e.g. cutting and relief faces, is of extreme importance.

7.2 Holes are usually designed so that after drilling, the last 0·08 to 0·15 mm (0·003 to 0·006 inch) are reamed out.

7.3 With a copious supply of cutting fluid, which may be either a similar fluid to that used during drilling operations (paragraph 6.4) or an extreme pressure soluble oil at normal dilution rates, the cutting speed should be between 4 and 5 metres (12 and 15 feet) per minute.

7.4 Through power feed should be employed whenever possible. If hand reaming is used, the feed must be uninterrupted. In general, feeds of 0·1 to 0·15 mm (0·004 to 0·006 inch) per revolution are recommended, and when possible, the reamer should pass through the hole, and not be withdrawn as this may score the reamed surface.

8 TAPPING High-speed steel, three-flute taps having straight flutes and a strong central web should be used. The standard 2° cutting edge rake angle normally employed for materials other than titanium or titanium alloys is not satisfactory, and angles of between 5° and 10° are more suitable; taps conforming to this geometry are obtainable from normal suppliers. Ground thread, full relief taps are recommended.

8.1 Complete rigidity of the set up is essential and it should be noted that the torque required for tapping titanium and its alloys is three times greater than that required for tapping similar holes in steel of comparable hardness.

8.2 Pitch control tapping should be used, but where this is not possible great care must be taken to maintain a positive feed; a torque restricting device is most desirable to avoid tap breakages. Cutting speeds should be between 3 and 8 surface metres (10 and 25 surface feet) per minute, and the use of chlorinated fatted oil in generous quantities is recommended.

8.3 For blind holes, the tapping speed should be reduced to the lower end of the range given in paragraph 8.2. It will be necessary to ascertain that the hole is deep enough for the tap not to bottom and, as plug taps cannot be used, the depth of the hole must be at least four threads greater than that over which full thread form is required.

9 GRINDING Close control of grinding operations is necessary to obtain good results, the basic problem being that of high localised temperatures. Conventional wheel speeds and feed rates may produce burning and induce surface stresses, and should not normally be used.

9.1 Vitrified bond, medium hardness grinding wheels of 46 grit should be used for roughing, and of 60 grit for finishing. The grinding conditions listed in (i) to (iv) will provide the most efficient metal removal, with minimum wheel wear and minimum abuse of the workpiece. Automatic feed should be used whenever possible.

(i) **Wheel Speeds.**

(a) Silicon carbide wheels, 1000 to 1700 surface metres (3000 to 5000 surface feet) per minute.

(b) Aluminium oxide wheels, 500 to 800 surface metres (1500 to 2500 surface feet) per minute.

(ii) **Feed.**

(a) Roughing, 0·02 mm (0·001 inch) per pass.

(b) Finishing, 0·01 mm (0·0005 inch) per pass.

(iii) Table speed or work speed, 13 metres (40 feet) per minute.

(iv) Cross feed, 0·8 to 1·2 mm (0·030 to 0·050 inch) per minute.

NOTE: Information on the classification of grinding wheels is contained in British Standard 4481.

9.1.1 A heavy load is imposed on the grinding wheel during grinding and, to prevent chatter, it is essential that the wheel is carefully balanced and rigidly mounted, and the workpiece adequately supported.

9.2 A copious supply of lubricant should be used during grinding. Water-based soluble oils give poor wheel life, but chlorinated or sulphurised grinding oils and rust inhibitors of the nitrite-amine type give good results.

9.3 Even when grinding under optimum conditions, some abuse of the material surface may result, and etch-inspection techniques are often used to reveal grinding burns. Since the degree of residual stress induced by grinding is difficult to detect, it may be necessary to shot-blast or stress relieve any component which will be used in a fatigue-sensitive environment.

10   SAWING   Machine sawing of titanium and titanium alloys is possible provided the speed employed is about half that used for steels of comparable hardness.

10.1 Hard oxidised surfaces should be removed before sawing is attempted; this surface is extremely difficult to cut and considerably reduces tooth life. De-scaling can be accomplished by vapour blasting, or by one of the various chemical methods which are available

10.2 A bandsaw running at about 5000 metres (15 000 feet) per minute is a convenient method of cutting plate up to 6 mm (¼ inch) thick, or bar of up to 25 mm (1 inch) diameter. As extreme heat is generated, in the case of high strength alloys it is advisable to stress relieve at about 500°C immediately after sawing, to avoid surface cracking.

10.3 For hand hack-sawing, high speed steel blades with 18 or 24 teeth per 25 mm (18 or 24 teeth per inch) are satisfactory, but for cutting sheet, blades with a finer tooth pitch are required. Sawing should be done with heavy pressure on the cutting stroke and rubbing avoided as far as possible on the return stroke.

10.4 The use of a soluble or sulphurised oil is recommended.

11   POLISHING   The polishing of titanium is often desirable, and, provided that smearing is avoided, can be satisfactorily accomplished using a buffing wheel or mop at reduced rotational speeds. A canvas wheel, coated with aluminium oxide abrasive and stearic acid, provides a good finish, particularly if light pressures are used during the final stages.

7

12   SAFETY PRECAUTIONS   Fine titanium swarf or powder, even when moist, is a possible fire risk, but is considerably less than that involved in the machining of magnesium.

12.1   Dust particles, arising from polishing and grinding etc., are highly inflammable and must be disposed of safely. Such dust may be kept totally immersed in water until it can be burnt under controlled conditions.

12.2   It is essential that piles of fine titanium swarf, or dust, are not allowed to accumulate around machines where they could be subsequently ignited.

12.3   When grinding, oils with a low flash point must be avoided.

12.4   Although the bulk metal is considered safe, swarf produced under certain conditions, e.g. turning at high speed with low feed, can cause fires.

12.5   A fire can be dealt with by covering it gently with a mixture of dry asbestos wool and chalk powder. No attempt should be made to put out a titanium fire with water or with any extinguisher not specified for titanium fires.

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ENGINEERING PRACTICES AND PROCESSES

CLEANLINESS OF AIRCRAFT

1   INTRODUCTION   The degree of cleanliness achieved, both internally and externally, during the construction and maintenance of aircraft has a direct bearing on airworthiness.   To ensure that engineers and inspectors are able to certify that aircraft are fit for flight, it is essential, particularly where closed structures are concerned, that the component history cards and aircraft build sheets used during construction and overhaul, should contain a clause requiring inspection to certify that each part has been inspected at the appropriate stage, and that it is free from loose articles, dirt, swarf and other extraneous matter.

2 THE EFFECTS OF EXTRANEOUS MATTER The presence of extraneous matter inside aircraft, components, systems, etc., can have serious consequences and special care is necessary to ensure thorough cleanliness at all times.   In the following paragraphs some of the adverse effects are briefly outlined.

2.1   Extraneous matter in the form of dirt or grit in moving parts may cause excessive wear and other damage.   Working clearances of many components are relatively minute and small particles of dirt may cause scoring or seizure of working surfaces and rapid deterioration of seals and glands.   Where systems are concerned (e.g. hydraulic, fuel and pneumatic systems), scrupulous cleanliness is essential during assembly and maintenance operations; contamination inside a system will often present a difficult cleaning problem and many cases are on record of malfunctioning due to ingress of extraneous matter.

2.2   The presence of loose extraneous articles inside a structure is always a dangerous hazard.   Such items as nuts, bolts, rivets, off-cuts of wire or sheet metal and hand tools have been found inside the more intricate and boxed-in type of structures.   These can cause jamming or restriction of vital controls and have been known to result in serious aircraft incidents.   Furthermore, loose items, especially of a heavy nature, which are trapped inside structures can, due to vibration, erode the protective treatment of the structure and cause damage to bag-type fuel tanks or the sealant of integral tanks.   Heavy loose items trapped inside control surfaces can result in their becoming unbalanced.

2.3   In structures where there are electrical installations, small metal particles can cause damage to the insulation of wires and looms, and these can produce short-circuits at terminal points.   The ingress of such particles into switches, solenoids, actuators, etc., is a common cause of malfunctioning.   Where inverters, generators, etc., are cooled by means of ducted air, special care is necessary with regard to cleanliness as the cooling air can collect dust and grit and deposit this

inside the component; foreign matter can also block the cooling-air filters of avionic equipment, resulting in overheating and failure.

NOTE: Loose particles of ferrous metal, such as filings, in the vicinity of electromagnetic mechanisms are particularly dangerous and difficult to remove; such mechanisms should, therefore, be adequately protected prior to filing and sawing ferrous parts in the vicinity.

2.4   Where pipes run in banks, loose extraneous parts may become wedged into the pipe clearances, and might restrict the natural whip or flexing of the pipes under surge loads, resulting either in fracture or perforation through chafing.

2.5   Grit or small metal particles inside bays fitted with flexible tanks will damage the tank envelope and produce leaks and, in the case of integral tanks, metal particles embedded in the tank sealant might cause leaks and promote corrosion of the structure from electrolytic action.

2.6   The presence of extraneous fluids, due to spillage or leaks, may have serious deleterious effects. Certain fluids, such as ester-base engine oil, hydraulic oil, glycol, de-icing fluid, etc., will damage most protective treatments or materials not intended to be in contact with these fluids, and bonding compounds, electric cables, rubber mouldings, tyres, etc., will deteriorate rapidly if these are left in contact with such fluids; the spillage or leaks of some fluids may increase the fire hazard, especially if they occur in the vicinity of electrical equipment or engine installations. Serious contamination can also be caused by spillages of toilet fluids, mercury, gallium and other chemicals.

NOTE: Leaflet AL/3—8 gives guidance on general fire precautions.

2.7   In remote areas of the structure where access and periodic cleaning are difficult, dirt or dust will tend to accumulate and could act as a wick for moisture which, in time, may penetrate the protective treatment and promote corrosion.

2.8   Special precautions are required regarding oxygen installations. The presence of extraneous matter, especially of an oily or greasy nature, in contact with pressure oxygen is explosive. It is important, therefore, to follow the special instructions regarding cleanliness of oxygen systems given in the installation drawings or Maintenance Manual.

3   GENERAL PRECAUTIONS   It will be difficult to ensure a high standard of cleanliness of aircraft, components, etc., unless a similar standard is maintained in hangars and workshops. Vigilance is necessary to ensure that conditions and workshop practices are such that extraneous matter will not enter or come into contact with any part of the aircraft, its systems or its components.

NOTE: It is recommended that placards and warning notices (preferably illustrated), pointing out the seriousness of extraneous matter in aircraft, should be placed in all departments.

3.1   In order to prevent small tools, torches, pencils, etc., from falling into the aircraft structure, personnel engaged on servicing operations should wear overalls fitted with closed pockets. Suitable footwear should also be provided, or vulnerable surfaces should be protected with mats, as even small scratches can destroy anti-corrosive treatment and lead to deterioration of a component.

3.1.1   An inventory should be made of all tools, spares or equipment taken to an aircraft for servicing purposes, and checked when the work has been completed. This action will reduce the possibility of such items being left in the structure.

3.2   Dirty floors, stagings, benches, test equipment or open tins of jointing compound, sealants, grease, paint, etc., (which may gather extraneous matter), should not be permitted.   For instance, no matter how careful an engineer might be regarding the final cleanliness of a component he may not be able to detect the presence of extraneous matter in jointing compound from a tin that has been left open; yet this may result in a serious attack of electrolytic corrosion or prevent the joint from closing completely.   All tins and containers should be kept closed when not in use and any tins and containers which have been open for an unknown length of time should be discarded.

NOTE: This trouble can be avoided if the compound is obtained from squeeze tubes and applied directly to the joint.

3.3   Engines, accessories, instruments, ball bearings, etc., which are usually supplied, as appropriate, in special transport cases or packagings, should not be unpacked until required for use.   Blanking plates on engines or components and blanks fitted to pipe connections or other openings, should only be removed for installation or functioning tests.

3.4   Parts that are not required for immediate installation should be kept in stores. For information on storage conditions for aeronautical supplies see Leaflet BL/1-7.

3.5   Whenever it is necessary to open or dismantle an accessory, component or system, the work should be done under controlled conditions where dust, grit, etc., (e.g. from cleaning operations), cannot enter the accessory, component or system. Stripping and cleaning sections should be adequately segregated from inspection and assembly areas.

NOTE: Care is necessary when using sawdust for cleaning hangar floors. Cases have arisen during maintenance work on fuel systems where the lighter particles of sawdust had entered the system and subsequently been found in the fuel filters.   Investigation revealed that these particles emanated from the sawdust used for cleaning purposes.

3.6   Transparent plastics panels (acrylic sheet), widely used for cabin window glazing, are affected by certain organic fluids and in some cases their vapours. Some of these fluids are in common use during aircraft maintenance operations and reference should be made to Leaflet AL/7-4, Transparent Plastics Panels, which lists these fluids and gives guidance on the necessary precautions and the cleaning procedures involved.

3.7   Engine runs should be carried out at some distance from maintenance installations or other aircraft, on hardstandings with clean, firm and well drained surfaces.   This will minimise damage to external parts of the aircraft and help to prevent water, grit or debris from entering engine intakes, breathers and vents.

4   AIRCRAFT IN SERVICE   When an aircraft is in service it should be cleaned periodically as part of the routine maintenance.   The cleaning solvents recommended for use on a particular aircraft are usually detailed in the relevant Maintenance Manual but in any case no unauthorised solvents or detergents should be used.   Chlorinated solvents such as trichlorethylene or carbon tetrachloride should not be used inside the aircraft due to the danger of toxic fumes given off by these liquids.

4.1 **Normal Exterior Cleaning.** Before commencing cleaning operations all panels and covers should be in place and apertures sealed off. Thick mud, grease or oil should be removed by, first, hand scraping using wood or soft plastic scrapers and then lint free cloth soaked in solvent. Care should be taken to avoid damage to paint or other anti-corrosive treatment. Cleaning should then be carried out using a recommended solvent. These solvents are usually used diluted in hot water. Application to the aircraft surface is best made with spraying equipment but care should be taken to ensure that the solution does not become atomised. After allowing the solution to penetrate, the dirty surface should be washed thoroughly with clean water until all traces of the solution are removed. Care should be exercised when using water hoses for rinsing as too high a pressure may cause damage or ingress of moisture. Undiluted solvents should never be allowed to come into contact with acrylic windows, etc., as crazing is likely to ensue. In all cases the recommended solvent manufacturer's instructions should be adhered to. Re-lubrication of mechanical parts may be necessary after washing, and application onto sealed bearings, etc., should be avoided.

4.1.1 **Exterior Cleaning of Heavily Contaminated Areas.** Certain areas of an aircraft may become heavily contaminated by exhaust gas deposits, the areas varying with different types of aircraft. This contamination, if not removed, could cause severe corrosion and require expensive repairs. Stronger cleaners recommended for the particular aircraft or part should be used with extreme care. Dilution may be required with either water or white spirit, and application can be made with a non-atomizing spray. In all cases, the solvent manufacturer's instructions must be strictly complied with. The solution, when applied, should be allowed to soak for a given period and care taken to avoid areas becoming dried out. After soaking, further application is usually required and agitation or scrubbing with a soft brush may be advantageous. Very thorough rinsing, preferably with clean warm water, is necessary. Painted surfaces as well as acrylic windows may become damaged if these stronger solutions are allowed to come into contact with them.

4.1.2 **Snow and Ice.** Chemical salts and other melting agents are often used on runways during the winter months. This slush will inevitably become splashed or sprayed onto the aircraft and could be detrimental. The contaminated areas should be washed down with clean water as soon as possible after exposure. The use of a wetting agent may prove helpful.

4.1.3 **Acrylic Windows.** After aircraft washing, the windows should be washed with soap or a mild detergent in warm water. Polishing minor scratched surfaces may be accomplished with an approved plastics polish and finally finished with an anti-static polish or cloth. Further guidance on this subject is given in **AL/7-4.**

4.1.4 **Radioactive Contamination.** This is usually confined to aircraft regularly flying above the stratosphere. Regular monitoring of high flying aircraft with a Geiger counter should be made. Normal regular cleaning will in most cases keep contamination within acceptable limits.

4.1.5 After cleaning of windows has been completed, the aircraft should be inspected for signs of damage, deterioration of protective treatment, cracks, corrosion, etc. A careful check should be made to ensure that all blanks and sealing fitted have been removed and that cleaning equipment such as rags, sponges, etc., are not left in the intakes, flying controls or other susceptible places. Vents and drain holes, etc., should be checked and cleared if necessary.

4.2 **Interior Cleaning.** The inside of the aircraft should be kept clean and special attention should be given to areas where spillages can occur. Dirt and grit are best removed by use of a vacuum cleaner but oil or grease stains should be removed with the aid of a cleaner recommended by the manufacturer. This should be applied in small quantities to prevent soaking the fabric or padding. Loose covers may be removed for washing but must be thoroughly dry before refitting in the aircraft. Where the materials have a non-permanent flame-proof protection they must be re-proofed after washing.

4.2.1 At the intervals prescribed in the appropriate Maintenance Schedule, the floor panels should be removed and an inspection of the underfloor skin and structure carried out. Corrosion and residues which result from spillages in the cabin, galleys or toilets should be removed, together with any extraneous material; if necessary, any corrosion-prevention treatment should be restored, and soaked or damaged insulation bags should be renewed. Debris may also be found in the compartments used for luggage and cargo.

4.2.2 Particular care is required when cleaning the cabins of pressurised aircraft since these tend to produce far more condensation than those of unpressurised aircraft. The moisture attracts dust and dirt and can quickly lead to corrosion of metal surfaces if the protective film is damaged. Dirt and grit could also lead to malfunction of the relief and vent valves used in the pressurising system and result in potentially dangerous cabin pressure conditions.

4.2.3 Plastic (polyester) foam may, under conditions where it is repeatedly moistened and dried, exude a mild acid capable of causing serious corrosion to aluminium alloys, particularly in poorly ventilated areas. Such plastic foam may have been used in the upholstery of seats and also in thermal/acoustic lining. If there is evidence of staining on such plastic it should be lifted to enable direct inspection of the adjacent seat frames or structure to be carried out. Appropriate action should be taken with the structure dependent upon the degree of attack, but, in any case, deterioration of the protective finish of the structure should be made good after thorough cleaning. Contaminated plastic foam should be renewed.

4.2.4 **Carriage of Livestock.** Very thorough internal cleaning is necessary after the carriage of livestock with particular attention being paid to the bilge areas. A disinfectant should be used recommended by the aircraft manufacturer. If any signs of vermin such as cockroaches, mice, etc., are found it may be necessary to contact the Health Authority to ascertain whether or not complete fumigation of the aircraft is necessary. Disinfestation is usually carried out by contractors who specialise in this work and complete ventilation of the aircraft is required afterwards for a period of several hours.

5 PARKED AIRCRAFT All doors and windows should be closed, and covers and protective blanks should be fitted to aircraft which are to stand for extended periods; this equipment often forms part of the aircraft flight kit, and is designed to protect air intakes, ducts, vents, pitot heads, etc., from ingress of extraneous matter.

5.1 Covers, blanks and other protective devices are usually interlinked by cords or fitted with warning streamers, to ensure that they are all removed when the aircraft is prepared for flight.

5.2   On turbine-engine aircraft, the air intake and jet pipe blanking covers should be fitted at all times when the aircraft is not in use, and only removed for maintenance purposes or engine runs when special engine running guards might be necessary.

NOTE: Dependent on the length of time out of service, the engine may require rotating or inhibiting in accordance with the instructions in the engine Maintenance Manual.

5.3   When aircraft are to be 'parked out' for long periods, special precautions in addition to those normally given in the Maintenance Manual will be required, and the manufacturer's advice should be sought.

**6**   **CLEANLINESS OF AIRFRAME STRUCTURES AND COMPONENTS** The task of ensuring cleanliness should begin at the initial assembly stage, even though further work may be required before final assembly is completed.

NOTE: Boxes or special trays should always be used for small items, such as hand tools, AGS parts, etc., which are to be used on aircraft.   Items left loose on the aircraft or adjacent trestles and stagings, may fall into the structure undetected and result in serious incidents when the aircraft is in service.   Supervision should also ensure that refreshments (e.g. mineral-waters, tea, etc.) are not taken onto the aircraft as spillages of these are common causes of corrosion.

6.1   Components such as flying control surfaces, wings, tail units and boxed-in structures should be inspected progressively for cleanliness.   When a structure is to be closed, either permanently or by a removable panel, inspection should verify that the compartment is entirely free of extraneous matter.   The inside of structures or components should be inspected for cleanliness using the visual aids and methods outlined in Leaflet AL/7-13 which gives guidance on the internal inspection of structures.

NOTE: If any part of the aircraft or engine control system is inside a closed-in compartment, consideration should be given to the requirements for duplicate inspections detailed in BCAR Chapter A5-3.

6.2   Large modifications, skin repairs, spar changes, etc., involve the production of large quantities of swarf, redundant parts and sealant; as much debris as possible should be removed as it is produced but a proper cleaning programme should also be implemented.   A thorough inspection should be carried out on the internal structure before it is sealed.   When the work involves fuel compartments the low pressure filters and booster pump screens should be checked after filling the tanks and again after initial engine runs.

6.3   The method of cleaning will be governed to some extent by size and structural features, but where possible the smaller structures such as ailerons, flaps, etc., should be rotated in all directions and shaken to dislodge any items which might be trapped or retained inside.   In instances where normal cleaning is not possible, full use should be made of powerful vacuum cleaners with suitable adaptors.   The use of an air jet as a cleaning medium is not recommended, since in the main it merely succeeds in distributing the extraneous matter over a wider area, sometimes into freshly cleaned compartments, and may drive unwanted particles into lap joints, bearings or electrical components.   Compressed-air supplies frequently have a high moisture content and their use in inaccessible places could lead to corrosion.

6.4   The final inspection should be made when there is no likelihood of the compartment being re-opened, except of course for assembly purposes, test flight adjustments, etc., and when it is certain that no further operations are necessary which might introduce extraneous matter into the compartment.   Compartments
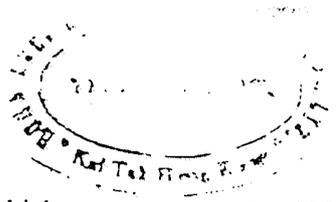
which are re-opened should be given further careful examination after the work which necessitated re-opening has been completed.

NOTE: Radiography is often used to examine boxed-in structures which have been progressively inspected for cleanliness but there may be small openings through which rivets or other small items could have gained access during work on adjacent structures.

6.5   On completion of the work, the engineer, having satisfied himself that the structure or component is perfectly clean, should witness its closing, and should endorse this inspection stage on the related history card.

6.6   Most aircraft have provision in the lower surfaces of the fuselage, wings, control surfaces and cowlings for the drainage of accumulated fluids, normally water. Some of these can be fully effective only when the particular structure is correctly positioned, e.g. stabilisers set to 'Aircraft nose-down trim position'. Engineers should therefore ensure that such drainage features are clear and effective when the aircraft is parked and at all times during maintenance.

7   CLEANLINESS OF INSTALLATIONS AND SYSTEMS   Compartments into which engines, etc., are to be installed should be thoroughly cleaned immediately prior to the installation.

- 7.1   During the installation, all connections should be examined for cleanliness and freedom from obstruction immediately prior to fitting. Any items, such as nuts, bolts and washers, which are dropped should be recovered immediately, and not left until the installation is complete, since by that time the incident may be forgotten.

7.2   On completing the installation and immediately prior to closing the compartment, a careful final examination should be made of the compartment and installation, and of any associated cooling ducts, panels, controls, etc., to ensure complete freedom from loose articles and other matter.

7.3   Electrical multipin plugs and sockets, which are extensively used in engine installations, are particularly susceptible to trapping of fine swarf or dirt and this can easily lead to electrical faults of a type very difficult to trace. When not coupled up, all multipin plugs and sockets should be suitable protected.

7.4   On completion of engine installations, inspection should verify that engine bays are clean and free from loose articles. Care should also be taken to ensure that drains are clear so that no accumulations of fuel or oil can be trapped in cowlings. Where temporary covers or blanks are fitted to turbine engines, inspection should ensure that covers and blanks are of the correct type, are clean and have no loose parts which, if detached, could enter the air intakes.

7.5   The cleanliness of all systems such as hydraulic, pneumatic, fuel systems, etc., cannot be over-emphasised. This applies not only to the systems installed or being installed in the aircraft, but also to any related ground equipment (see paragraph 9).

NOTE: Guidance on cleanliness procedures for systems is given in the following Leaflets:
        AL/3-13   Hose and Hose Assemblies,
        AL/3-14   Installation of Rigid Pipes,
        AL/3-17   Fuel Systems,
        AL/3-19   Wheel Brakes,
        AL/3-21   Hydraulic Systems,
        AL/3-23   Pneumatic Systems.

7.5.1 Whenever an orifice or connection in a system has to be left open, protection against the entry of extraneous matter must be provided by means of blanks or specially-made covers.

7.5.2 The design of blanks and covers is very important. In many cases standard AGS blanks are used in the form of plugs or caps, but where a non-standard orifice is concerned, it is often necessary to make a special cover, in which case the design and choice of material must be carefully considered. Cotton and other textile materials should not be used because of danger of small particles of fluff entering the system; for the same reason, paper, wood or cork should be avoided, as small fragments of these materials may become detached and enter the system. Blanks should be so designed that it is impossible to connect up the system with a blank in position.

7.5.3 For short-term protection, especially in the case of a group of open connections such as a junction block, a polythene bag tied over the unit is often used. However, where plastics protective devices are concerned it is important that they are not used on systems the fluids of which may have a deleterious effect on the plastics material. The possibility of plastics slivers being cut by engagement with a metallic coupling and gaining entry into a component should also be considered.

7.5.4 Wear of control cables is accelerated very considerably where dirt clings to surplus grease or protective films on the surface of control cables where they pass through fibre, tufnol or ferrobestos fairleads and over pulleys. It is therefore important that lubricants or sticky protective films to which dirt might adhere are removed from cables in positions where wear may take place. This should be done by wiping with a cloth and not by washing with solvents or detergents.

8   **CLEANLINESS OF COMPLETE AIRCRAFT**   Prior to the final inspection of a new or overhauled aircraft, inspection should verify that all boxed-in compartments have been checked for internal cleanliness.

8.1   Special attention should be given to compartments which have been opened for the purpose of adjustments; all sections through which engine and flying controls pass; the cockpit and associated equipment; the landing gear bays and the landing gear.

8.2   The cleanliness of warning notices, data plates, transparent covers of notices or indicators and instruments should also be checked.

8.3   On completion of the inspection, the engineer, having satisfied himself that the aircraft is clean, should endorse this inspection stage on the aircraft history sheet.

NOTE: It is good practise to carry out a final inspection for loose articles immediately following the first flight after construction or overhaul.

9   **GROUND EQUIPMENT**   The cleanliness of ground equipment is important, particularly in respect of test rigs which are connected into an aircraft system.

9.1 The degree of filtration demanded in modern fuel and hydraulic systems is such that particles which are not visible to the naked eye are capable, if not filtered out, of causing malfunction of a component. It is, therefore, most important that the filtering arrangements included in the test rig should be at least equal to those in the system itself. Before using a rig the connections should be thoroughly cleaned and when not in use the hoses should be blanked off and properly stowed.

9.2 Mobile dispensers used for fuel, oil, de-icing fluids, etc., must be kept clean and all covers and blanks should be fitted when the equipment is not in use.

9.3 Regular checks should be made for water contamination in fuel dispensers and in bulk storage. Reference should be made to Leaflet AL/3-17, Fuel Systems, for guidance on the procedure for checking fuels for contamination.

BASIC

ENGINEERING PRACTICES AND PROCESSES

PAINT FINISHING OF METAL AIRCRAFT

I   INTRODUCTION   This Leaflet gives guidance on the application of paint to metal aircraft and aircraft parts. The treatment of wooden structures is described in Leaflet BL/6-25, and the doping of fabric-covered aircraft is described in Leaflet BL/6-26. The term 'paint' is used in a general sense, and includes primers, varnishes, lacquers and enamels.

1.1   The primary reason for applying paint to an aircraft, is to protect the skin and structure from corrosion. Paint does this by excluding the atmosphere and liquids, and by providing a supply of chromate in the primer, which leaches out in the presence of moisture and inhibits corrosive action on the metal surface. The top coat of paint provides an abrasion and fluid resisting cover to the primer, and also the decorative finish.

1.2   The various paint schemes used, may be in accordance with British Standards or DTD specifications, or may be specially prepared by the manufacturer. No single scheme would be satisfactory for use on all parts of an aircraft, because of the particular requirements for the different areas and for the different metals to be treated. For example, engines are subjected to heat, and require the use of a heat-resistant paint; skin and structure in the lower fuselage may be in contact with condensation and spilled corrosive fluids, and may require more protection than other areas; magnesium always requires special treatment.

1.3   The effectiveness of a paint scheme depends on the proper preparation of the surface, the maintenance of suitable conditions in the paint shop, and the application of the paint in accordance with the relevant specifications.

2   PAINTING MATERIALS   A paint scheme is broadly classified according to the type of material used in the finishing coats, but the undercoat or primer and, where applicable, the filler coats, may be manufactured from different materials. The various types of primers and finishing coats are discussed in the following paragraphs.

2.1   **Primers.**   The main purpose of a primer coat is to provide adhesion to the metal surface. There are four main types of primers—synthetic, stoving, etch and epoxy—with wide variations within each type.

2.1.1   Synthetic and stoving primers are very similar, and are usually derived from resins and fatty acids. They are pigmented with chromates and produce a thick coating, but their resistance to fluids used in modern aircraft is not particularly good.

2.1.2   Etch primers contain resin, chromate, solvent, and phosphoric acid, and have very good adhesion on untreated sheet metals. Etch primers can often be applied directly to aluminium without any pre-treatment other than cleaning, but some sheet metals possess a surface to which the adhesion of etch primers may be unsatisfactory; such surfaces should be given an etching pre-treatment prior to application of the etch primer.

2.1.3   Epoxy primers are twin-pack materials (i.e. the two ingredients must be mixed before use) and often consist of an amine cured epoxy resin, with strontium chromate as an inhibitor.   They have a very good resistance to fluids used in modern aircraft, and may also be used for stoving.   They are generally used where maximum resistance to corrosion is required.

2.2   **Finishes.**   There are many different types of finishes used on aircraft, the main types being cellulose, synthetic, stoving enamel, acrylic, epoxy and polyurethane. Other materials may be used in small areas where a particular property, such as resistance to battery acid, is required.

2.2.1   Cellulose and synthetic finishes were widely used in the past, mainly because they are easily applied, polished, and repaired.   Cellulose nitrate is used as a tautening dope on aircraft fabric coverings, and is also used, to a certain extent, on wooden and metal aircraft.   Synthetic finishing schemes such as BS X 28, are often used as an alternative to cellulose schemes on metal aircraft.   As the thinners, primer and filler used in some synthetic finishing schemes are not always compatible with cellulose materials, care must be taken to use only the approved materials.   Both cellulose and synthetic finishes have good adhesion and weathering properties, but are not usually resistant to fluids used in modern aircraft.

2.2.2   Stoving enamels generally have a high resistance to abrasion, and are used for power plant and airframe components which are not adversely affected by the stoving temperature.   Stoving temperature is normally below 125°C (257°F), and does not have any deleterious effect on aluminium alloys, although stoving must be carried out at any early stage of manufacture, before the inclusion of heat-sensitive parts.   One stoving scheme (DTD 56) calls for one or two coats of enamel to be stoved separately, without use of a primer, whilst with another scheme (BS X 31), a primer coat is used, which may be allowed to air dry and then both primer and top coats are stoved together.

2.2.3   Acrylic paint for use on aircraft, is usually developed from methyl methacrylate. This paint has good resistance to high temperatures, but has poor resistance to fluids; it is rapid drying and is a single-pack material.

2.2.4   Epoxy paint relies on a chemical reaction for curing, and is supplied in twin-pack form.   It produces a hard glossy surface, and is resistant to aircraft fluids and acids. Its weathering properties are rather poor from the appearance point of view, and it tends to 'chalk' quickly.

2.2.5   Polyurethane paint is generally derived from polyester and di-isocyanate, and is supplied in twin-pack form.   It dries to a hard glossy finish, and has exceptional weathering properties and resistance to organic fluids.   One drawback to the use of polyurethane is its toxicity during spraying.

2.3   Whilst most painting materials are manufactured to meet DTD or BS specifications, individual manufacturers usually vary the chemical compositions to suit their own particular purposes, and although a number of paints may satisfy the requirements of a specification they may not be compatible with one another.   Paints supplied by different manufacturers should not, therefore, be used in the same paint scheme, unless they are proved to be compatible.

3   SURFACE PREPARATION   Paint and primer are rarely applied directly to a metal surface which has not received some form of anti-corrosive treatment, or surface preparation designed to assist adhesion of the paint.   The type of pre-treatment applied depends on the type of metal, and on the corrosive conditions likely to be encountered in

service. DEF STAN 03-2/1 describes the methods which may be used for the cleaning and preparation of metal surfaces prior to painting. These methods, which are briefly described in the following paragraphs, consist essentially of de-greasing, followed by a pre-treatment such as chromating, etching, anodising and cadmium plating.

3.1 **De-greasing.** All new metal should be thoroughly de-greased, preferably using trichloroethylene, unless the metal is known to be adversely affected by chlorinated solvents (Leaflet BL/6-8). A liquid or vapour de-greasing bath may be used for small items, and heavily contaminated parts may be scrubbed with liquid solvent. Where an item is too large for de-greasing in a bath, its surface should be washed with rags dipped in solvent. It is important to use clean rags, and frequent changes of solvent, to prevent the spreading of contamination from one area to another.

NOTE: Trichloroethylene should not be used for hand cleaning, particularly in poorly ventilated areas, because of the health hazard to the operator.

3.2 **Aluminium.** Aluminium and its alloys should be anodised, or chemically pre-treated, using an approved etching or filming process.

3.2.1 Anodising is a process by which a thin film of oxide is formed on a surface by electrolysis (Leaflet BL/7-1). Anodising is often used on aluminium parts, since it is also a method of crack detection. Initially the anodic film is porous, and readily absorbs dirt and grease, but after a few days the film hardens, and provides a poor surface for paint to adhere to; thus it is important that the surface is primed as soon as possible after anodising.

3.2.2 A chromic/sulphuric acid etching treatment which may be applied to unanodised surfaces prior to painting, is described in DEF STAN 03-2/1. Other etching treatments, which are approved under DTD 900, are also available. The parts to be treated are usually immersed in a bath containing the specified pre-treatment chemicals at a pre-determined concentration. After immersion for a time governed by the particular process, the parts are removed and thoroughly washed in water.

3.2.3 A useful combined cleaning and pre-treatment agent, which complies with a DTD 900 specification, is available for use on assembled aircraft and parts. This agent is in the form of a paste which, when applied to the surface, removes corrosion products and grease, and also etches the surface. All traces of the paste must be washed off with water, using a brush to remove it from skin joints and rivet heads. After the surface has dried, it is usually given a filming treatment.

3.2.4 A number of filming pre-treatment processes are approved to DTD 900 specifications, and these are generally simple chemical processes, which may be applied by dipping, spraying or brushing. A filming treatment provides a chromate rich film on the surface, which gives good protection from corrosion and good paint adhesion; this treatment is particularly useful for repair work. On some aircraft surfaces, subsequent painting is unnecessary.

3.3 **Magnesium.** Magnesium rich alloys are very prone to corrosion, and should be treated in accordance with DTD 911. The treatment consists of dipping the parts in ᵣ .ᴤ of several types of chromating baths (Leaflet BL/7-3), and is usually followed by a surface sealing process (Leaflet BL/7-5). One method used by a particular aircraft manufacturer consists of an epoxy primer applied over the chromate film, followed by a nylon coating process, but other approved methods may be used.

3.4 **Titanium.** Titanium alloys have very good resistance to corrosion and do not require any special surface preparation. Solvent cleaning may be used, but care must

BL/6-20

be taken to ensure that the solvent will not cause hydrogen embrittlement or stress corrosion (see DEF STAN 03-2/1 and Leaflet BL/6-8). When titanium is to be painted, an etch primer is normally used.

3.5   Steel.   Non-stainless steels are generally cadmium plated (Leaflet BL/7-2), but a phosphate dip or spray process is sometimes used instead. Where paint is to be applied directly to the steel, the surface to be painted should be mechanically cleaned by abrasive blasting or scouring. Stainless steels are not usually painted, but if they are, an etch primer should be used after cleaning.

3.6   Glass Fibre.   Before glass fibre is painted, all traces of parting agent should be removed. Warm water will remove water soluble agents, but white spirit or methyl ethyl keytone (MEK) should be used for other types. The surface to be painted should then be rubbed down with fine emery cloth, and the dust should be removed using a lint-free cloth soaked in white spirit or MEK. An epoxy primer is generally used, the first coat being brushed on, to fill any pinholes which may be present.

3.7   General Precautions.   Pre-treatment materials, solvents and their vapours, may have a deleterious effect on many components and materials used in an aircraft. Individual items can generally be treated away from parts which are liable to be affected, but when assemblies and complete aircraft are to be painted, precautions must be taken to prevent these liquids and vapours from coming into contact with any parts which are liable to be affected by them. All such parts, such as bearings, vents, drains, sealant, transparencies, aerials and insulators, must be masked, with plugs or adhesive tape and non-absorbent paper. Any parts in the area which do not require treatment should also be covered up, to guard against the effects of splashes, overspray and vapour. Masking material and plugs must be removed after the completion of painting.

3.7.1   Chemically pre-treated metal surfaces should, where possible, be primed immediately after the pre-treatment is completed, so as to avoid any risk of contamination. This procedure may be difficult to follow when a complete aircraft is being painted externally, and the use of a suitable covering is recommended. The surface should be covered after pre-treatment, and progressively uncovered as the primer is applied.

3.7.2   All traces of aqueous washes containing acids or alkalies should be thoroughly washed off, since their residues may affect the adhesion of the paint. Water used for washing or rinsing the surface after cleaning, pre-treatment, or 'flatting', should be blown off with clean oil-free compressed air, and drops of water should be prevented from drying on the surface.

3.7.3   When bare metal components are solvent-de-greased, the temperature of the surface may fall as a result of evaporation. In such instances the components should be allowed to stabilize at ambient temperature before painting is commenced.

4   PAINTING SCHEMES   Apart from commercial considerations, the paint schemes applied to a particular aircraft will depend mainly on the corrosive fluids likely to be encountered. The aircraft manufacturer may specify schemes of his own, but often the schemes will be devised by the paint manufacturer and approved under DTD or BS specifications.

4.1   A painting scheme will normally contain full details concerning pre-treatment, materials to use, extent of thinning required, paint viscosity, and methods of application.

4.2   Pre-treatment, cleaning and painting involve a number of operations, and provision must be made to ensure that all specified operations, including previously carried out repairs and inspections, have been checked and certified by an inspector. Evidence

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that a particular operation has been carried out may not always be visually apparent, and could well be covered up by a subsequent operation.

4.3   The general procedures and precautions which should be taken when painting aircraft or aircraft parts, are outlined in paragraphs 5 to 12.

5   PAINTING CONDITIONS The evaporation of solvents, and the presence of spray dust, necessitate draught-free ventilation in paint shops. The temperature should, generally, be maintained between 15°C (60°F) and 25°C (77°F), and the humidity should be kept below 75%. However, some paints require closer control of the temperature; for example, DTD 5555 requires epoxy materials to be applied at a temperature above 18°C (65°F). In addition, for the application of etch primers, the humidity should not be less than 30%.

5.1   Ventilation may be provided by extractor fans and filtered air inlets, but the most satisfactory method of maintaining the required conditions is by filtering and cooling the incoming air to a sufficiently low temperature to remove excess moisture, then re-heating the air before passing it to the paint shop. The air conditioning system should be capable of changing the air in the paint shop every two minutes, and it is recommended that the paint shop should be kept at a slight positive pressure in order to prevent dust and draughts from entering through doors and windows.

5.2   The temperature and humidity should be checked at frequent intervals. A wet and dry bulb hygrometer is normally used for this purpose, the dry bulb indicating the actual temperature, and the difference between the dry and wet bulb readings being used, in conjunction with appropriate tables (Leaflet BL/6-26), to determine the humidity.

5.3   Cleanliness is essential to a good standard of paint finishing. Paint shop floors should be painted or sealed to prevent 'dusting', and should be swept at the end of each day so that the air is free from dust and contamination the following morning. Dried paint and spray dust present a serious fire hazard, and these should be removed at least once per week. When the paint shop is also used for pre-treatment and flatting, floor drainage should also be provided, so that rinsing water can be quickly removed and the floor can be dried before painting is commenced. Clean and dirty rags should be stored in separate bins.

5.4   The surface to be painted must be adequately illuminated, and portable flameproof lamps may be necessary when painting the undersurfaces of wings and fuselage. The provision of good scaffolding or working platforms will be necessary with large aircraft, so that the paint can be correctly applied (see paragraph 7).

5.5   When ideal painting conditions are not available, e.g. when it is necessary to paint in an open hangar, a reasonable paint finish may be obtained by observing a few simple precautions.

(a) Freedom from dust, draughts and condensation must be ensured.

(b) The item to be painted must be allowed to assume room temperature, and should be slightly warmed, if necessary, to prevent condensation.

(c) Care must be taken to prevent the surface being handled after it has been cleaned.

(d) All parts adjacent to the item to be painted which might be affected by the painting operation should be masked or covered with dust sheets.

5.5.1   Precautions must also be taken to prevent the possibility of fire, by removing naked lights and arcing electrical equipment; suitable fire-extinguishing equipment must be readily available.

5.6 **Regulations.** Because of the flammability of the materials used in painting, a number of laws and by-laws have been issued relating to the handling, storage and use of paints, particularly for cellulose and other low flash point materials generally. Reference should be made to the Cellulose Solution Regulations, The Petroleum Act, the General Sections of the Factories Acts, and any relevant local by-laws, for particulars regarding these materials, and the types of equipment to be used in paint shops.

6   PAINT PREPARATION

6.1 **Stirring.** Solid particles in a pigmented paint tend to settle whilst the paint is left standing, and, even when no sediment is apparent, the paint may vary in consistency from top to bottom. In order to ensure that consistent results are obtained, therefore, all paints, except glossy varnishes and lacquers, should be thoroughly stirred before use. The top of the can should be wiped clean before the lid is opened, and if a skin has formed on the paint, this should be removed by running a knife round the inside of the tin and lifting the skin out complete.

6.1.1 Mechanical stirring is preferable to hand stirring, and when the amount of work justifies it, a mechanical agitator or tumbler should be used.

6.1.2 For hand stirring, a flat bladed non-ferrous metal paddle should be used. This may be used with a spiral lifting action to circulate the solid particles throughout the paint.

6.1.3 When the sediment is hard, and difficult to disperse, the upper liquid should be poured into a separate container, and the sediment should then be stirred to a smooth paste, after this the poured-off liquid should be added gradually, until it is all returned to the original container.

6.2 **Thinning.** Paint manufacturers normally recommend the amount of thinners to be added to a paint, depending on the method of application. This basic mixture will often need to be adjusted to suit local conditions. To ensure satisfactory and consistent results, some manufacturers recommend that the viscosity of the thinned paint should be checked before application, by the use of a British Standards Type B flow cup (see BS 1733), the size of which depends on the viscosity range of the paint. The equipment consists of a cup and stand, a stop-watch, a thermometer and a suitable container. The temperature of the paint should be checked before the test to ensure that it is at approximately room temperature. A finger is placed under the calibrated orifice of the cup, and the cup is filled with the paint to be tested. The stop-watch is started simultaneously with removal of the finger from the cup orifice, and the time taken for the stream of paint to break into droplets, is noted. The viscosity is expressed as 'X seconds BS B3 or B4 cup', as appropriate. Thinners or paint are then added to bring the mixture to the required viscosity.

6.3 **Straining.** In many cases, paint manufacturers recommend that paint should be strained before use, to remove any extraneous matter which may have been picked up after the can is opened. Metal gauze of 60-120 mesh is the most suitable filter for this purpose, but paper or lint-free cloth or muslin may also be used. Metal gauze should be cleaned in solvent immediately after use, but other types of filters should be discarded. The paint should be allowed to flow through the filter, and not worked through with a brush. Some manufacturers recommend that all filters used with epoxy materials should be discarded after use, to avoid subsequent contamination.

6.4 **Twin-pack Materials.** Before mixing twin-pack materials, each of the constituents should be stirred separately. If thinning is required, only the approved thinner should
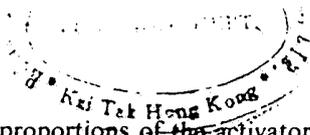
be used; the proportions of the activator and base material must not be altered in an attempt to correct the viscosity. To avoid wastage, the amount mixed at any one time should be limited to the amount which can be used within the pot-life period. After mixing, the paint should be strained, then allowed to stand for a specified period before use, so that entrapped air may escape.

7   METHODS OF APPLICATION   There are numerous methods of applying paint to a metal surface, including spraying, dipping, brushing and rolling. Exterior surfaces are generally sprayed, and small components may be sprayed, dipped or brushed.

     7.1   **Conventional Spray.** This is the method used for the application of the majority of aircraft paints. It is a convenient, fast and easily controlled method of application, which gives consistent results The main disadvantage of this method is that the over-spray may become a nuisance when other work is being carried out in the area. For small areas the use of spray guns with integral paint containers is satisfactory, but for larger areas pressure feed equipment is generally recommended.

     7.2   **Airless Spray.** This method is particularly suitable for applying polyurethane paint, with which spray dust in the atmosphere must be kept to a minimum for health reasons. Since no air is used in atomising the paint, atmospheric pollution is minimised. The spraying equipment is more expensive, however, and the thickness of the paint film is difficult to control. Many paints cannot be applied by this method, either because their viscosity is unsuitable, or because their pigments are too coarse to pass through the spray orifice.

     7.3   **Dipping.** This method can only be used with single-pack materials, since twin-pack materials have a limited pot life. When dipping is used, the smallest dip tank consistent with the size of the work should be used, and the viscosity of the paint should be checked frequently. Straining and stirring of paint used for dipping is most important, and the best method of stirring is by pump circulation, in which the paint is filtered before it is returned to the tank. Where small tanks are used, hand stirring should be carried out frequently, and the paint should be drained off and strained at appropriate intervals. Dip tanks should be provided with lids, in order to minimise contamination and evaporation of solvents when the tank is not in use.

     7.4   **Brushing.** Brushing should only be used for small repairs, and for surfaces and corners which are not accessible for spraying.

     7.5   **Rolling.** Where an open surface has to be painted, and other work is being carried out in the vicinity, use of a hand roller may be recommended. However, this method results in a thick layer of paint thus adding to the weight of the finish, and spraying is generally preferred.

8   PAINT SPRAYING   Prior to the commencement of spraying, the effects of the paint on surrounding structure, aerials, sealants, sealed bearings, joints and grease nipples must be considered, and precautions must be taken to shield these parts if this has not already been done prior to pre-treatment (paragraph 3.7). Identification plates and windows should be blanked with greaseproof paper and masking tape, or with paper and soft soap, and any open pipes or intakes which are not to be painted should be suitably protected.

     8.1   The paint should be applied as an even, wet coat, which will flow out smoothly. Spray dust and inadequate coverage will result from spraying too lightly, and 'runs' or 'sags' will result from spraying too heavily.

8.2 For conventional spraying, the air pressure at the spray gun should be maintained at 275 to 550 kN/m² (40 to 80 lbf/in²), to produce a satisfactory spray. When pressure feed equipment is used the air pressure at the container should be varied according to the viscosity of the paint, so that the paint reaches the gun in a gentle continuous flow; generally, a pressure of between 35 and 105 kN/m² (5 to 15 lbf/in²) should be used. For airless spraying, the pressures recommended by the equipment manufacturer should be used. In all cases allowance should be made for the loss of pressure between the gauge and gun, and some manufacturers provide tables showing the pressure drop which can be expected with hoses of various diameters and lengths.

8.3 A spray gun should be adjusted to give the required spray pattern (generally fan shaped for normal painting, and circular for 'spotting in'), and its operation should be checked briefly on scrap material. The gun should be held 15 to 25 cm (6 to 10 in) from, and at right angles to, the surface being painted, and each stroke should follow the contour of the surface. Each stroke of the gun should be straight, and the trigger should be released at the end of each sweep, the speed of movement being regulated to deposit an even wet coat. Each successive stroke of the gun should overlap the previous stroke, to keep a wet paint film and to provide an even overall coating.

8.4 When the paint scheme requires a number of coats to be applied, or a filler coat to be flatted, the drying times specified by the paint manufacturer should be observed. After flatting, the surface should be washed-off and allowed to dry before the next coat is applied.

8.5 Care of Equipment

8.5.1 Spray guns should be thoroughly cleaned immediately after use, using the solvent appropriate to the type of paint. Cleaning is particularly important after using twin-pack paints, since once these have cured they are very difficult to remove. It is recommended that, where possible, a spray gun is set aside solely for use with twin-pack materials. A gun should be cleaned by firstly flushing it through with solvent and then partially stripping it in order to remove any residual paint; stiff bristle or nylon brushes should be used for cleaning areas which are difficult to get at. The gun should not be immersed in solvent, since this would remove lubricant from the working parts and glands.

8.5.2 Paint hoses in pressure feed and airless spray systems should also be washed out with solvent immediately after use, since once the paint has dried it could flake off and cause blockages during future use.

8.5.3 The air compressor should be well maintained, and the air storage tank should be drained daily. Oil and water traps, and air filters, should be located adjacent to the coupling point for the spray equipment, so as to prevent contamination from the main supply and to be readily available for servicing. It is recommended that a record should be kept of all equipment servicing operations.

9 PAINTING FAULTS Provided that the metal surface is properly cleaned and pre-treated, and the paint is applied in accordance with the particular specification and the manufacturer's recommendations, the paint should adhere satisfactorily, and, when cured or dried, should not be easily removable by abrasion or washing. The main faults which can occur when applying a paint scheme to an aircraft, are described in the following paragraphs.

9.1 Lifting of Paint. Lifting of paint is usually the result of the lifting of the primer from the metal surface, and is usually first indicated by blistering, swelling, or wrinkling

of the paint film. In the majority of cases this is caused by inefficient cleaning of the metal surface, but may result from the presence of corrosion under the primer. It may also be caused by incompatibility of the primer and the top coat.

9.2 **Poor Adhesion.** Poor adhesion may result from inadequate cleaning, pre-treatment or preparation of the paint, from application under adverse conditions, or from failure to comply with the drying requirement specified for the particular scheme.

9.3 **Spray Mottle.** Sometimes known as 'orange peel' or 'pebble', spray mottle may be caused by incorrect paint viscosity, air pressure, spray gun setting, or the distance the gun is held from the work.

9.4 **Spray Dust.** Spray dust is caused by the atomised particles of paint drying before reaching the surface being painted. The usual causes are excessive air pressure, the gun held too far from the surface, or incorrect gun setting.

9.5 **Runs and Sags.** Runs and sags result from too much paint being applied, so that the film of paint falls under its own weight before drying. The faults may be caused by over-thinning of the paint, incorrect adjustment of the gun, and, occasionally, by inadequate surface preparation.

9.6 **Blushing.** This is a fault most commonly experienced with cellulose materials, and appears as a 'clouding' or 'blooming' of the paint film. It may be caused by moisture in the air supply, excessive humidity, draughts, or sudden changes of temperature. The use of 'anti-chill' thinners is recommended when conditions are such that blushing can be expected. Blushing can often be removed by softening the paint surface with thinners, and drying in a warm, dry atmosphere.

10   PAINT REPAIRS After an aircraft has been in use for some time, the paintwork ages and hardens, and accumulates a layer of dirt, grease and polish, which may be very difficult to remove. In addition, greases and lubricants may contaminate the paint and be absorbed into crevices, sealing strips, soundproofing and furnishings. When it becomes necessary to repair chipped or blemished paintwork, to re-paint part of an aircraft after repairs have been carried out, or to apply new paint over the existing paintwork (e.g. lettering, stencilled instructions and crests), these contaminants must be removed in order to obtain satisfactory adhesion of the new paint.

10.1   Parts of an assembly which may be adversely affected by the materials used in re-painting, and parts not needing to be re-painted, should be blanked or masked (see also paragraph 3.7). Any absorbent material adjacent to the areas to be re-painted should, where possible, be removed to prevent contamination; where removal is not practicable, the part should be thoroughly de-greased and dried before painting is commenced.

10.2   When an area is re-painted after the removal of corrosion, or after repairs have been carried out, all debris, swarf, globules of sealant, and oil or dye penetrant which may have been used for non-destructive testing, should be cleaned off.

10.3   All loosely-adhering or chipped paint should be removed from the area to be re-painted using paint stripper or aluminium wire wool, and the area should be thoroughly cleaned with solvent to remove any contamination. Several applications of solvent may be required to remove contamination from older paintwork. The area should then be wet 'flatted' with fine emery cloth, to roughen the paint, to form a feathered edge where paint has been removed, and to remove pre-treatment from bare areas.

Residues should then be removed, by washing and by use of a brush in seams and crevices. The area should then be thoroughly dried, and allowed to assume room temperature before painting.

NOTES: (1) When emery cloth is used for rubbing down, care must be taken to avoid damage to clad or plated surfaces, and to exposed joints incorporating sealant and structural adhesives.

(2) When glass fibre surfaces are being prepared for re-painting, they must be thoroughly roughened in order to ensure adhesion of the paint.

10.4   When painting over existing paintwork, and when applying lettering, crests, or stencilled instructions, the compatibility of the new paint with the original paint should be checked. The surface to be painted should be lightly wiped over with a clean cloth moistened with the thinners appropriate to the paint to be applied; a reaction such as wrinkling or blistering of the old paint will indicate incompatibility, but light removal of pigment from the paint will indicate that the new paint is compatible, and that the cleaning operation was satisfactory.

10.5   After the surface to be painted has been cleaned and prepared, the original paint scheme should be restored, and any dry spray edges should be polished to blend in with the existing paintwork. Materials, drying times and painting precautions, should be the same as those specified for the original paint scheme, except that if a filler coat is used it must be of the same material as the top coat. For example, the original filler may have been synthetic and the top coat cellulose, but for the repair both filler and top coat must be cellulose.

10.6   Any masking or plugs which have been fitted must be removed after the paint has dried.

11   PAINT STRIPPING   When re-finishing an aircraft, it is usual to strip back the paint to the bare metal and to re-apply the desired paint scheme. The ease with which the paint can be removed depends on the paint type, its thickness and its age, but approved proprietary paint strippers are available, which are specially prepared for removing particular types of paint. Epoxy and polyurethane paints are the most difficult to remove.

11.1   Some paint strippers may have an adverse effect upon structural bonding adhesives, some may affect the adhesives used for the attachment of sealing and chafing strips, and others may result in hydrogen embrittlement of high strength structural steel parts. Only the approved paint stripper should be used, and precautions should be taken to prevent its contact with susceptible materials, by masking or plugging. An inspection should be carried out after stripping, to ensure that these precautions were effective. Vents and drains should also be plugged, to prevent the entry of paint stripper, washing water and paint particles.

11.2   The paint stripper should be applied freely to the surface of the paint, and left until the paint has softened; the paint can then be removed with a wooden scraper. Residues should be washed off with water, and care should be taken to remove all paint and paint remover from seams and crevices, using a short-bristled nylon brush. When the paint is particularly thick it may be necessary to apply the paint stripper a second time after the initial softened coat has been removed. The removal of debris after stripping is most important, since the softened paint could harden in piano wire hinges, control rod bearings and other moving parts, and present a serious hazard. After the surface has been washed, it should be wiped with a rag soaked in solvent, to remove the final traces of paint.

11.3   Some paint schemes involve the use of an epoxy primer, followed by an air-drying synthetic or acrylic finish, and, provided that the primer is in a satisfactory condition, the top coat can be selectively stripped, using a specially formulated paint remover. This paint remover is applied in the normal way, but a rubber scraper should be used

to prevent damage to the primer. After removal of the top coat, the primer should be thoroughly washed with solvent to remove any contaminants, and the finish should be re-applied.

12   HEALTH HAZARDS As stated in paragraph 5, a paint shop must be well ventilated, to remove solvents and spray dust which may present a health hazard. Solvents have an irritating effect on the skin and eyes, and may be toxic. Constant contact with solvents may dry out the skin and cause dermatitis, and the use of a barrier cream is recommended. Inhalation of solvent vapours and spray dust should be avoided, and a face mask should be worn in areas where concentrations may be high.

12.1   Polyurethane spray dust can cause chest irritation if inhaled, and this is the main reason for using an airless spray to apply this material. When polyurethane is applied by conventional spray, it is recommended that a full face mask with an independent air supply is worn.

12.2   When mixing twin-pack materials, care should be taken to avoid splashing the skin or eyes. If this does occur, the material must immediately be washed off with running water.

12.3   When using paint strippers, it is advisable to wear goggles and PVC gloves, and all contact between the stripper and the skin should be avoided.

13   STORAGE Paints should be kept at room temperature, in a dry store. Containers should be marked with the date of receipt, and used in strict rotation; they should not be held longer than their stated storage life. Unpigmented glossy material should be disturbed as little as possible, so that any sediment may settle at the bottom of the can, but cans containing other materials should be inverted at frequent intervals, to reduce the settlement of pigments.

BASIC

ENGINEERING PRACTICES AND PROCESSES

THREAD INSERTS

I   INTRODUCTION   This Leaflet gives guidance on the design, fitting and removal of thread inserts, which are frequently used in threaded attachment holes of airframe and engine components.

2   GENERAL   Thread inserts are usually fitted in light alloy materials such as aluminium, magnesium, bronze and brass, to provide a larger diameter thread and thus a stronger attachment point for bolts or studs. In addition, thread inserts are often specified for repair work, where the original thread has been damaged and fitment of an insert enables the original size bolts to be used without affecting interchangeability.

2.1   There are basically two types of inserts available. One is known as a wire thread insert and is made from specially formed wire wound into a helical coil, and the other is known as a thin wall insert and is made from a tube with threads formed on both the inside and the outside surfaces. Both types are manufactured in a variety of materials and finishes, and may have either plain or self-locking threads.

2.2   Thread inserts should only be used when specified in the relevant manual, drawing or repair scheme and care should be taken to ensure that the correct insert is used. Inserts should be installed strictly in accordance with the manufacturer's instructions, since there may be slight variations between inserts conforming to the same specifications.

2.3   Because of the basic differences between wire thread and thin wall inserts, these are dealt with separately in paragraphs 3 and 4 respectively.

3   WIRE THREAD INSERTS   A wire thread insert (Figure 1) is a precision formed wire of diamond section (usually of spring steel or stainless steel) wound into a helical coil, the cross-section of the wire forming a thread both inside and outside the coil. When correctly installed the coil provides a thread which conforms to a particular British Standard or other specification, with a good surface finish and the inherent flexibility to compensate to some degree for any errors of form in the engaging bolt or screw; the radial pressure attained in fitting the insert produces good self-locking characteristics, and the possibility of thread failure from vibration, fatigue, corrosion or seizure is reduced. Wire thread inserts have a tang at the inner end to facilitate fitting with a special tool; this tang may be removed after installation if required.

3.1   **Identification.**   Wire thread inserts manufactured in the UK generally conform to SBAC(AS) standards, those with BA, BSF and BSP threads being identified by having the tang painted yellow. This range of inserts is supplied in five standard lengths of approximately 1, 1½, 2, 2½ and 3 times the nominal thread diameter. Wire thread inserts manufactured to different standards are often identified in a different way, and reference should be made to the particular manufacturer's literature for details concerning identification.
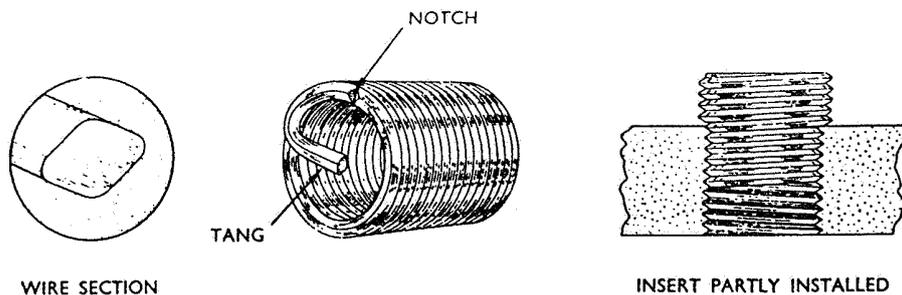
WIRE SECTION   INSERT PARTLY INSTALLED

Figure 1 TYPICAL WIRE THREAD INSERT

3.1.1   In its free state an insert is shorter and has a larger diameter than when installed, and, since the Parts Lists refer to the installed dimensions, identification by measurement is not practical.

3.2   **Installation.** Since the internal and external threads on a thread insert have the same number of threads per inch, and the internal thread is designed to be of standard size, then a special size tap is required to cut the threads into which the insert is fitted. These special taps and checking gauges are provided by the insert manufacturers. Installation procedures, which comprise drilling and tapping the hole, thread gauging, insertion of the insert and removal of the tang, are outlined in paragraphs 3.2.1 to 3.2.5.

3.2.1   **Drilling.** The hole for the insert should be drilled to the diameter and depth specified in tables supplied by the insert manufacturer, the depth being calculated from the fitted length of the insert, plus the thread runout, plus a half pitch gap at each end of the insert (see Figure 2). Care should be taken to ensure that the hole is drilled in the correct location and square to the surface, and that all swarf is removed before tapping. In some cases, particularly when the hole is near to the edge of the component, it may be necessary to check for cracks by a specified non-destructive testing method.
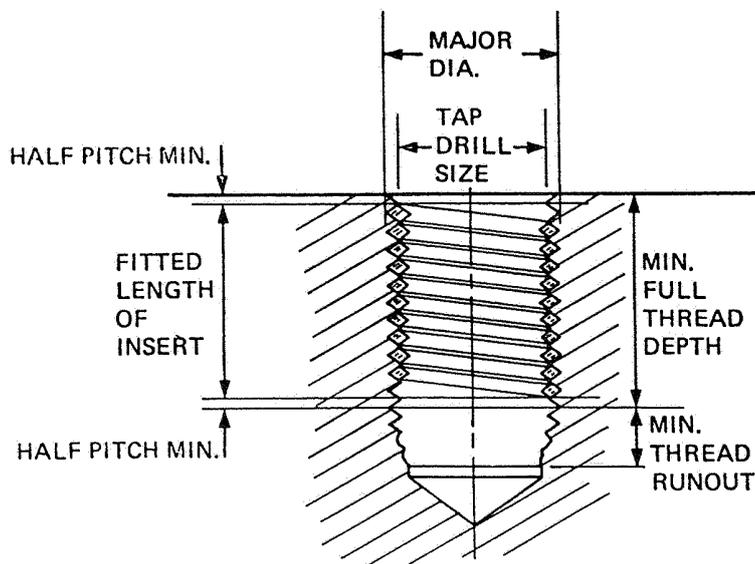

Figure 2 WIRE THREAD INSERT HOLE DATA

3.2.2   **Thread Tapping.** The thread should be tapped with a special tap provided by the insert manufacturer, a straight-fluted tap being used for hand tapping and a spiral-fluted tap for machine tapping where this is possible. Normal workshop practices should be used for tapping, with special emphasis on cutting the thread coaxially with the hole. Lubricant should be used according to the type of metal being cut, e.g. a light mineral oil is generally recommended for tapping light alloys.

3.2.3   **Thread Gauging.** After the insert thread has been cut it should be cleaned of all swarf and foreign matter. The thread should then be checked with a special GO/ NO GO plug gauge provided by the insert manufacturer to ensure that the thread is satisfactory. Any thread imperfections indicated by tightness of the GO gauge should be removed by further use of the original tap or, if this is ineffective, by use of a new tap.

3.2.4   **Fitting the Insert.** An insert should be screwed into the tapped hole by the use of either an inserting key or an inserting tool of the prewind type (see Figure 3), depending upon which is recommended for the particular insert. A different sized key or tool is provided for each size of insert.
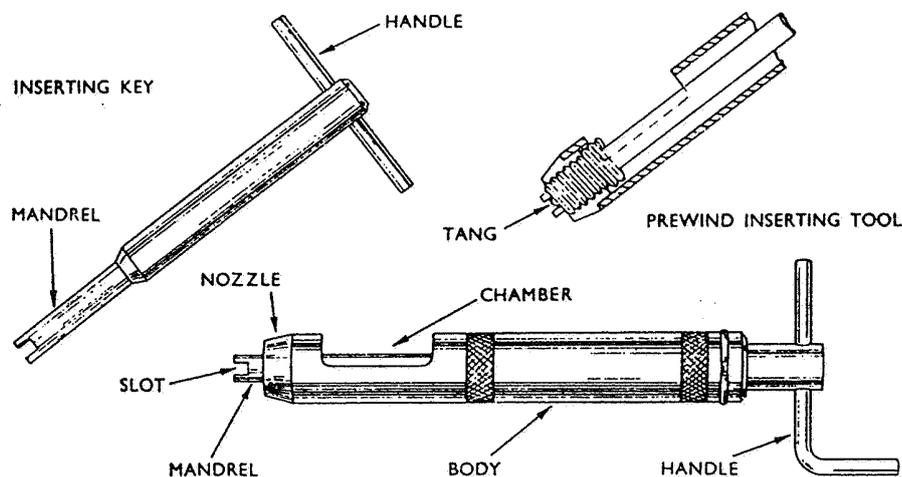

Figure 3 INSERTING KEY AND PREWIND INSERTING TOOL

(a)   The inserting key should be used by sliding the insert onto it so that the tang is engaged in the driving slot at its forward end; the assembly should then be applied to the tapped hole, compressing the insert downwards with the thumb and fore-finger of one hand while turning the key with the other hand; no downward pressure should be applied on the key. The insert will wind into the thread and should be installed so that the outer end of the insert is at least half a pitch below the surface of the component.

(b)   When a prewind tool is used the insert should be placed in the chamber with the tang towards the nozzle and the mandrel pushed forward through the insert to engage the tang in the slot. The mandrel should be rotated clockwise anu pushed gently forward to engage the insert coil in the nozzle threads, rotation being continued until the insert is about to emerge from the outer end of the nozzle. The tool should then be placed squarely over the tapped hole and the handle rotated to transfer the insert from the tool into the tapped hole; no forward pressure should be used.

(c) Unless otherwise stated, inserts should be installed so that the outer coil is at least half a pitch below the component surface.

(d) Absolute cleanliness of the tapped hole and freedom from burrs is essential to prevent distortion of an insert. When jointing compound or anti-corrosive compounds are specified, they should be applied strictly according to the relevant instructions and surplus compound should be removed as specified after installing the insert.

3.2.5 **Removal of the Tang.** It is not always necessary to remove the tang of a wire thread insert, but removal may be specified in some cases for screw clearance or product appearance, both in blind holes and through holes. A tang in a through hole is removed by use of the inserting key used as a punch, with the tang outside the engaging slot, or by use of a special punch (Figure 4). A sharp blow with a hammer on the key or punch will fracture the wire at the notch where the tang joins the coil. To remove the tang from an insert fitted in a blind hole, long round-nosed pliers are required; the tang should be bent backwards and forwards through the insert bore until it fractures at the notch and can be removed.
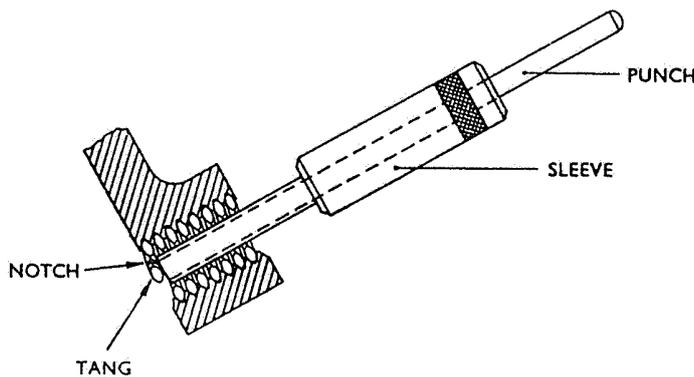

Figure 4 TANG BREAK-OFF PUNCH

3.3 **Removal of Inserts.** Under normal circumstances, particularly when fitting instructions have been carefully carried out, the removal of inserts should be unnecessary. However, if an insert has to be removed because of bad fitting, damage or wear, this can be done by bending the top coil inwards to form a rough tang and unscrewing the insert with the insertion tool or a pair of pliers. Some manufacturers recommend the use of a tapered left-hand tap of appropriate size, which grips the top coils internally and unwinds the insert when rotated. Other manufacturers provide a range of extractor tools which are fitted with hardened and tempered blades (Figure 5); the blade will bite into the inner surface of the insert, which can then be unscrewed. After removal of an insert, the threads in the hole should be carefully examined for damage before fitting a new insert.
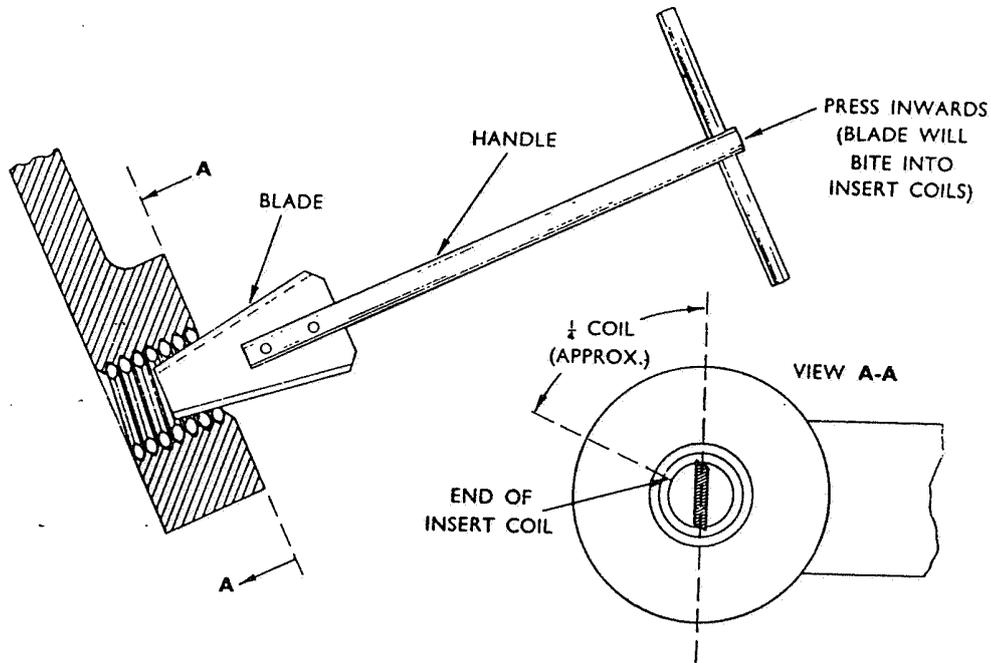
Figure 5 TYPICAL EXTRACTOR TOOL

4   THIN WALL INSERTS   A thin wall insert (Figure 6), comprises a tube with threads formed on its internal and external surfaces. These inserts do not exert any outward radial pressure on the threaded holes into which they fit, and are locked in position by driving a number of pre-assembled keys into slots round the outer surface of the insert, by swaging a knurled outer portion into a counterbore, or by fitting a separate serrated locking ring after the insert is installed. Inserts are supplied in a variety of types, materials and finishes, and the internal thread may be non-locking, or self-locking by means of a deformed thread or nylon insert; inserts are identified and ordered by manufacturer's part numbers.

4.1   Key-locked Inserts

4.1.1   Drilling and Tapping. Tables provided by the manufacturer give details of the drill diameters, hole depths and taps to be used to form the threaded holes for each size of insert; with key-locked inserts the outer edges of the holes should also be countersunk to a specified depth. When preparing the threaded holes, the general precautions outlined in paragraph 3.2.1 and 3.2.2 should be carefully followed.

4.1.2   Installation. The inserts may be screwed in by hand or by the use of an installation tool (Figure 7), until the keys butt against the component surface, this being the correct installed depth. The keys are then driven into place by hammer blows or a press, using the installation tool as a punch. When the keys are flush with the top of the insert, installation is complete.
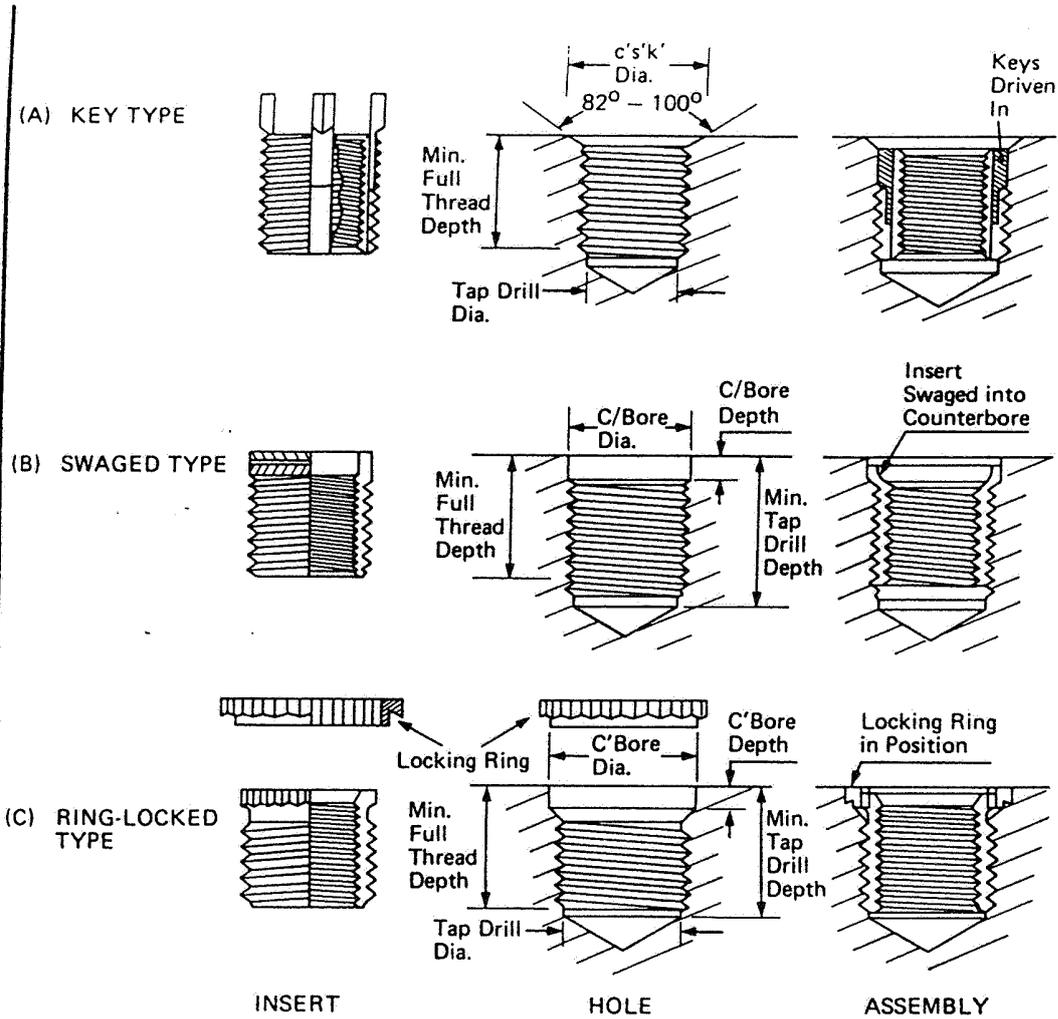
Figure 6 THIN WALL INSERTS

4.1.3 **Removal.** Should it become necessary to remove a key-locked insert, this may be done as follows:—

(a) Drill out the insert to a diameter equal to the distance between two opposing key slots and to the depth of the key heads.

(ʰ) Deflect the keys inward with a punch and break them off.

(c) Remove the insert with a standard extractor.

(d) After removal of the insert, the threads on the part should be inspected for damage. If the threads are undamaged a replacement insert of the same size may be fitted, but care should be taken to ensure that the keys are located in different places from the original keys.

Hammer
Blows

Tool ——

Insert ——

(A) INSTALLATION
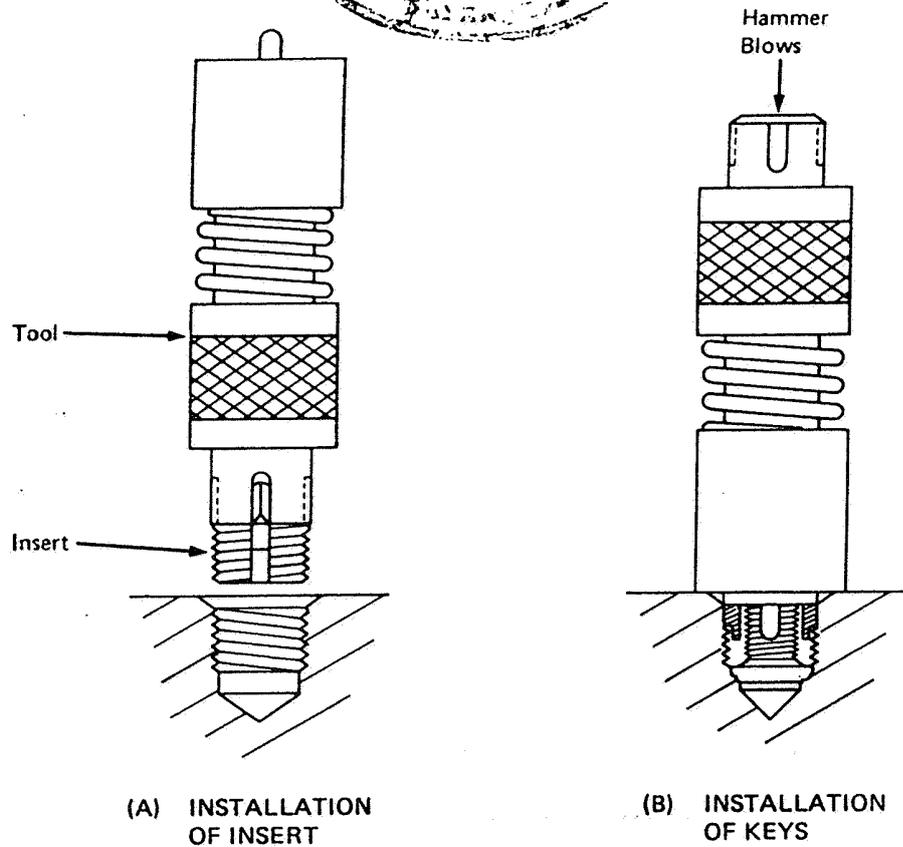OF INSERT

(B) INSTALLATION
OF KEYS

Figure 7 INSTALLATION TOOL (KEY-LOCKED INSERTS)

4.2 Swaged Inserts

4.2.1 Drilling and Tapping. The holes for these inserts must be drilled with a special drill and counterboring tool supplied by the insert manufacturer for each size of insert. Holes should be drilled so that the counterbore depth is as specified in the relevant tables for the insert concerned, and the precautions outlined in paragraph 3.2.1. should be observed. The hole should be tapped using a tap of the relevant size, to the drawing requirements. All swarf should then be removed and the thread inspected.

NOTE: The drill/counterboring tool has a drill portion of sufficient length to permit regrinding a number of times before the minimum drilling depth is reached. It is important to check the length of the drill portion when drilling blind holes, to prevent breaking through the lower surface.

4.2.2 Installation. A special insertion tool is used for installing these inserts (Figure 8). The insert internal thread is deformed in such a way as to permit the insertion of the hexagonal driver (unified threads), or has three axial grooves (metric threads), so that the insert can be rotated. The insert should be screwed into the threaded hole until it

is the specified distance below the component surface. The insert is swaged by hammer blows on the end of the tool and installation is complete when the stop washer face contacts the component surface.

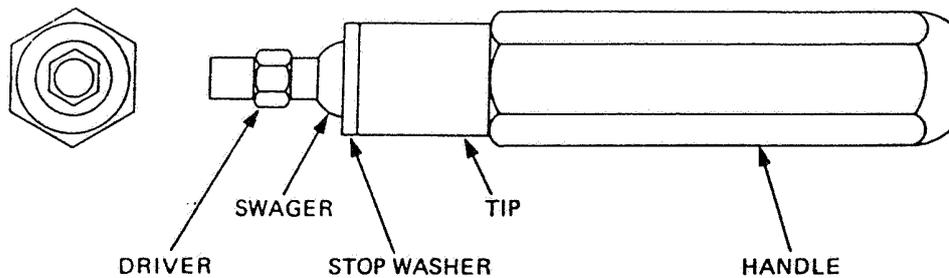NOTE: Insertion tools for the larger sizes of inserts are power operated.

Figure 8 TYPICAL INSERTION TOOL (SWAGED INSERTS)

4.2.3 **Removal.** Where necessary, swaged inserts may be removed in the following way:—

    (a) Using a drill of the relevant diameter, drill the insert to the depth specified in the manufacturer's tables to separate the swaged portion of the insert.

    (b) Carefully remove the swaged portion with a scriber or similar tool.

    (c) Using the installation tool, unscrew and remove the threaded part of the insert.

    (d) The thread and counterbore should be checked for size and damage. If satisfactory, a replacement insert of the same size may be fitted.

4.3 **Ring-locked Inserts**

4.3.1 **Drilling and Tapping.** The holes for these inserts should be drilled and counterbored in a similar way to those for swaged inserts. Similar drilling/counterboring tools should be used and the dimensions of the holes should conform to those listed in the tables provided by the manufacturer; the precautions outlined in paragraph 3.2.1 should also be observed. The holes should be tapped using a tap of the specified size, to drawing requirements. All swarf should then be removed and the thread should be inspected.

4.3.2 **Installation.** A special tool is used to install these inserts (Figure 9), the bore having serrations which fit the serrations of one particular size of insert. The insert should be screwed into the prepared hole until its upper surface is 0·25 to 0·5 mm (0·010 to 0·020 in) below the component surface. The locking ring should then be placed over the insert, so that the inner serrations engage those of the insert. Installation is completed by fitting the drive tool (Figure 9) into the locking ring (ensuring that it is square to the component surface), and hammering the end of the tool so that the outer serrations on the locking ring bite into the material surrounding the counterbore. The installed locking ring should be flush with the surface of the component.

Serrations

(A)   INSERTION TOOL   (B)   LOCKING RING DRIVE TOOL
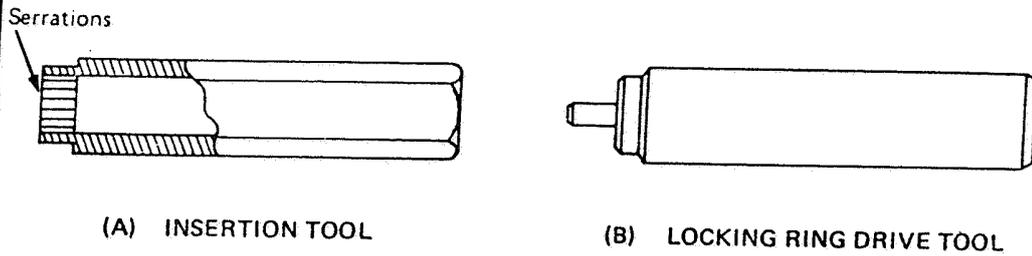
Figure 9 TOOLS FOR RING-LOCKED INSERTS

4.3.3   Removal.   When necessary, ring-locked inserts may be removed in the following way:—

(a)   Drill out the insert to the depth of the counterbore, using a drill of the diameter specified in the tables provided by the manufacturer.

(b)   Remove the insert by use of a standard stud extractor or a left-hand threaded tap of suitable size.

(c)   If necessary, use a punch to separate and remove the remaining portion of the locking ring.

(d)   Provided the hole thread is not damaged, a replacement insert and locking ring of the same size may be fitted.

BL/6-24

Issue 2.

16th May, 1975.

BASIC

ENGINEERING PRACTICES AND PROCESSES

CABLE—SPLICING AND SWAGING

1   INTRODUCTION   This Leaflet gives guidance on the recommended procedures for splicing and swaging the cable used in aircraft control systems. The methods by which completed cable assemblies may be identified are described in Leaflet BL/2-1.

2   CABLE

2.1   The cable used in British aircraft control systems is preformed, and complies with British Standards (BS) Specifications W9, W11, W12 or W13, or with American Specification MIL-W-83420 (formerly MIL-W-1511 and MIL-L-5424). Preforming is a process in which each individual strand is formed into the shape it will take up in the completed cable. This makes the cable more flexible, easier to splice, and more resistant to kinking. Preformed cable will not unravel; also, if a wire in a preformed cable should break, the broken wire will lie flat, and, therefore, be less likely to prevent the cable from passing round pulleys and through fairleads.

2.2   The construction of a cable is determined by the number of strands it contains, and by the number of individual wires in each strand. For example, a cable designated 7×19, consists of 7 strands, each strand containing 19 wires. Wires are wound round a king wire in one or two layers, and strands are generally wound round a core strand in one layer, the direction of winding being stipulated in the relevant specification. The two most common forms of construction are illustrated in Figure 1, and the construction of the various sizes of cable is included in Tables 1 and 2.
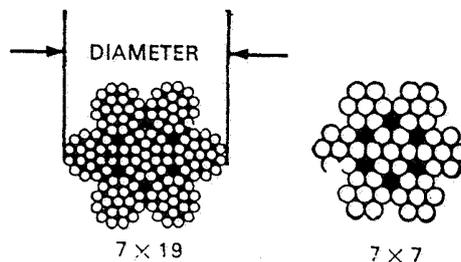

Figure 1   STEEL WIRE CABLE

1

2.3 Preformed cable is manufactured from either galvanised carbon steel (BS W9 and W12, and American Standard MIL-W-83420, Composition A) or corrosion resisting steel (BS W11 and W13, and American Standard MIL-W-83420, Composition B), and is impregnated with friction preventive lubricant during manufacture. The American specification also provides for a range of nylon-covered cable. Non-preformed single strand cable may be found on some aircraft, but will normally only be used for relatively unimportant systems. Tables 1 and 2 list the more common sizes of cable according to the method of classification.

TABLE 1

CABLE CLASSIFIED BY BREAKING LOAD IN HUNDREDWEIGHTS

Minimum breaking load (cwtf)	Construction	Maximum diameter of cable (in)	
		BS W9	BS W11
3	4×7	0·065	0·065
5	7×7	0·08	0·08
10	7×14	0·12	0·12
15	7×19	0·15	0·15
20	7×19	0·16	0·16
25	7×19	0·18	0·18
30	7×19	—	0·21
35	7×19	0·21	—
40	7×19	—	0·24
45	7×19	0·24	—
55	7×19	—	0·27
60	7×19	0·27	—

TABLE 2

CABLE CLASSIFIED BY NOMINAL DIAMETER

Nominal diameter of cable		Construction	Minimum breaking load*		
			Carbon steel	CR steel	
(in)	(mm)		MIL-W-83420 type A and BS W12 (lbf)	MIL-W-83420 type B (lbf)	BS W13 (kN)
1/16	1·6	7×7†	480	480	2·15
3/32	2·4	7×7†‡	920	920	4·10
1/8	3·2	7×19	2000	1760	7·85
5/32	4·0	7×19	2800	2400	10·70
3/16	4·8	7×19	4200	3700	16·50
7/32	5·6	7×19	5600	5000	22·25
1/4	6·4	7×19	7000	6400	28·40

* The breaking loads listed are those quoted in the current issues of the specifications. 1 lbf = 4·448 N.
† 1/16 in and 3/32 in cable to specification MIL-W-83420 may also be of 7 × 19 construction.
‡ 2·4 mm cable to BS W13 may also be of 7 × 19 construction.

3   HANDLING OF CABLE   Cable may be permanently damaged, or its working life may be considerably curtailed, by careless handling and unwinding.   Care is necessary to prevent the cable from forming itself into a loop, which, if pulled tight, could produce a kink.   A kink is shown by the core strand leaving the centre of the rope, and lying between the outer strands or protruding in the form of a small loop.

3.1   Cable should always be stored on suitably designed reels.   The diameter of the reel barrel should be at least forty times the cable diameter.   British Standards stipulate that reels should be made from a wood which will not corrode the cable, and that interior surfaces should be lined with an inert waterproof material.   Precautions should also be taken to protect the cable from grit and moisture, and from damage in transit.

3.2   To remove cable from a reel, a spindle should be placed through the centre of the reel, and supported in a suitable stand.   Cable may then be removed by pulling the free end in line with the reel, allowing the reel to rotate.   Cable should not be unwound by paying off loose coils, or by pulling the cable away from a stationary reel laid on its side.

3.3   When a long length of cable has been cut from a reel, and it is necessary to coil the cut piece, the coil diameter should be at least 50 times the cable diameter, with a minimum diameter of 150 mm (6 in).   Care must be taken to prevent dust, grit and moisture, from coming into contact with the coiled cable.

-3.4   The ends of stored cable are whipped to prevent fraying, and, if a length has been cut from the reel, the remaining free end should be whipped.

3.5   When a coil is being unwound, the coil should be rotated so that the cable is paid out in a straight line.

3.6   **Cutting Cable.**   Cable should always be cut using mechanical methods.   Cable cutters or heavy duty pliers should normally be used, but alternatively, the cable may be laid on an anvil and cut with a sharp chisel and hammer blows.   Cable should not be cut by flame.   If a non-preformed cable is being cut, it should be whipped with waxed cord on both sides of the cut, prior to being cut.   With a preformed cable it will normally only be necessary to bind the cable temporarily with masking tape.

4   SWAGING   Swaging is an operation in which a metallic end fitting is secured to the end of a cable by plastic deformation of the hollow shank of the end fitting.   The end of the cable is inserted into the hollow shank of the fitting, and the shank is then squeezed in a swaging machine, so that it grips the cable.   This is the most satisfactory method of attaching an end fitting to a cable, and it can be expected to provide a cable assembly at least as strong as the cable itself.   Most transport aircraft. and a large number of light aircraft, use control cables manufactured in this way.

4.1   Manufacturers of cable assemblies normally swage with rotary machines.   In these machines the shank of the end fitting is placed between suitable dies, and is subjected to a series of forming blows, which reduce the shank diameter, and lock the fitting to the cable.

4.2   Swaging may also be carried out on a portable swaging machine, which squeezes the shank of the end fitting between dies.   The use of a portable swaging machine is discussed in paragraph 5.

4.3   A range of swaged end fittings is covered by BS specifications, but some older types of aircraft may be fitted with cable assemblies containing components complying with SBAC AS specifications which are now obsolete.   When it is necessary to make up control cables for these aircraft, approval may be granted for the use of equivalent BS parts, but the complete cable control run may have to be changed.

4.4   BS specifications provide a range of fittings which prevent incorrect assembly of control cables.   Turnbarrels and tension rods are designed to connect to screwed end and tapped end swaged fittings respectively.   For each size of cable two alternative sizes of end fittings are available, and each size is provided with either a left or right hand thread.   Swaged fittings can thus be arranged to ensure that a control run cannot be incorrectly assembled.

5   PORTABLE SWAGING MACHINES   Although unserviceable cables are usually replaced by cables which have been manufactured, pre-stretched and proof loaded in accordance with an approved drawing, and which have been supplied by the aircraft manufacturer, occasions may arise when such a cable is not available, and it is necessary to make up a cable assembly locally.   Provided that the process is permitted, and that the appropriate drawings or instructions are available, end fittings may be swaged onto a cable using a hand-operated machine such as the one illustrated in Figure 2.

NOTE: The proficiency of a person engaged in the manufacture of locally made cable assemblies, should be established by trial swagings on test cables, which should be tested to the satisfaction of the supervising inspector.   The effectiveness of subsequent swaging operations should be checked periodically, by selecting a representative sample, and subjecting it to a tensile test to destruction.
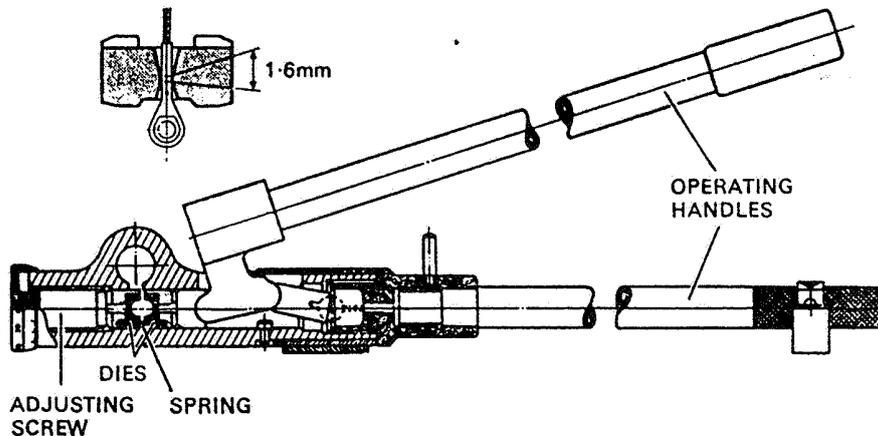
Figure 2   PORTABLE SWAGING MACHINE

5.1   A portable swaging machine is supplied with sets of dies for swaging various types of fittings to cables of appropriate size, and with gauges for checking shank diameter after swaging.   It is normally mounted on a wooden block, and should be used on a low bench so that adequate pressure can be applied to the lever.   An adjusting screw in the head of the machine alters the amount of squeeze applied, and a graduated scale permits accurate setting.

5.2 Swaging Procedure. The procedure outlined below is applicable when a machine of the type illustrated in Figure 2 is used. Where use of a different type of machine is authorised, the procedure is similar, except for the setting and operation of the machine, which in all cases should be in accordance with the manufacturer's instructions.

(a) Ensure that the new cable is the correct size, by using a suitable gauge, or by measuring the diameter as indicated in Figure 1.

(b) Cut the cable to the length specified on the drawing (see paragraph 3.6), and ensure that the ends are clean and square.

  NOTE: Swaging elongates the end fitting, and an allowance for this must be made when cutting the cable. The allowance to be made should be stated on the appropriate drawing or specification.

(c) Select the appropriate end fitting, and clean it by immersing it in solvent; then shake, and wipe dry.

(d) Assemble the end fitting to drawing requirements. With drilled-through fittings, the cable end must pass the inspection hole, but be clear of the locking wire hole. For fittings with a blind hole, the cable must bottom in the hole. Bottoming may be checked by marking the cable with paint, at a distance from the end equal to the depth of the hole, and by ensuring that the paint mark reaches the fitting when the cable is inserted. When the cable and the fitting are correctly assembled, they should both be lightly lubricated.

(e) Fit the dies for the particular end fitting in the swaging machine, open the handles of the machine, and unscrew the adjuster until the end fitting can be placed in the dies. With the end fitting centred in the die recess, close the handles fully, and screw in the adjuster until the dies grip the fitting. Open the handles, and tighten the adjuster by the amount of squeeze required for the particular end fitting; normally this should be approximately 0·18 mm (0·007 in).

(f) Place the fitting in the position shown in the small sketch in Figure 2, so as to swage to within approximately 1·2 mm (0·050 in) from the inspection hole. Check that the cable is in the correct position (see (d)), and operate the handles to squeeze the fitting.

(g) Release the handles and rotate the fitting through approximately 50°. Repeat the squeezing and rotating until the fitting has been moved one full turn.

(h) Withdraw the end fitting from the dies 1·6 mm ($\frac{1}{16}$ in) and repeat the cycle of squeezing and turning.

(j) Continue operation until the whole shank is swaged. Check the diameter of the shank, and if it has not been reduced to the size required by the appropriate drawing or specification, re-set the adjusting screw and repeat the swaging operation.

(k) When the shank of the end fitting has been reduced to the correct diameter, remove and inspect the fitting (see paragraph 5.3).

(l) Fit the identification device as prescribed in the drawing, and mark it with the cable part number in the prescribed manner (in some cases the part number may be etched directly onto the end fitting). The identification may be in the form of a wired-on tag, as illustrated in Leaflet BL/2-1, or a cylindrical sleeve lightly swaged onto the shank of the end fitting.

(m)Assemble any fittings, such as cable stops, on the cable, and swage on the opposite end fitting.

(n) Dip the end fittings in lanolin, to prevent corrosion resulting from damaged plating, and to exclude moisture.

5.3 **Inspection of Swaged Fittings.** On completion of the swaging operations, the following inspection should be carried out.

(a) Check that the correct combination of cable and fittings has been used.

(b) Re-check the diameter of the swaged shank, using a GO–NOT GO gauge or a micrometer. If the diameter of the fitting is too small, it has been over-swaged, and the cable and the fitting must be rejected. Excessive work hardening of the fitting will cause it to crack, and may also damage the cable.

(c) Check, by means of the inspection hole or paint mark, that the cable is correctly engaged in the end fitting (see paragraph 5.2 (d)).

(d) Check that the swaging operation has not disturbed the lay of the cable, where the cable enters the end fitting.

(e) Ensure that the shank is smooth, parallel, and in line with the head of the fitting, and that the swaged shank length is correct.

(f) Proof load the completed cable assembly in accordance with the appropriate drawing (see also paragraph 8).

(g) Inspect the fittings for cracks using a lens of 10×magnification, or carry out a crack detection test, using magnetic or dye processes, as appropriate.

(h) Check that the cable assembly is the correct length (see paragraph 8.7), and ensure that any required identification marking, including evidence of proof loading, has been carried out, and that any specified protective treatment has been applied.

NOTE: The first swaged fitting in a production batch is usually sectioned after proof loading, so that the interior surface can be examined for cracks. If this check is satisfactory, the settings on the swaging machine should be noted, and used for completion of the batch.

6 **SWAGED SPLICES** A number of proprietary methods are used to secure cable in the form of a loop, which may then be used to attach the cable to a terminal fitting or turnbuckle. The 'Talurit' swaged splice is approved for use on some British aircraft control cables, and is also widely used on ground equipment. The process provides a cable assembly which, when used with cable to BS W9 and W11, has a strength equal to approximately 90% of the breaking strength of the cable. It may only be used to replace cables employing the same type of splice, or hand splices, and must not be used where swaged end fittings were used previously.

6.1 A typical 'Talurit' splice is illustrated in Figure 3. To make this type of splice, the end of the cable is threaded through a ferrule of the appropriate size, looped, and passed back through the ferrule. A thimble is fitted in the loop, and the ferrule is squeezed between swages (dies) in a hand-operated or power-operated press. The metal of the ferrule is extruded between the two parallel lengths of cable, and around the cable strands, and firmly locks the cable without disturbing its lay.

6.2 Ferrules are made in a variety of shapes, sizes and materials. Aluminium alloy ferrules are used with galvanised or tinned carbon steel cable, and copper ferrules are used with corrosion resisting steel cable.
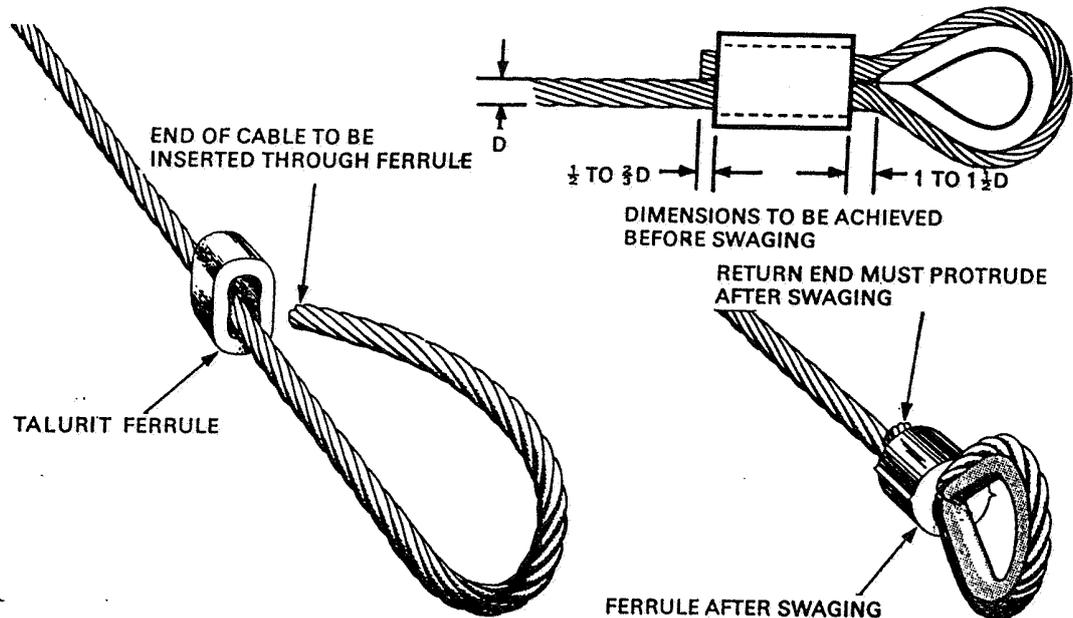
END OF CABLE TO BE
INSERTED THROUGH FERRULE

D

TALURIT FERRULE

½ TO ⅜D

DIMENSIONS TO BE ACHIEVED
BEFORE SWAGING

1 TO 1½D

RETURN END MUST PROTRUDE
AFTER SWAGING

FERRULE AFTER SWAGING

Figure 3   'TALURIT' SWAGED SPLICE

6.3   When making a splice, the proper ferrule should be selected by the code numbers indicated on the appropriate drawing, and the associated swages should be fitted to the press.   The loop and thimble should be adjusted after the swages have closed sufficiently to grip the ferrule; the cable must grip the thimble firmly, and the dimensions indicated in Figure 3, must be obtained before swaging commences.

6.4   The press should be operated until the faces of the swages are touching, then the pressure should be released.   Continuing to apply pressure after the faces have met, may cause damage to the press and swages.   Only one pressing operation is normally required, but some long ferrules are designed for swaging in two separate operations, the swages in these cases being half the length of the ferrule.

6.5   After swaging, surplus metal is visible as a flash along each side of the ferrule, and may be removed with a file.   If no flash has been formed, the sizes of the ferrule and swages should be re-checked, and it should be ascertained that the press is operating correctly.

6.6   The inspection of the finished splice consists of ensuring that the ferrule is correctly formed and not cracked, and of carrying out a proof test, as described in paragraph 8. In some instances a dimensional check is also specified, but, since the swages meet during the pressing operation, little variation in diameter will normally be obtained.

7   MANUAL SPLICING   Although manual splicing may be permitted for some particular applications, it is seldom used on modern aircraft.   It is less strong than either the swaged fitting or the swaged splice, and considerable experience is required in order to consistently obtain splices of adequate strength by this method.   Persons engaged on splicing should be given an initial competency test, and representative samples of their work should be selected periodically, for tensile tests.   Splices on cable manufactured to BS W9 or W11, should not fail at less than 80% of the breaking strength of the cable. There are several methods of splicing, the procedure in each case varying in detail.   A recommended method is given in the following paragraphs, but other methods may be used, provided that the resulting splice is no less strong.

7.1   Splicing Procedure.   The cable is normally spliced around a brass or steel thimble. The identification tag and, where applicable, the turnbuckle eye-end, should be placed on the thimble, and the centre of the thimble bound to the cable.   The cable should be whipped with waxed thread on either side of the thimble, as shown in Figure 5.

NOTE: When cutting the cable to length, approximately 23 cm (9 in) should be allowed for each splice on cable up to 3·2 mm (⅛ in) diameter, and 30 cm (12 in) should be allowed for each splice in cable between 4·0 mm (₃₂ in) and 6·4 mm (¼ in) diameter.
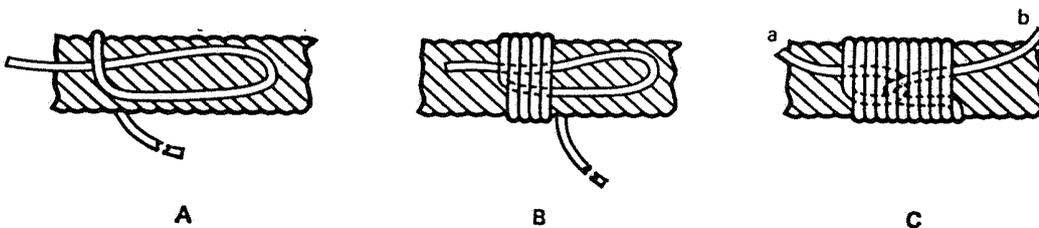
Figure 4 METHOD OF WHIPPING
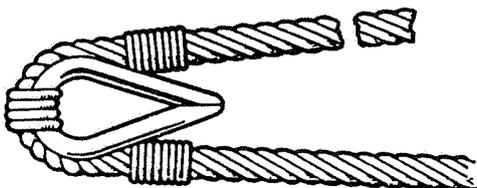
Figure 5
WHIPPING OF CABLE
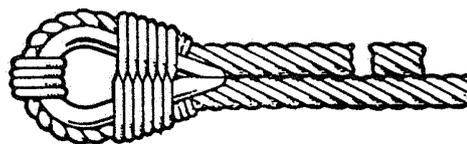
Figure 6
FIGURE-OF-EIGHT BINDING

7.1.1   The method of whipping with a waxed thread is illustrated in Figure 4.   A loop is formed in the thread (sketch A), and binding commenced from the open end of the loop towards the closed end (sketch B).   When a sufficient length has been whipped, end 'b' of the thread is passed through the loop, and secured under the whipping by pulling end 'a' (sketch C); the loose ends are then cut off.

7.1.2 It is essential that the cable and thimble are securely held in a vice, using cable clamps or specially prepared vice blocks, and bound with a figure of eight binding as illustrated in Figure 6. No attempt should be made to splice a cable without fully effective clamping devices.

7.1.3 The strands at the end of the cable should be separated, and whipped or soldered to prevent unlaying of single wires. The cable is then ready for splicing.

NOTE: For descriptive purposes, the six outer strands of the free end of the cable will, in paragraphs 7.1.4 to 7.1.9, be called the 'free strands', and will be numbered 1 to 6, while the outer strands of the main cable will be lettered 'a' to 'f', as shown in Figures 7 and 8.
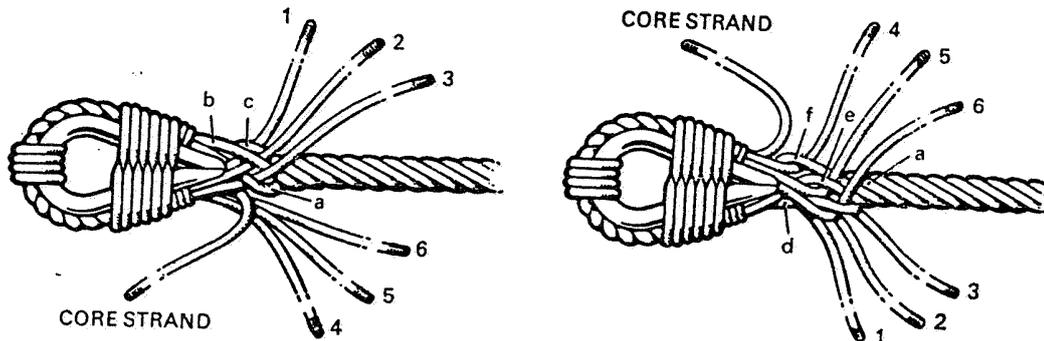
Figure 7
FIRST ROUND OF TUCKS (FRONT)

Figure 8
FIRST ROUND OF TUCKS (REVERSE)

7.1.4 The core strand should be positioned so that there are three free strands on either side, and it should be bent back slightly (see Figure 7).

7.1.5 The first round of tucks should be completed as follows— 3 under a, 1 under b and c, 2 under b (see Figure 7); turn over and tuck 4 under f, 5 under e, and 6 under d (see Figure 8). All free strands should be pulled tight, and then bent back to lock them in position. Care should be taken to avoid disturbing the lay of the cable by excessive pulling.

7.1.6 The core strand should be taken forward and temporarily secured to the main cable with thread, then pulled under a suitable free strand into the centre of the splice. The six free strands should then, in turn, be tucked over a strand and under a strand, e.g. 3 over b and under c, 1 over d and under e. On completing the second round of tucks, the free strands should be pulled tight, and locked back as before.

7.1.7 The third round of tucks should be completed in a similar manner to the second, taking care to bury the core strand in the centre of the splice.

7.1.8 The last full round of tucks, i.e. the fourth, should be the same as the second and third rounds.

7.1.9 The half round of tucks for finishing the splice should be completed by tucking alternate free strands over one, and under two main cable strands. To finish and shape the splice, it should be beaten with a hardwood or rawhide mallet on a hardwood block, while the cable is held taut. The splice should be rotated against the direction of tucking during the beating process. Excessive hammering must be avoided. Free strands should be cut off flush with the splice, and the last one and a half tucks should be whipped with waxed cord. The central binding and figure-of-eight lashing should be removed.

7.1.10 If both ends of the cable are to be spliced, the cable length should be checked before commencing the second splice, so that the completed cable will be of the required length.

7.2 Inspection of Splice

7.2.1 The splice should be inspected for symmetry and appearance. The wires should be close together, and no light should show between the strands or wires. A typical splice is shown in Figure 9.

Figure 9 TYPICAL SPLICED JOINT

7.2.2 The resistance of the splice to bending should be checked. A bad splice will not be resistant to bending, and, when it is bent, the strands and wires will slacken.

7.2.3 The tightness of the thimble in the loop should be checked. The lay of the strands in the cable should be maintained as far as the splice permits, as disturbance in the lay of the cable adjacent to the splice may result in considerable weakening of the cable.

7.2.4 The completed cable must be proof loaded in accordance with paragraph 8.

8   PROOF LOADING

8.1   All cables must be proof loaded after swaging or splicing, by subjecting the cable to a specified load. The purpose of proof loading is both to ensure that the end fittings are satisfactorily installed, and to pre-stretch the cable, i.e. to bed-in the strands and wires. British practice is to load the cable to 50% of its declared minimum breaking strength, and American practice is to load the cable to 60% of its declared minimum breaking strength. If no specific instructions are included in the drawing, then loading of the cable should be carried out in accordance with whichever of these practices is appropriate.

8.2   If end fittings have been fitted or splices have been made on pre-stretched cable, no appreciable elongation will result from proof loading. If the cable was not pre-stretched, it may be expected to elongate slightly, and this should have been taken into consideration on the appropriate drawing.

8.3 A test rig suitable for proof loading cables is illustrated in Figure 10, but other similar methods would be acceptable. The cable should be contained within a trough or other protective structure, to safeguard the operator in the event of failure of the cable. Adaptors should be used to attach the cable end fittings to the test rig, and these should be at least as strong as the cable. Particular care should be taken not to damage the thimbles on spliced cables; packing or bushes should be used to spread the load.

MOVABLE
ANCHORAGE   SPRING BALANCE   CABLE UNDER TEST   SCREW JACK
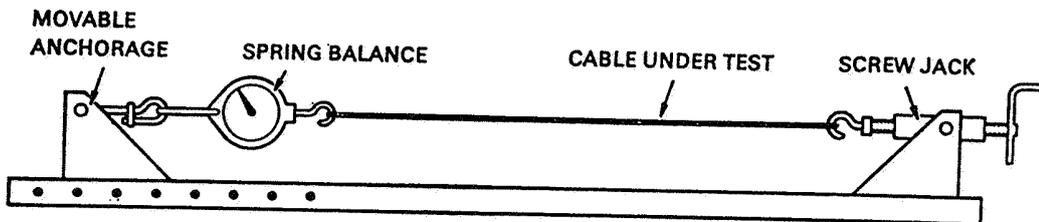
Figure 10 TEST RIG FOR PROOF LOADING

8.4 Before proof loading a cable with swaged end fittings, the cable should be painted with a quick-drying paint at its point of entry into the fittings, and allowed to dry. Cracking of the dried paint during proof loading will indicate slipping of the cable resulting from an unsatisfactory joint.
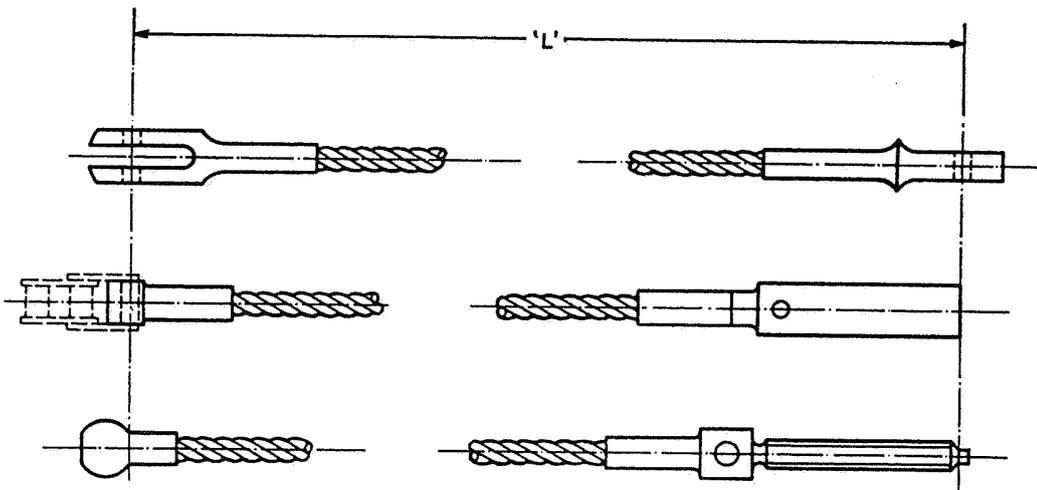
Length 'L' $\pm$1·6 mm ($\frac{1}{16}$ in) up to 2 m (6 ft)

$\pm$3·2 mm ($\frac{1}{8}$ in) over 2 m (6 ft) up to 6 m (20 ft)

$+$9·6 mm ($\frac{3}{8}$ in) $\Big\}$ over 6 m (20 ft)
$-$3·2 mm ($\frac{1}{8}$ in)

Figure 11 LENGTH OF ASSEMBLIES

11

8.5   The test should consist of slowly applying the specified load, maintaining this load for a minimum specified period (normally 30 seconds for swaged fittings, but up to 3 minutes for splices), then releasing it, and carefully examining the cable for signs of pulling out of the end fittings, or stretching of the splice.

8.6   'The end fittings should be checked for cracks using an electro-magnetic method (Leaflet BL/8-5) or, if the fitting is of stainless steel, a penetrant dye process (Leaflet BL/8-2).

8.7   The length of the completed cable assembly should be measured after proof loading. Prior to measurement cables longer than 120 cm (4 ft) should be tensioned with a load of approximately 550 N (112 lbf), or 2% of the breaking load of the cable, whichever is the least.   Figure 11 shows the datum points and tolerances for the measurement of cables fitted with swaged end fittings to British Standards.   Cables with different types of end fittings, or loops, should be measured according to the appropriate drawings or specifications.

BASIC

ENGINEERING PRACTICES AND PROCESSES

FABRIC COVERING

1   INTRODUCTION   This Leaflet gives guidance on the covering of aircraft components with fabric and on the methods employed for repairing and testing such coverings. Guidance on the application of dope to fabric is given in Leaflet BL/6-26.

2   GENERAL   Before the covering of any component is commenced the structure must be inspected, all foreign matter removed, and protective treatments (as prescribed in the relevant drawings) must be applied.   Often it is necessary to install flying control cables, electric cables, fuel tanks and other systems before covering large components, and these should be inspected as necessary and checked for security.   The most suitable conditions for the application of fabric are a room temperature of 16°C to 21°C and a relative humidity of not more than 70%.

NOTE: Information on the method of determining relative humidity is given in Leaflet BL/6-26, and on the testing and inspection of textiles in British Standard F100.

3   MATERIALS   This paragraph describes the natural-fibre materials used in the covering of British-manufactured aircraft.   Foreign fabric-covered aircraft use these or similar materials manufactured in accordance with equivalent specifications.   Information on the use of fabrics produced from man-made fibres for aircraft will be found in paragraph 12.

3.1   Fabrics.   Aircraft fabrics are woven from spun threads or 'yarns'; those running lengthwise are termed the 'warp'; and those running crosswise are termed the 'weft'. The number of yarns per centimetre (inch) varies with different weights of fabric and is not necessarily the same in both warp and weft.   The non-fraying edge of the fabric is termed the 'selvedge'.

3.1.1   When an unsupported fabric cover is required to carry air loads, unbleached linen to British Standard (BS) F1 is normally used, but some aircraft have coverings of cotton fabric complying with BS F8, BS F57, BS F116 or DTD 575.

3.1.2   A light cotton fabric complying with BS F114 (referred to as Madapollam) is generally used for covering wooden surfaces.   This acts as a key to the doping scheme, giving added strength and improving surface finish.

3.2   T_pes.   Linen tapes complying with BS F1 and cotton tapes complying with BS F8 are available in various widths for covering leading edges, trailing edges and ribs, and for repair work.   The materials are supplied with serrated edges, as illustrated in Figure 2.   Cotton tape complying with BS F47 (referred to as 'Egyptian tape') is generally used on those members where chafing may occur between the structure and the fabric (see also paragraph 4.1) and is also used externally to protect the fabric against damage by the stringing cord.

I

3.3 **Thread.** Linen thread complying with BS F34 is normally used. For hand sewing, No. 40 thread (minimum breaking strength 3 kg (7 lb)) used double, or No. 18 thread (minimum breaking strength 7·25 kg (16 lb)) used single, are suitable. For machine sewing, No. 30 thread (minimum breaking strength 4·5 kg (10 lb)) or No. 40 thread is used.

3.4 **Stringing.** Flax cordage complying with BS F35 or braided nylon cord (coreless) complying with DTD 786 is normally used.

3.5 **Eyeleted Fuselage Webbing.** On a number of older types of aircraft, cotton webbing braid with hooks, or lacing eyelets and kite cord, are used for securing the fuselage fabric.

3.6 **Storage.** All materials used for fabric covering should be stored at a temperature of about 20°C in dry, clean conditions and away from direct sunlight. When required for use the materials should be inspected for possible flaws (e.g. iron mould discoloration, signs of insect, rodent, or other damage) and any affected parts rejected.

4 **PREPARATION OF STRUCTURE** The structure to be covered should be inspected as outlined in paragraph 2. All corners or edges and any projections such as bolts or screw heads likely to chafe the fabric must be covered with tape. Where serious chafing may occur and a strong reinforcement is required, a canvas or leather patch may be sewn to a fabric patch, then doped into position.

4.1 In order to prevent dope from reacting with any protective treatment, and to prevent fabric from adhering to wooden structure, all aerofoil members which will be in contact with the fabric are normally covered with adhesive cellulose or aluminium tape, or painted with dope-resistant white paint. Exceptions to this requirement are discussed in paragraphs 7.3, 7.4 and 12.1.

4.2 On some aircraft, which have a tubular metal fuselage frame, the fuselage shape is made up with wooden formers attached directly to the main framework, and to these wooden formers are secured light longitudinal members onto which the fabric covering is doped. This secondary structure must be inspected for security, and any sharp edges removed with fine glass paper.

4.3 Where stringing is likely to be chafed by parts of the structure, protection should be provided by wrapping such parts with cotton tape. Before the tape is applied the structure should be treated with varnish to protect it from corrosion should the tape become wet.

4.4 Internal controls and cables should be tightened to assume their normal positions, and secured at the root rib. Their location should be noted so that stringing pitch can be selected to avoid chafing.

5 **COVERING METHODS** An aircraft fabric may be fitted with the warp or weft running at 45° to the slipstream, or in line with the slipstream. The former (bias) method is generally considered to be stronger and more resistant to tearing, but the latter method is used on most light aircraft. The two methods used to re-cover an aircraft are outlined in paragraphs 5.1 and 5.2, but the method used in a particular instance should follow that of the original manufacture unless otherwise approved.

5.1   **Prefabricated Envelopes.** A number of manufacturers produce fabric envelopes for re-covering various models of aircraft. Separate envelopes are made up from patterns for the mainplanes, fuselage, tailplane, fin and flying control surfaces, and greatly simplify the task of re-covering. The envelopes are made loose enough to facilitate slipping them over the structure, and to achieve the proper tautness after doping.

5.1.1   **Mainplanes.** The envelope is drawn over the wing tip and gradually worked down over the mainplane, generally keeping the spanwise seam in line with the trailing edge. When the cover is located it is secured (by stitching, cementing, or retaining strip) to the inboard end of the mainplane, any necessary openings for cables, struts, tank caps, etc., are cut, and stringing is applied as necessary (paragraph 6).

5.1.2   **Fuselage.** The fin and fuselage envelopes are often supplied separately, and in some cases the fuselage envelope is open, or partially open, at the bottom, to simplify fitting. The fin envelope is usually fitted first, then the fuselage envelope is stretched forwards over the fuselage and secured in the same way as the original fabric. The cover is usually cemented or doped to the fuselage formers (paragraph 4).

5.1.3   **Control Surfaces.** Control surface envelopes are usually left open at the hinge line, where they are secured by cementing, doping or stitching.

5.2   **"Blanket" Method of Covering.** With this method a bolt of fabric is used, and covers are made-up on the site of the aircraft, lengths of fabric, or a number of lengths joined side-by-side, being used to cover the aircraft structure.

5.2.1   **Mainplanes and Tailplanes.** The cover is normally made-up from lengths of fabric machine-stitched together side-by-side. This is laid round the surface, starting and finishing at the trailing edge, and joined by hand stitching as shown in Figure 3. On some aircraft with light alloy structure, hand stitching is dispensed with, the cover edges being wrapped round the tip and trailing edge, and doped into position. The cover is then attached to the ribs by stringing (paragraph 6).

5.2.2   **Fuselage.** A number of different methods are used to attach fabric to the fuselage; the more common being as described in paragraph 4.2. The fabric is not normally attached in one piece, but usually consists of several pieces (sides, top and bottom, for example) which are doped separately onto the frame, or sewn together at their edges. Joins or seams are covered with doped-on tape. Since the air loads on the fuselage are not as great as on the mainplanes, it is not usual to employ stringing, although it may be specified in some instances.

5.2.3   **Control Surfaces.** These are covered in a similar way to the mainplanes and usually require stringing. The fabric is normally folded round the hinge line, since this is usually straight, and sewn together round the remaining contour of the surface.

6   SEAMS, STITCHES AND STRINGING

6.1   **Seams.** The seams in the fabric covering should be either parallel to the fore-and-aft line of the aircraft or on a bias, depending on the covering method used (paragraph 5). With the exception of trailing edge or leading edge joints (where such action cannot be avoided) seams should never be made at right angles to the direction of airflow. Two types of machined seams are employed, i.e. the balloon seam and the lap seam.

6.1.1 The Balloon Seam. The balloon seam, sometimes referred to as the 'French fell', is normally specified for all fabric joints and is illustrated in Figure 1. To make the seam, the edges of the fabric are folded back 16 mm (0·625 in) and are then fitted into each other as shown, tacked together, and then machine sewn with four stitches per centimetre (nine stitches per inch) in two parallel lines 9 mm (0·375 in) apart and 3 mm (0·125 in) from either edge. After completion, the seam should be examined over a strong electric light (preferably a light-box) to ensure that the inside edges of the fabric have not been missed during sewing.

STITCHING

3mm ◄──── 9mm ────► 3mm
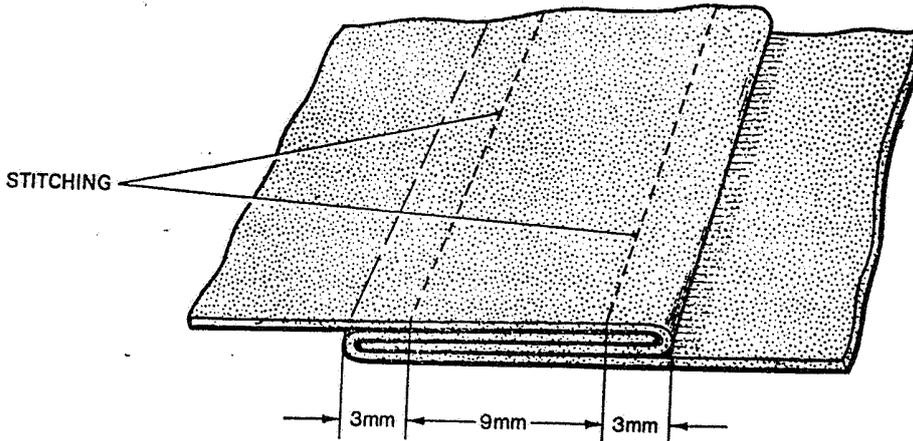
Figure 1 BALLOON SEAM

6.1.2 The Lap Seam. The lap seam, illustrated in Figure 2, should only be used when specified by the manufacturer. Unless the selvedges are present, the edges of the fabric should be serrated with 'pinking' shears. The edges should overlap each other by 31 mm (1·25 in) and should be machine sewn with four stitches per centimetre (nine stitches per inch), the stitch lines being 12 mm (0·5 in) apart and 9 mm (0·375 in) from the edges. After stitching, a 75 mm (3 in) wide serrated-edge fabric strip should be doped in position.

75 mm
COVERING
STRIP

9 mm

31 mm   9 mm

Figure 2 LAP SEAM

4
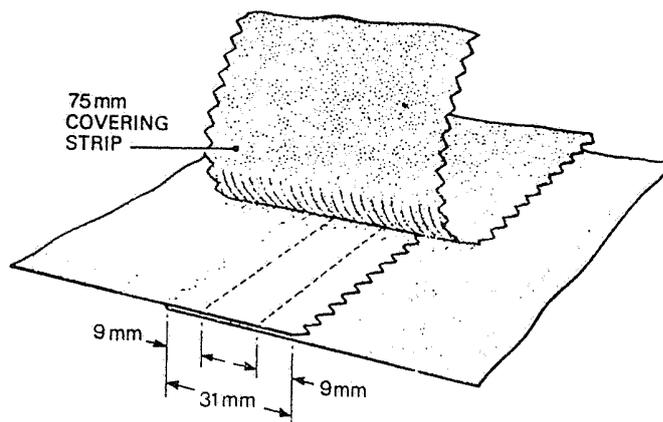
6.2 **Hand Sewing.** Apart from the herring-bone stitch (Figure 9) and the boot stitch (Figure 13), which are used for repair work and are described in paragraph 10, the only other stitches used are the overhand stitch (sometimes referred to as the 'trailing-edge' stitch) and the lock stitch. The overhand stitch is used for trailing edges, wing tips, wing root ends, and wherever a sudden change of section occurs.

6.2.1 **Overhand Stitch.** Sufficient excess fabric should be allowed for turning under before sewing is commenced; a 12 mm (0·5 in) turn-under is usually sufficient. An even gap of about 6 mm (0·25 in) (usually) should be allowed for pulling up the two edges to obtain the correct fabric tension, but this figure can only be determined finally by experience of the work in hand.

OVERHAND STITCHES

TRAILING-EDGE MEMBER
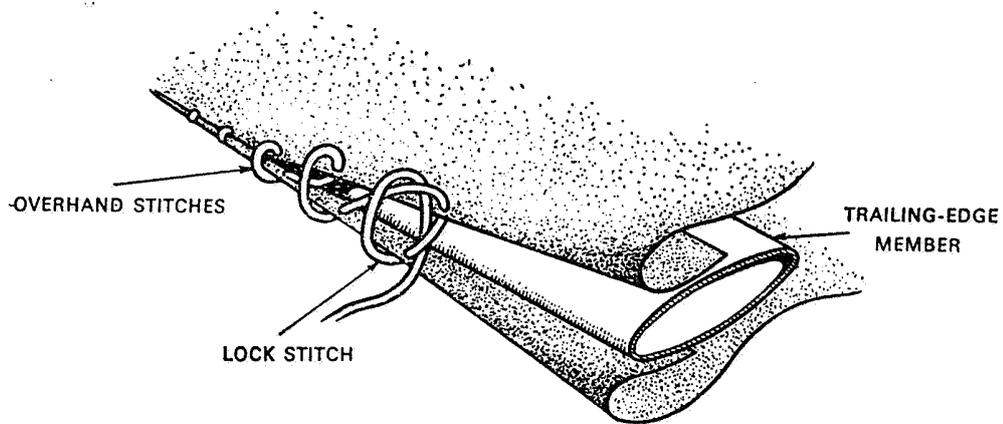
LOCK STITCH

Figure 3 OVERHAND STITCH

6.2.2 The sewing should follow the contour of the component evenly to ensure a good finish after doping. The number of stitches should be three per centimetre (eight per inch), a lock stitch being included approximately every 50 mm (2 in). Overhand stitching is illustrated in Figure 3, the lock stitch being shown as the last stitch before the stitching is pulled tight.

6.3 **Use of Beeswax.** All threads used for hand sewing, and all cord used for stringing (when not pre-waxed), should be given a liberal coating of beeswax. This protects the thread, facilitates sewing, and reduces the likelihood of damaging the fabric or enlarging the stitch holes.

6.4 **Stringing.** Flax cord complying with BS F35 is normally used for stringing purposes and is generally applied in single strands as shown in Figure 4. As an alternative, but only when approved by the manufacturer, doubled No. 18 thread may be used during repair work.

6.4.1 When the fabric covering of the component has been completed, cotton tape to BS F47 should be stretched centrally over each rib, top and bottom, and stitched into position at the trailing edge.

5
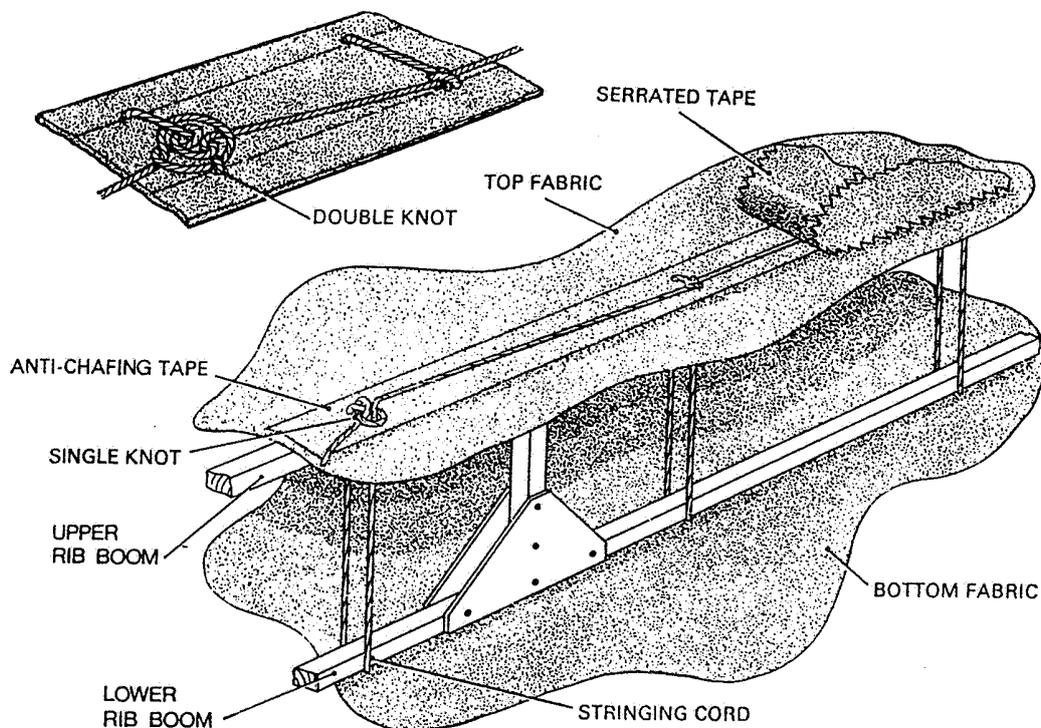
Figure 4 TYPICAL STRINGING

(a) Using a stringing needle and commencing at the top surface, the stringing cord should be passed through the tape and fabric as close to the rib as possible, out through the bottom fabric and tape, round the lower rib boom and back up through both surfaces again. A double knot should be used to secure the first and last stringing loops, and after each 450 mm (18 in). In between, single knots may be used.

(b) The stringing pitch is normally 75 mm (3 in) but in the slipstream area (see paragraph 6.4.4), or on aircraft of more than 910 kg (2000 lb) weight, the pitch is often reduced to 37 mm (1·5 in). Variations from these pitches will be stipulated in the relevant aircraft manuals, and it may be necessary to vary the pitch in order to avoid internal structure or control runs.

(c) When the stringing has been completed a strip of serrated tape, 37 mm (1·5 in) wide, should be doped over the stringing line on both surfaces, care being taken to ensure that no air is trapped under the tape and that the tape is securely attached to the main cover.

NOTE: The knots depicted in Figure 4 are typical but a different type of knot may be specified by the manufacturer.

6.4.2 Boom Stringing. This type of stringing is used on deep aerofoil sections. The procedure is similar to that described above, except that the cord is passed round the rib boom instead of round the entire rib. Top and bottom surfaces are therefore attached separately, and the inside of each boom must be taped to prevent chafing of the stringing cord. Alternate rib and boom stringing is sometimes used on aerofoils of medium depth, i.e. between 150 and 300 mm (6 and 12 in).

6.4.3 Stringing Tension. Care must be taken to ensure that all stringing is maintained at a satisfactory tension and that it is not so tight as to cause distortion of the ribs.

6.4.4 Slipstream Area. For stringing purposes, the slipstream area is considered to be the diameter of the propeller plus one rib on either side. In the case of multi-engined aircraft, the entire gap between the slipstreams, regardless of its width, is also considered to be slipstream area.
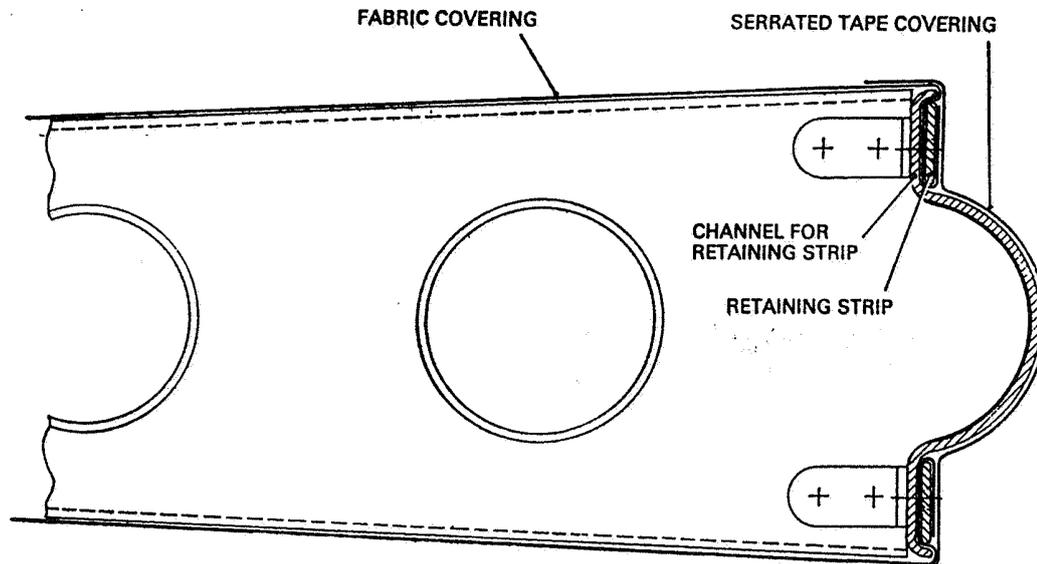
Figure 5 ATTACHMENT OF FABRIC BY STRIP

7   MISCELLANEOUS METHODS OF FABRIC ATTACHMENT   In addition to the standard methods of fabric attachment described in paragraph 6, other methods are sometimes employed, and those most commonly used are outlined below.

7.1   Attachment by Strip. Attachment of the fabric by wrapping it around a light alloy strip or rod which is then secured in a channel or groove is sometimes used with metal structures. This method is illustrated in Figure 5.

7.2 **Special Stringing.** A variation of the method described in paragraph 7.1, used for attaching fabric to metal ribs, and known as 'special stringing' is shown in Figure 6.

CHANNEL ATTACHMENT SCREW
(SCREWS INTO A CAGED NUT
FIXED TO UNDERSIDE OF RIB BOOM)

SERRATED OR FRAYED EDGE
STRIP DOPED ON

TAPE

FABRIC

TAPE

RIB BOOM

ALUMINIUM ALLOY CHANNEL
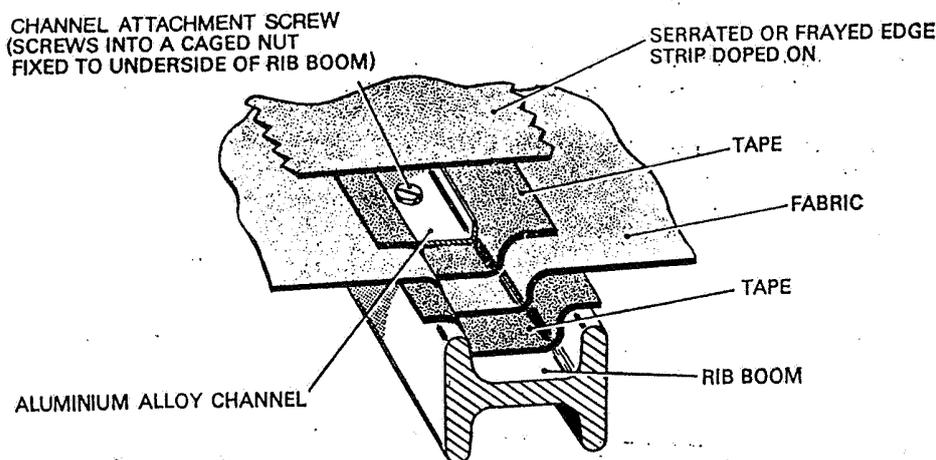
Figure 6 SPECIAL STRINGING

7.3 **Adhesives.** On some small aircraft, where air loads are light, stringing is dispensed with on the wing and tail surfaces and the fabric is attached to the structure by means of a proprietary adhesive. This method produces a much smoother surface on the components and saves time during construction and repair.

7.4 **Attachment of Fabric to Plywood.** Dope is generally used for the attachment of fabric to plywood, but before the fabric is applied, the wood surface should be smoothed with fine glass paper and any cavities, such as those caused by the countersinking for screwheads, filled and allowed to set. The filler area should be reduced to an absolute minimum because of the reduced adhesion of the doped fabric in such areas.

7.4.1 The wooden surface should then be treated with one coat of tautening dope, followed by a further coat after the first one has dried. After the second coat of dope has dried, the fabric should be spread over the wood and stretched evenly to avoid wrinkling. A coat of tautening dope should then be brushed into the fabric sufficiently to ensure good penetration. For this purpose a fabric pad is useful for rubbing in the dope.

7.4.2 After the dope has dried it should be lightly rubbed down using 'wet and dry' rubbing paper Grade 0 or Grade 00, and then the required finishing scheme applied.

7.5 **Attachment of Fabric to Metal Surfaces.** Where a light alloy is used as part of the structure of a mainplane (such as to form the leading edge profile) the fabric is generally doped into position. Alternatively, a thermoplastic adhesive may be used, and guidance on the use of this material may be obtained from the relevant aircraft manuals.

7.5.1 To ensure satisfactory adhesion of the fabric, the metal surfaces should be thoroughly cleaned, and primed with an etch primer.

8   DRAINAGE AND VENTILATION   Drainage and ventilation holes are necessary in fabric-covered components to minimize corrosion of the structure, rotting of the fabric, etc., and, to ensure maximum efficiency, it is important that they should be positioned as prescribed on the relevant drawing.

8.1   Drainage holes are usually positioned in the lower surface of components or wherever entrapment of moisture is possible, but when holes are used for ventilating purposes, e.g. to permit the air pressure inside the component to equalize with the surrounding air at various altitudes, the holes may be located in sheltered positions regardless of drainage qualities.

8.2   **Drainage Eyelets.**   Drainage eyelets are usually oval or circular in shape and are doped on to the surface of the fabric, but in some cases may be secured by stitching through pre-pierced holes in the eyelets before the finishing scheme is applied.

8.3   .**Shielded Eyelets.**   Shielded or shrouded eyelets are sometimes used in special positions to improve either drainage or ventilation.   On marine aircraft they are used to prevent the entry of sea spray.   These special eyelets must only be used in specified positions and must not be used as an alternative to standard eyelets.   It is also important that the shroud is facing in the correct direction, otherwise it will not be fully effective.

NOTE: Inspectors must ensure that drain holes are clear; it is common practice to affix the eyelets at an early stage of doping and to pierce the fabric after the final finish has been applied.

9   INSPECTION PANELS   For inspection and servicing purposes it is essential that access be provided at specified positions in all fabric coverings.   The three methods commonly used are described below.

9.1   **Woods Frames.**   These are light circular or square frames, made from celluloid sheet, which are doped onto the fabric cover at the required positions. The fabric is then cut away from inside the frames and a serrated edged fabric patch doped over the hole as shown in Figure 7.   The disadvantage of this type of panel is that a new patch must be doped on after each inspection, and the finishing scheme re-applied.
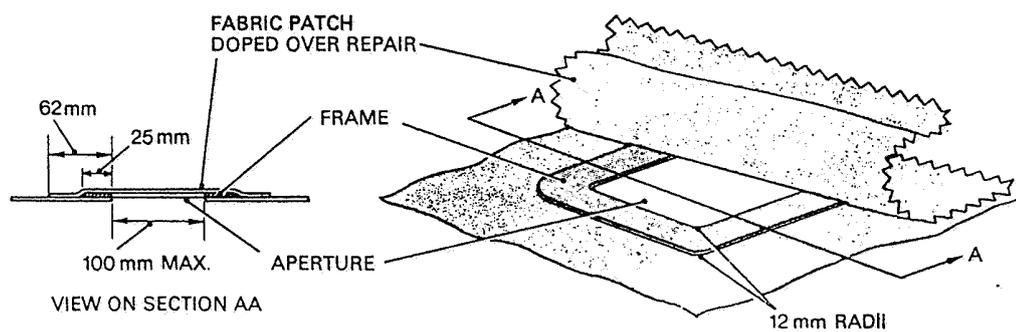
FABRIC PATCH
DOPED OVER REPAIR

62mm
25mm
FRAME
A
100 mm MAX.   APERTURE
A
VIEW ON SECTION AA
12 mm RADII

Figure 7 WOODS FRAME INSPECTION PANEL

9.2   **Zip Panels.** These consist of two zip fasteners sewn into the fabric in the form of a vee, the open ends of each fastener being at the apex of the vee.   This type of access is suitable for positions where frequent inspection or servicing is necessary.   Care should be taken to avoid clogging the zip segments when dope is applied to the fabric.

9.3   **Spring Panels.** A panel particularly suitable for use on light aircraft, the spring panel consists of a circular plastic ring and dished light alloy cover.   The ring is doped into position in the same way as the Woods frame, and the fabric cut away from the inside. By pressing the centre of the cover the dish shape is reversed, allowing the clip to be inserted in the hole; when pressure is released the dish reverts to its normal shape and closes round the plastic ring as shown in Figure 8.

PLASTIC RING   DISHED COVER

FABRIC   CLIP   ACCESS HOLE
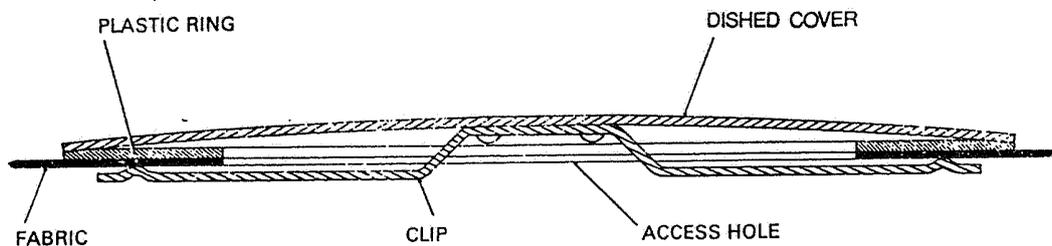
Figure 8 CROSS-SECTION OF SPRING PANEL

10   **REPAIRS TO FABRIC COVERINGS**   If the fabric has been damaged extensively, it is usually impractical and uneconomical to make satisfactory repairs by sewing and patching.   The extent and location of damage to the fabric that may be repaired will be detailed in the repair section of the aircraft manual concerned, but extensive damage is often made good by replacing complete fabric panels.   However, the replacement of large fabric panels, particularly on one side of a component, may lead to distortion of the structure, and it may be advisable to completely re-cover the component.

10.1   Before attempting any repair to the fabric covering, the cause of the damage should be ascertained.   The internal structure should be inspected for loose objects such as stones, remains of birds, insects, etc., and any structural damage made good.   Using thinners, all dope should be removed from the fabric surrounding the damaged area before any stitching is carried out, since doped fabric will tear if anv tension is applied to the repair stitches.

10.2   **Repair of Cuts and Tears.** Cuts and tears in fabric are sometimes caused by stones thrown up by the slipstream or wheels, but more generally result from accidental damage during ground movement or servicing.   Damage may also be caused by bird strikes. Any damaged structure should be made good and fabric repairs carried out according to the type of damage, as detailed in the following paragraphs.

10.2.1   Herring-Bone Stitch. The herring-bone stitch (also known as the 'ladder stitch') should be used for repairing straight cuts or tears which have sound edges. The stitches should be made as shown in Figure 9, with a lock knot every 150 mm (6 in).

(a) There should be a minimum of two stitches to the centimetre (four stitches to the inch) and the stitches should be 6 mm (0·25 in) from the edge of the cut or tear. The thread used should be that described in paragraph 3.3.
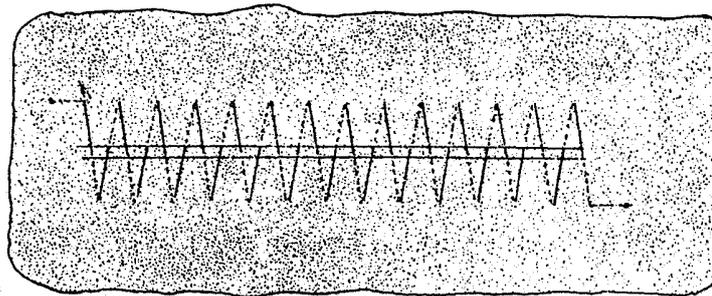
Figure 9 HERRING-BONE STITCH

(b) After the stitching has been completed, 25 mm (1 in) wide serrated tape should be doped over the stitching. A square or rectangular fabric patch should then be doped over the whole repair, ensuring that the edges of the patch are parallel to the warp and weft of the fabric covering, and that they overlap the repair by 37 mm (1·5 in). The original doping scheme should then be restored.

10.2.2   Repairs with Woods Frames. On some aircraft, repairs to cuts and tears with jagged edges, which cannot be stitched as described in the previous paragraphs, can be repaired by using the Woods frame method described for inspection panels in paragraph 9.1. Repairs of up to 50 mm (2 in) square may be made, provided they are clear of seams or attachments by a distance of not less than 50 mm (2 in). The affected area should be cleaned with thinners or acetone and repaired in the following manner:—

(a) The Woods frame should be doped into position surrounding the damaged fabric and, if the frame is of the square type, the edges should be parallel to the weft and warp of the covering. When the dope has dried, the damaged portion of the fabric should be cut out and the aperture covered by a fabric patch as described in paragraph 9.1.

(b) If Woods frames are not readily available they can be made from cellulose sheet 0·8 mm (0·030 in) thick with minimum frame width of 25 mm (1 in); in the case of the square type of frame the minimum corner radii should be 12 mm (0·5 in). In some special cases, aircraft manufacturers use 2 mm plywood complying with British Standard V3 for the manufacture of the frames, in which case it is important to chamfer the outer edges of the frame to blend with the aerofoil contour.

10.2.3 **Repair by Darning.** Irregular holes or jagged tears in fabric may be repaired by darning provided the hole is not more than 50 mm (2 in) wide at any point. The stitches should follow the lines of the warp and weft, and should be closely spaced, as shown in Figure 10. The whole repair should be covered with a serrated fabric patch in the usual way, with an overlap of 37 mm (1·5 in) from the start of the darn.

10.3 **Repair by Insertion.** For damage over 100 mm (4 in) square, insertion repairs are generally used, either of the two methods described below being suitable.

10.3.1 **Normal Insertion Repair**

(a) The damaged area of the fabric should be cut out to form a square or rectangular hole with the edges parallel to the weft and warp. The corners of the hole should then be cut diagonally, to allow a 12 mm (0·5 in) wide edge to be folded under the fabric, and this should be held in position with tacking or hemming stitches.

FABRIC PATCH
DOPED OVER REPAIR
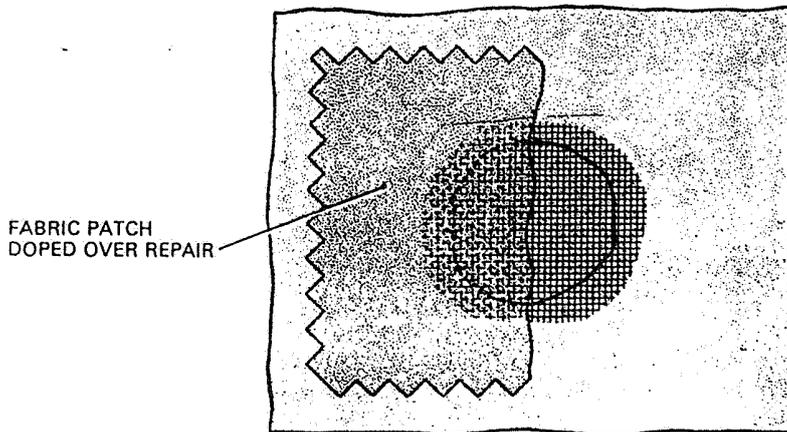
Figure 10 REPAIR BY DARNING

(b) The patch should be made 25 mm (1 in) larger than the cut-out area and its edges should be folded under for 12 mm (0·5 in) and tacked in position in a manner similar to that described in paragraph 10.3.1 (a). In this condition the size of the insertion patch should be similar to, or slightly smaller than, that of the cut-out area.

(c) The insertion patch should be held in position inside the cut-out area with a few tacking stitches and then sewn in position using a herring-bone stitch of not less than two stitches to the centimetre (four stitches to the inch), as shown in Figure 11. A 25 mm (1 in) wide tape should then be doped over the seams.

25 mm COVERING STRIP   COVER PATCH POSITION

12 mm FOLDED UNDER
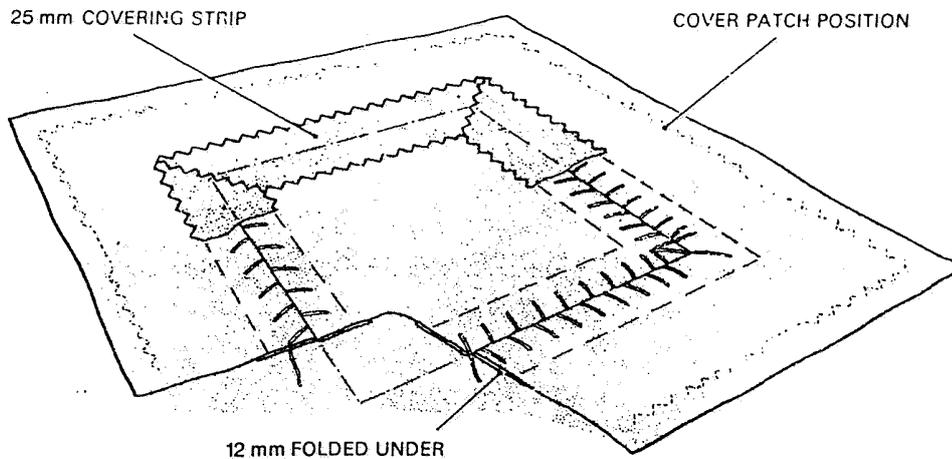
Figure 11 NORMAL INSERTION REPAIR

(d) For small repairs a square or rectangular cover patch, with frayed or serrated edges, should be doped in position ensuring that the patch overlaps the edge of the tape by 31 mm (1·25 in). Where the size of the insertion patch is more than 225 mm (9 in) square, a 75 mm (3 in) wide fabric serrated tape is often used; the tape should be mitred at the corners and doped in position. The original finish should then be restored.

10.3.2 **Alternative Insertion Repair.** An alternative repair is shown diagrammatically in Figure 12. This consists of cutting away the damaged fabric as described in paragraph 10.3.1, but, in this case, the edges of the aperture as well as the edges of the insertion patch are turned upwards. The insertion patch is attached to the fabric cover by stitching along the folded-up edges as near to the contour of the component as practicable (i.e. about 1 mm (0·0625 in) above the surface) using the boot stitch described in paragraph 10.3.3 (Stage 1 of Figure 12). The edges are then doped down (Stage 2 of Figure 12) and the repair covered with a doped-on fabric patch.

10.3.3 **Boot Stitch.** A single, well-waxed No. 18 linen thread to BS F34 should be used for the boot stitch. The stitches should be made as shown (diagrammatically) in Figure 13 and the ends of both threads tied together in a lock knot every 150 mm (6 in), and at the end of a seam.

11   CHECKING OF FABRIC   The fabric covering of an aircraft will deteriorate in service, the rate of deterioration depending, to a large extent, on the type of operation, climate, storage conditions, and the maintenance of a satisfactory surface finish. In addition, as a result of water soakage, chafing against structure, and local wear, the covering will not deteriorate uniformly. In the case of fabric covered components on large aircraft an arbitrary life may be placed on the fabric, but with light-aircraft coverings the fabric should be checked at the periods specified in the approved Maintenance Schedule and prior to renewal of the Certificate of Airworthiness.

37mm

INSERTION PATCH

12mm

BOOT STITCH

STAGE 1

FABRIC PATCH TO BE DOPED OVER REPAIR   STAGE 3

25mm
OVERLAP

INSERTION PATCH

BOTH EDGES WELL   STAGE 2
DOPED DOWN

Figure 12 ALTERNATIVE INSERTION REPAIR

START KNOTS

FABRIC

25mm

Figure 13 BOOT STITCH

14

11.1 A visual examination in which particular attention is given to places where water soakage, local wear, fretting or oil contamination are likely to occur, or are known to occur on that particular aircraft type, supplemented by a knowledge of the aircraft history, will often be sufficient to justify acceptance of the covering as a whole, or replacement of some local areas which have deteriorated. In cases of doubt as to the strength of the fabric, further tests will be necessary.
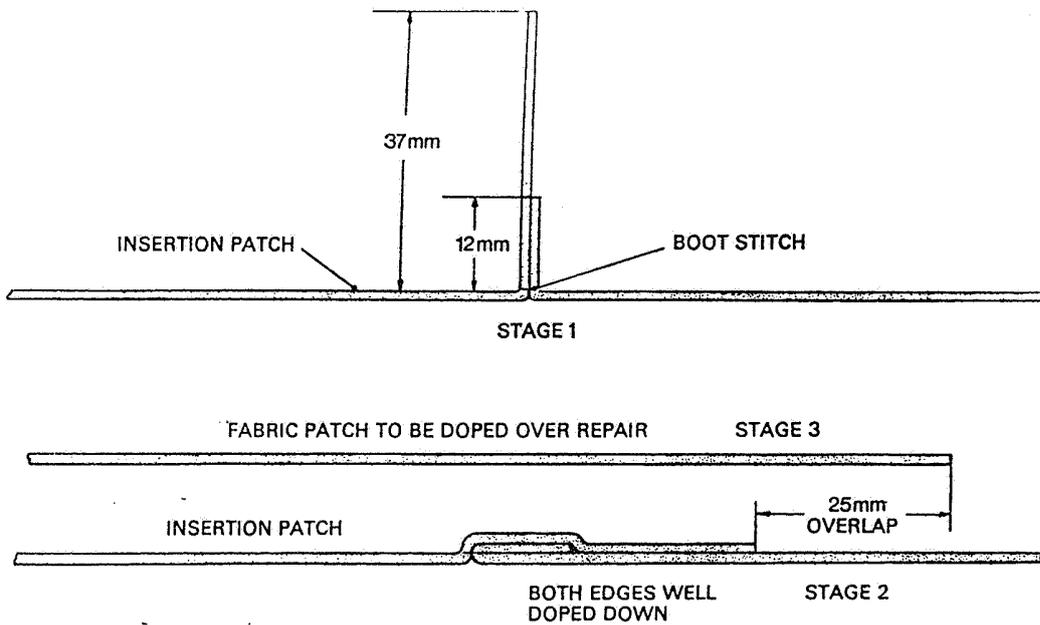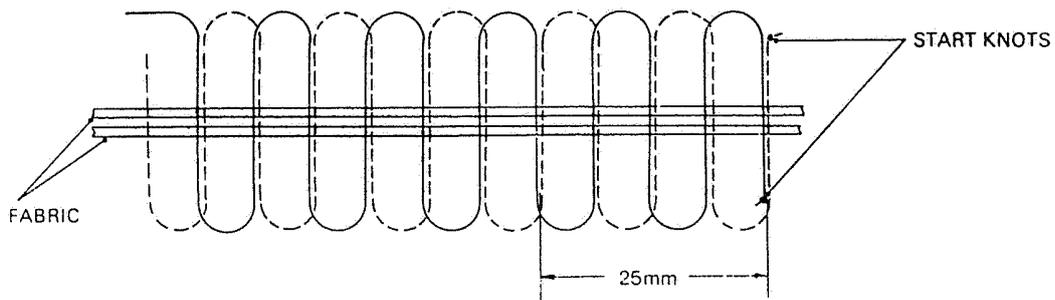
11.2 One method of checking the strength of an aircraft covering is by the use of a portable tester such as the one described in paragraph 11.3 and illustrated in Figure 14. These testers are, generally, only suitable for checking the condition of coverings on which the dope finish has penetrated the fabric. Finishes such as cellulose acetate butyrate dope do not normally penetrate the fabric, and experience has shown that the absorption of moisture in humid conditions can produce unreliable test results. In addition, butyrate dope, even when some penetration of the fabric has occurred, produces a finish which hardens with age; as a result the conical point on the tester will not readily penetrate the covering, and the test will tend to indicate that the fabric is stronger than it actually is. Thus where butyrate dope has been used, or the dope, irrespective of type, does not penetrate the fabric, laboratory tests should be carried out. For a laboratory test the dope should be removed from the fabric, using a suitable solvent where necessary. Fabric having a strength of at least 70% of the strength of new fabric to the appropriate specification (as assessed by either test), may be considered airworthy, but fabric which falls only just within the acceptable range should be checked more frequently thereafter to ensure continued serviceability.

11.3 **Portable Tester.** This consists of a penetrating cone and plunger housed within a sleeve assembly. When pressed against a surface the cone is forced up through the sleeve against spring pressure and the plunger projects through the top of the sleeve in the same way as a tyre pressure gauge. When inspecting fabric, the tester should be held at 90° to the surface and pressure applied towards the fabric in a rotary motion, until the sleeve flange touches the surface (Figure 14). The degree to which the cone has penetrated the fabric is indicated by the length of plunger showing above the sleeve, and this is marked either by coloured bands or a graduated scale.

11.3.1 A table is provided with the tester giving the colour or scale reading required for a particular type of fabric.

NOTE: The portable tester described here is of American manufacture and the table supplied refers to fabric complying with American specifications (A.M.S., T.S.O. and MIL). It can be adapted for use on fabrics complying with DTD and BS specifications by comparing the strength requirements of the fabrics.

11.3.2 The test should be repeated at various positions and the lowest reading obtained, other than in isolated repairable areas, should be considered representative of the surface as a whole.

NOTE: It is important to ensure that the test is not made through double layers of fabric, since this would not be representative of the entire surface.

11.3.3 All punctures produced by the tester should be repaired with a 50 mm or 75 mm (2 in or 3 in) diameter doped fabric patch.
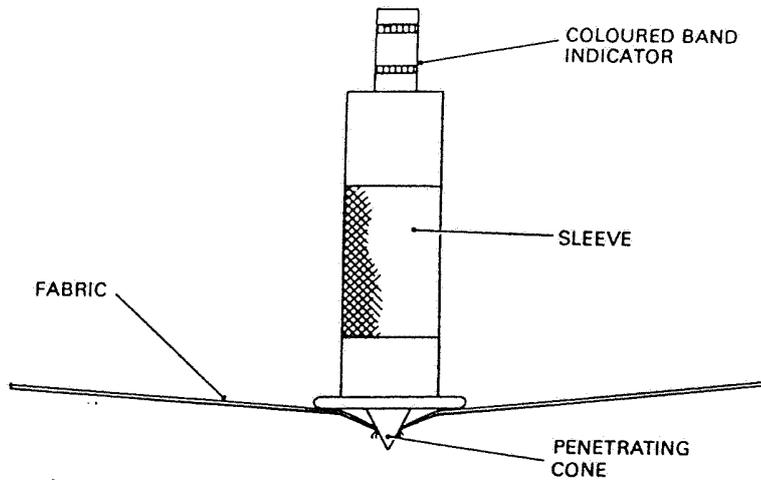
Figure 14 FABRIC TESTER

11.4 **Laboratory Tests.** Tensile strength tests are included in laboratory tests specified for new fabric and require the use of six warp and six weft samples, each 62 mm × 300 to 400 mm (2·5 in × 12 to 16 in). These tests are thus an uneconomical proposition for used fabric coverings on aircraft, since they would necessitate partial re-covering even if the fabric proved to be serviceable. It is recommended, therefore, that when the portable tester is considered unsatisfactory or inappropriate, samples of fabric should be sent to a laboratory acceptable to the CAA, for bursting strength tests in accordance with the specification for the particular type of fabric. These tests require the use of samples approximately 87 mm (3·5 in) in diameter.

11.4.1 Bursting strength tests can be carried out on a machine operating on the principle of applying force to a polished steel ball of 25·40 mm (1·00 in) diameter, the ball being in contact with the test sample, which is clamped between two circular brass plates having coaxial apertures of 44·45 mm (1·75 in) diameter. The load should be applied at a constant rate, and the load at break point is the bursting strength of the fabric. An Instron machine, which operates on this principle, is suitable for conducting tests on used aircraft fabric. As an alternative, a machine operating on hydraulic principles can be used; in such a machine, liquid pressure is applied at a constant rate to a rubber diaphragm, which is positioned to expand through a clamp aperture of 30·99 mm (1·22 in) diameter, exerting force against the fabric sample held between the clamps.

NOTE: The test methods referred to above are in accordance with the American Federal Test Method Standard No. 191, Methods 5120 and 5122 respectively.

12 . MAN-MADE FABRICS   Natural fabrics, such as cotton or linen, deteriorate in use as a result of the effects of sunlight, mildew or atmospheric pollution, and may require replacement several times during the life of an aircraft. With a view to lengthening the intervals between fabric replacements, several man-made fabrics have been developed and are approved in some countries for use on specific aircraft. The two main types of materials are polyester-fibre and glass-fibre, which are marketed under various trade names. The methods of covering aircraft with these fabrics are briefly discussed in paragraphs 12.1 and 12.2, but it is important that the instructions issued by the manufacturer of the aircraft or fabric should be carefully followed, and only the specified materials used.

12.1   **Polyester-Fibre Materials.** These materials may be attached to the structure by the method described in paragraph 5, by use of pre-sewn covering envelopes or by use of an approved adhesive at the points of contact with the structure. The materials used for attachment and stringing must be compatible with the main fabric.

12.1.1   Before stringing, polyester fibre covers are tautened by the application of heat, the degree of shrinkage being proportional to the heat applied. The most common method of applying heat is a household iron set at about 120°C ('wool' setting), and used in an ironing motion. Care is necessary to prevent the application of excessive heat as this may melt the fibre, or overtauten the cover and distort the underlying structure. Where non-tautening dope is used, the cover may be fully tautened prior to doping, but where tautening dope is used the initial shrinkage should leave the cover fairly slack, since tautening will continue over a period of months after the dope has been applied.

12.1.2   Repairs within the specified limits may be carried out as described in paragraph 10, or patches may be stuck on, using a suitable adhesive. Large patches should be tautened in the same way as the main cover.

12.2   **Glass-Fibre Materials.** Glass-fibre fabric is normally fitted to the mainplane and tailplane in a spanwise direction, being attached at the leading and trailing edges with a 50 mm (2 in) doped seam. Fuselages may conveniently be covered using four pieces of material at the top, bottom and sides, doped seams again being employed. Some glass-fibre material is pre-treated to make it compatible with cellulose acetate butyrate dope and is not suitable for use with cellulose nitrate dope.

12.2.1   The structure should be prepared by removing all sharp edges from the parts which will be in contact with the cover. Wooden parts should be lightly sanded, and metal edges taped to prevent chafing.

12.2.2   Glass-fibre material is only slightly tautened by doping, and must be a good initial fit, after which glass-fibre stringing should be fitted in the appropriate manner (paragraph 6.4).

12.2.3   Repairs within the specified limits may be made by cutting out the damaged area of fabric and doping on a cover patch which overlaps 50 mm (2 in) all round.

BL/6-26

Issue 2

June, 1984

BASIC

ENGINEERING PRACTICES AND PROCESSES

DOPING

1   INTRODUCTION   Fabric has been used from the early days of the aeroplane as a covering for fuselages and aerofoils. It still continues to provide good service for light aircraft but must be protected from deterioration by the application of a dope film. Natural fabrics, such as cotton or linen, deteriorate in use as a result of the effects of sunlight, mildew and atmospheric pollution. Man-made fibres resist some of these agents better than natural fabrics but still require protection. The dope film then achieves the following functions:

(a)   Tautening of natural fabrics.

(b)   Waterproofing.

(c)   Airproofing.

(d)   Lightproofing.

1.1   The object of this Leaflet is to provide guidance on the appropriate working conditions and methods of application of dope to aircraft fabric. Other Leaflets with related information are **BL/6-20** Paint Finishing of Metal Aircraft and **BL/6-25** Fabric Covering.

2   MATERIALS   The basic film consists of dope but other materials are used in its application, as described in the following paragraphs.

2.1   **Dopes.**   Dope consists of a number of resins dissolved in a solvent to permit application by brush or spray. This formulation is then modified with plasticizers and pigments to add flexibility and the required colour (see Figure 1). There are two types of dope in use, namely, cellulose nitrate and cellulose acetate butyrate. The former is usually known simply as nitrate dope and the latter as butyrate or CAB dope. The main difference between the two types of dope is the film base. In nitrate dope a special cotton is dissolved in nitric acid, whilst in butyrate dope cellulose fibres are dissolved in acetic acid and mixed with butyl alcohols. The plasticizers in the two dopes are also different, as are the resin balance and solvent balances. Dope must be stored under suitable conditions (see Leaflet **BL/1-7**), and has a tendency to become acid with age; if old dope is used for refinishing an aircraft it will quickly rot the fabric. Only fresh dope should be used, preferably buying it for the job in hand.

2.2   **Dope-proof Paints.**   Due to the nature of the solvents used in dope, many paints will be attacked and softened by it. Dope-proof paint is therefore used to coat structure which will be in contact with the doped fabric. In the case of wooden structure, spar varnish provides a good dope-resistant finish, and an epoxy primer is suitable for metal structures.

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┌─────────────────────┐   ┌──────────┐   ┌──────────────┐   ┌──────────┐
│  RESINS & PRIMARY   │   │ SOLVENTS │   │ PLASTICIZERS │   │ PIGMENTS │
│    FILM FORMERS     │   └──────────┘   └──────────────┘   └──────────┘
└─────────────────────┘
            ┌─────────────────────┐         ┌──────────────────┐
            │   RESIN SOLUTIONS   │         │  PIGMENT PASTE   │
            └─────────────────────┘         └──────────────────┘
                        ┌──────────────────┐
                        │  FINISHED DOPE   │
                        └──────────────────┘
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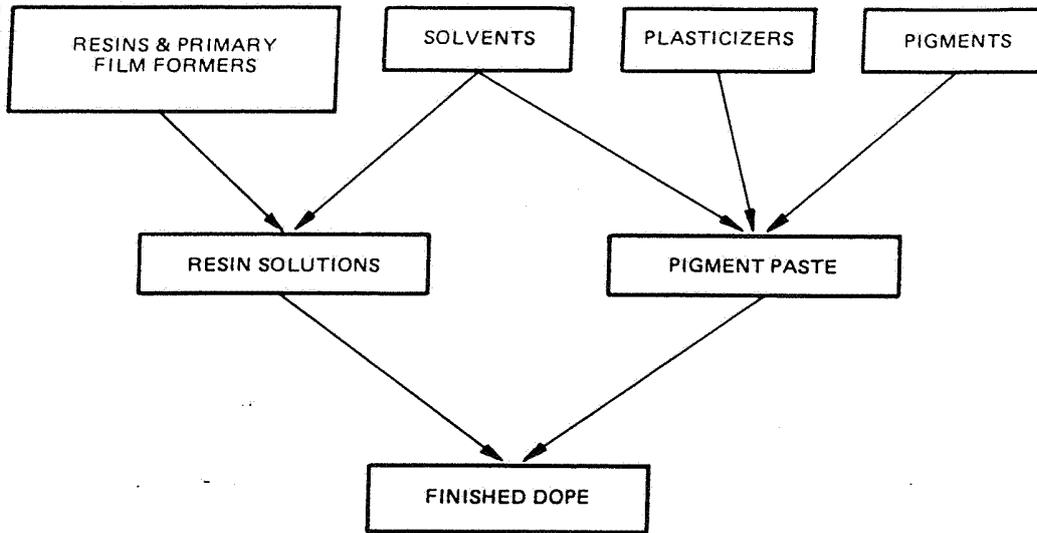
Figure 1   DOPE CONSTITUENTS

2.3 **Aluminium Dope.** To make the fabric lightproof and so prevent damage from ultra-violet radiation, an aluminium dope is used. This is usually supplied ready mixed but can be prepared by mixing aluminium paste or powder in clear dope but it is essential that the materials are obtained from an approved supplier and mixed in accordance with the manufacturer's instructions.

2.4 **Thinners.** Dopes are formulated in such a way that the solid constituents are suspended in the appropriate solvents. It will normally be necessary to thin or reduce the dope to make it suitable for spraying. It is important that only the thinners recommended by the manufacturer of the dope is used. The amount of thinners is determined from the manufacturer's recommendations and is modified by experience to take account of the equipment used and the atmospheric conditions. The viscosity can be measured by using a viscosity cup which contains a small hole in the bottom. In use, the cup is dipped into the dope and the flow of fluid is timed from when the cup is lifted from the container to the first break in the flow. In this way subsequent batches of dope can be mixed to exactly the same viscosity as the first batch. It is important that nitrate and butyrate dopes are mixed only with their own specialised thinners. A retarder, or anti-blush thinners, is a special type of thinners with slow-drying solvents. By drying more slowly they prevent the temperature drop and consequent moisture condensation that cause blushing in a dope finish. In use, the retarder replaces some of the standard thinners and can be used in a ratio of up to one part retarder to four parts of thinners. The use of more retarder than this is unlikely to achieve the desired result.

2.5 **Cleaning Agent.** Methyl-ethyl-ketone (MEK) is an important, relatively low cost, solvent similar to acetone. It is widely used as a cleaning agent to remove wax and dirt and to prepare surfaces for painting or re-doping. It is also useful as a solvent for cleaning spray guns and other equipment.

2.6 **Fungicides.** Since natural fabrics can be attacked by various forms of mildew and fungus, it may be necessary to provide protection for cottons and linens when doping. This is achieved by having a fungicide added to the first coat of dope. The dope is usually supplied ready mixed but can be prepared by using a fungicidal paste obtained from an approved supplier. If the latter course is necessary, the fungicidal paste should be mixed with the clear dope in accordance with the manufacturer's instructions; all fungicides are poisonous and, therefore, standard precautions should be taken to prevent any ill effects. Since mildew or mould form on the inside of the fabric, it is important to ensure that this first coat of dope completely penetrates the fabric.

2.7 **Tack Rags.** A tack rag is a rag slightly dampened with thinners and is used to wipe a surface after it has been sanded to prepare it for the application of the next coat. Proprietary cloths are also available.

2.8 **Sandpaper.** Sanding is carried out using wet-or-dry paper. This is a waterproof sandpaper that will remain flexible and not clog. The grades most likely to be used are 280, 360 and 600, the last mentioned being the finest grade.

2.9 **Drainage Eyelets and Inspection Rings.** Openings in the fabric cover for drain holes and inspection panels are always reinforced with eyelets or grommets (see Figure 2) and inspection rings. These are made from cellulose nitrate sheet and are doped into position (see Leaflet **BL/6-25**).
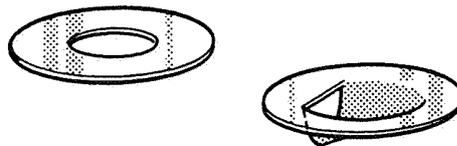
Figure 2 PLAIN AND SHIELDED DRAINAGE EYELETS

3 SAFETY PRECAUTIONS The storage and use of dopes is covered by various Government regulations made under the Factories Act. This paragraph does not replace or override any of those regulations.

3.1 The hazard with the use of dopes comes about because of the flammability of the solvents that are used. The solvents have a low flash point and the vapour produced is heavier than air. Accumulations of vapour are readily ignited producing a serious fire which can spread very rapidly.

3.2 One of the most common causes of ignition is a spark produced by the discharge of static electricity. For example, during the course of doping, the fumes from the solvents will accumulate inside the structure. When the dope has dried, subsequent dry sanding and dusting will build up a static charge on the surface. If the operator is wearing rubber soled shoes he will be at the same electrical potential as the surface and nothing will happen. Should the charge on the operator now be lost through his touching some metal

part of the spray shop, for example, and he then touches some metal part of the structure being doped the static charge will jump to earth creating a spark and igniting the fumes. The best way to prevent this type of problem is to eliminate the static charge altogether by grounding the structure being doped. A wire connected from the structure to a clean metal part of the spray shop will do the job satisfactorily. Clothing that is made of synthetic fibres will build up a static charge more readily than that made from cotton. Leather soled shoes will allow any static charge to be dissipated to ground. When spraying nitrate dope ensure that the spray gun, the operator and the structure being doped are all grounded together.

3.3 The standard of housekeeping in the spray shop is an important aspect of safety. If the floor becomes contaminated with dried nitrate dope overspray, subsequent sweeping will produce a static charge with the attendant risk of ignition and possible explosion. To clean the floor, it should be doused well with water and then swept whilst it is still wet. Since dopes will not be the only materials used in a spray shop, it should be noted that spontaneous combustion can be the result of a mixing of dope and zinc chromate oversprays.

3.4 The fumes created during the spraying process are hazardous to health as well as being a fire risk. Proper operator protection must be provided as recommended in the dope manufacturer's technical literature. At the first sign of any irritation of the skin or eyes, difficulty in breathing or a dry cough, the operator should stop work and seek medical advice.

3.5 Electrical equipment to be used in the spray shop must be of such a nature that it cannot ignite the vapours that will be present. Lead lamps must be of the explosion-proof variety and dopes must not be mixed using stirrers driven by portable electric drills.

4   WORKING CONDITIONS   In order to accomplish a proper dope job it is important to control both the temperature and humidity of the air in the spray shop. In addition to this it is necessary to maintain sufficient airflow through the shop to remove the heavy vapours caused by atomisation and evaporation of the solvents used.

4.1 To maintain a suitable airflow through the spray shop it is necessary to install a fan at floor level since the vapours produced are heavier than air. The fan must be explosion proof, as must be all other electrical equipment installed in the area. The rate of air flow is dictated by the size of the spray shop and is the subject of various Government regulations. The discharge of the vapours may also be the subject of further requirements and the advice of the Factory Inspectorate should be sought. The air inlet to the spray shop should preferably be in an adjoining room, or at least behind a suitable baffle, in order to reduce draughts to a minimum. If the inlet is in a separate room then the air temperature can be raised to that required before entering the spray shop.

4.2 Many problems associated with doping can be traced to incorrect temperatures of the air or the dope. If the dope has been left overnight in a cold place then it will take many hours to bring it to the room temperature. Overnight heating of the spray shop is the most satisfactory method to prepare for doping since it usually results in more uniform temperatures throughout the shop. Rapid heating tends to result in stratified heating with the ceiling being considerably hotter than the floor level. Air temperature should be maintained between approximately 21 and 26 C for best results. If the temperature is too low the rapid evaporation of the solvents will lower the temperature of the surface

to the point where moisture will condense and be trapped in the finish. Too high a temperature causes very rapid drying of the dope which can result in pin holes and blisters. The only satisfactory way to operate is to constantly monitor and control the air temperature as necessary.

4.3   In addition to the proper control of air temperature, the humidity of the air must also be controlled. The desirable range of air humidity is 45 to 50%. Satisfactory work can be produced with air humidity as high as 70% or as low as 20%, depending upon other variables such as temperature and air flow, but the control of the dope application at extremes is always more difficult.

4.4   Humidity should be measured with a hygrometer and, although direct reading instruments are available, the wet and dry bulb type is still the most common. In this instrument two thermometers are mounted side by side, the bulb of one being kept wet by water evaporating through a wick. To take a reading of humidity, both thermometers should be read and the difference between them noted; the wet bulb thermometer will be lower. After finding the dry bulb reading in Table 1, a reading should be taken across to the column headed with the depression of the wet bulb. The relative humidity as a percentage is given at the intersection of the two lines. **Example.** Assuming a dry bulb reading of 17°C and a wet bulb reading of 14°C, the depression of the wet bulb, that is the amount by which the reading of the wet bulb is reduced below that of the dry bulb, is 3°C. Reading across from 17°C in the dry bulb column to the depression column headed 3°C indicates a relative humidity of 72%.

4.5   In order to produce a satisfactory dope film, it is vitally important that all brushes, spray equipment and containers should be scrupulously clean. It is important that oil and water traps in the air lines are properly cleaned and that air reservoirs are drained of accumulated moisture. Pressure pots and spray guns should be thoroughly cleaned with thinners before the dope hardens. If passages have become obstructed with dried dope, the equipment should be dismantled and the parts soaked in methyl-ethyl-ketone or a similar solvent. Packings and seals should never be soaked in solvents or they will harden and become useless.

5   PREPARATION PRIOR TO DOPING   Before the component is moved into the spray shop, normal housekeeping tasks should be carried out. All dirt, dust and dried overspray should be removed, bearing in mind the safety precautions in paragraph 3.3. Then the working conditions of temperature and humidity should be achieved with the dope and other materials being brought to the correct temperature.

5.1   An inspection should be made of the fabric-covered component to verify the following points:

(a)   The structure has been painted with dope-proof paint where required.

(b)   Correct and secure attachment of the fabric to the structure.

(c)   Correct allowance for tautening of the cover where this is of a natural fabric such as cotton or linen. If the cover is too slack, no amount of doping will rectify this. If it is too tight, a lightweight structure, such as a control surface, could easily be distorted.

(d)   All dust has been removed from the fabric.

(e)   The fabric has reached the temperature of the air in the spray shop.

(f)   Plastics components, such as windows and windscreens, are adequately protected against solvent attack; newspaper is not satisfactory for this purpose.

TABLE 1

RELATIVE HUMIDITY (%)

Dry Bulb Reading (°C)	Depression of the Wet Bulb (°C)									
	1	2	3	4	5	6	7	8	9	10
0	82	–	–	–	–	–	–	–	–	–
1	83	–	–	–	–	–	–	–	–	–
2	84	68	–	–	–	–	–	–	–	–
3	84	69	54	–	–	–	–	–	–	–
4	85	70	56	42	–	–	–	–	–	–
5	86	72	58	45	32	–	–	–	–	–
6	86	73	60	47	35	23	–	–	–	–
7	87	74	61	49	37	26	14	–	–	–
8	87	75	63	51	40	29	18	7	–	–
9	88	76	64	53	42	31	21	11	1	–
10	88	77	65	54	44	34	24	14	5	–
11	88	77	66	56	46	36	26	17	8	–
12	89	78	68	57	48	38	29	20	11	3
13	89	79	69	59	49	40	31	23	14	6
14	90	79	70	60	51	42	33	25	17	9
15	90	80	71	61	52	44	36	27	20	12
16	90	81	71	62	54	46	37	30	22	15
17	90	81	72	64	55	47	39	32	24	17
18	91	82	73	65	56	49	41	34	27	20
19	91	82	74	65	58	50	43	35	29	22
20	91	83	74	66	59	51	44	37	30	24
21	91	83	75	67	60	52	46	39	32	26
22	92	83	76	68	61	54	47	40	34	28
23	92	84	76	69	62	55	48	42	36	30
24	92	84	77	69	62	56	49	43	37	31
25	92	84	77	70	63	57	50	44	38	33
26	92	85	78	71	64	58	51	46	40	34
27	92	85	78	71	65	59	52	47	41	36
28	93	85	79	72	65	59	53	48	42	37
29	93	86	79	72	66	60	54	49	43	38
30	93	86	79	73	67	61	55	50	44	39
31	93	86	80	73	67	62	56	51	45	41
32	93	86	80	74	68	62	57	52	46	42
33	93	87	80	74	69	63	58	52	47	43
34	93	87	81	75	69	64	58	53	48	44
35	93	87	81	75	70	64	59	54	49	44

NOTE: Intermediate values may be obtained by interpolation.
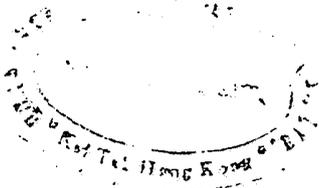
5.2 With the dope at the correct temperature, it should be mixed and then thinned to a suitable consistency for brush or spray application as appropriate. Whilst the dope is in storage the solid materials tend to settle and the purpose of mixing is to bring these materials back into suspension. To mix any dope satisfactorily, half the contents of the tin should be poured into a clean tin of the same size. The remaining material should be stirred until all the solid material is in suspension, paying particular attention to the bottom of the tin. The contents of the first tin should then be poured into the second tin and a check made that all pigment has been loosened from the bottom. Finally, the dope from one tin should be poured into the other, and back again, until it is thoroughly mixed.

6 APPLICATION TO NATURAL FABRIC   The best looking and most durable film is produced by using multiple coats of a dope that is low in solids. A large number of thin coats, however, requires a great deal of time and modern dope schemes tend to use fewer, but thicker, coats than the earlier schemes. The dope scheme is a schedule listing the number and order of coats of each type of dope. Typical examples of schemes detailed in British Standard BS X26 are given in Tables 2, 3 and 4. The standard aircraft doping scheme is 752, but 751 is used on light structures that would be distorted by overtautening and 753 is used where an extra taut cover is required.

6.1 **Priming Coats.**   This name is given to the first coats applied to the raw fabric. The first coat of dope provides the foundation for all the subsequent coats and as such its mechanical attachment to the fabric is very important. This mechanical attachment is formed by the dope encapsulating the fibres of the fabric. Nitrate dope has much better properties with regard to encapsulating the fibres and is therefore preferred for the first coat. The dope should be thinned by 25 to 50% and then applied by brush. The dope should be worked into the fabric to ensure adequate penetration, but not to the point where it drips through to the opposite surface. Since organic fabrics are subject to attack by mildew, a fungicide should be added to the dope used for this first coat (see paragraph 2.6). When applying the first coat of dope to the wings, the entire wing should first be doped on both sides aft of the front spar. The dope should be allowed to shrink the fabric before doping the leading edge. In this way the fabric will tauten evenly and adjust itself over the leading edge cap without forming wrinkles.

TABLE 2

LOW TAUTNESS SCHEME BS X26/751

Dope	Weight		Normally obtained in the following number of coats
	g/m²	oz/yd²	
(a) Transparent tautening dope	68	2·0	3 or 4
(b) Aluminium non-tautening finish	34	1·0	2
(c) Pigmented non-tautening finishes	34	1·0	1 or 2
Where a glossy finish is required, follow with:			
(d) Transparent non-tautening finish	34	1·0	1 or 2
NOTE: Where an aluminium finish is required, it is necessary to apply only (a) and (b) above, followed by (d) if required.			

TABLE 3

MEDIUM TAUTNESS SCHEME BS X26/752

Dope	Weight		Normally obtained in the following number of coats
	g/m²	oz/yd²	
(a) Red oxide tautening dope	68	2·0	3
(b) Aluminium tautening dope	34	1·0	2
(c) Pigmented non-tautening finishes	34	1·0	1 or 2
Where an aluminium finish is required, the scheme should be:			
(d) Red oxide tautening dope	102	3·0	4
(e) Aluminium non-tautening finish	34	1·0	2
Where a glossy finish is required, follow with:			
(f) Transparent non-tautening finish	34	1·0	1 or 2

TABLE 4

HIGH TAUTNESS SCHEME BS X26/753

Dope	Weight		Normally obtained in the following number of coats
	g/m²	oz/yd²	
(a) Red oxide tautening dope	25·5	0·75	1
(b) Transparent tautening dope	161	4·75	6 or 7
(c) Aluminium tautening dope	34	1·0	2
(d) Pigmented non-tautening finishes	34	1·0	1 or 2
Where an aluminium finish is required, the scheme should be:			
(e) Red oxide tautening dope	25·5	0·75	1
(f) Transparent tautening dope	195	5·75	8
(g) Aluminium non-tautening finish	34	1·0	2
Where a glossy finish is required, follow with:			
(h) Transparent non-tautening finish	34	1·0	1 or 2

NOTE: A tolerance of ±20% is permissible on any of the weights given in Tables 2 to 4.

6.2 After the dope has dried for a minimum of 1 hour, the tapes, drainage eyelets or grommets and inspection panel rings may be applied. (See Leaflet **BL/6-25** for rib stitching procedures.) A heavy coat of nitrate dope should be brushed on where required and the tape laid into it, working it down to the surface and rubbing out any air pockets as the tape is laid. A further coat of clear dope is brushed over the top of the tapes. Drainage eyelets or grommets and inspection rings are attached in a similar fashion at this time. To ensure the best adhesion, eyelets or grommets and rings may be soaked in dope thinners for no more than two minutes to soften them. Inspection rings are best reinforced with a circular pinked-edge patch, a little larger than the ring, doped over the top. The holes in eyelets or grommets and rings are opened with a sharp, pointed knife after doping is complete. The taping is followed by another coat of clear dope which may be butyrate and may be applied by spray gun.

6.3 **Filling Coats.** When the first butyrate coat has fully dried, the fabric will feel rough due to the short fibre ends (the nap) standing up. This nap should be very lightly sanded off, using dry sandpaper, to leave a smooth finish. The surface should then be rinsed clean with water and dried thoroughly. Two full wet cross-coats of butyrate dope should now follow; a cross-coat is a coat of dope sprayed on in one direction and then covered with a second coat at right angles to it before the first coat dries. These in turn should be followed with one good cross-coat of aluminium dope after lightly sanding the clear dope to encourage adhesion. The aluminium coat is in its turn lightly wet sanded to produce a smooth surface, and the residue rinsed off with water. Once the aluminium coat has dried, it should be checked for continuity by shining a light inside the structure. The film should be completely lightproof.

6.4 **Finishing Coats.** The finishing coats of pigmented butyrate dope may now be sprayed on. The number of coats will be determined as a balance between quality and cost but should not be less than three. A high gloss finish is obtained by lightly sanding each coat when dry and spraying multiple thin coats rather than several thick coats. The use of a retarder in the colour coats will allow the dope to flow out and form a smoother film. The final coat should be allowed to dry for at least a month before it is polished with rubbing compound and then waxed. The surface should be waxed at least once a year with a hard wax to reduce the possibility of oxidation of the finish.

7 **APPLICATION TO POLYESTER-FIBRE FABRIC** Polyester-fibre fabrics are being increasingly widely used for covering aircraft because of their long life and resistance to deterioration. For this reason it is extremely important that the dope film is of the highest quality so that its life will match that of the fabric.

7.1 **Priming Coats.** Tautening of the fabric cover is not a function of the dope film where synthetic fabrics are used, although all dopes will tauten to some extent. Polyester-fibre fabrics are heat shrunk when the structure is covered. The most notable difference in doping a synthetic cover is the difficulty, when compared with natural fabrics, of obtaining a good mechanical bond between the dope and the fibres of the material. Unlike natural fibres the polyester filaments are not wet by the dope, and the security of attachment depends upon them being totally encapsulated by the first coat of dope. The first coat must be nitrate dope thinned in the ratio of two or three parts of dope to one part of thinners. This coat is then brushed into the fabric in order to completely encapsulate every fibre. The dope should form a wet film on the inside of the cover but it should not be so wet that it drips through to the opposite side of the structure. The initial coat should be followed by two more brush coats of nitrate dope thinned to an easy brushing consistency. Certain additives are approved by the material manufacturer for use with the first coat for improving adhesion to the fabric. However, since polyester is not organic, there is no need for a fungicide to be added to the first coat of dope.

7.2 **Filling Coats.** Taping and attaching of drainage eyelets or grommets and inspection rings follows the same procedure as for natural fabrics. The priming coats should be followed by spraying two full-bodied cross-coats of clear butyrate dope. After these coasts have completely dried they should be lightly sanded (400 grit) and cleaned thoroughly with a tack rag. One full cross-coat of aluminium dope should then be sprayed on and lightly wet sanded when dry, the residue being rinsed off with water. This coat should be tested to verify that it is lightproof by shining a light inside the structure.

7.3 **Finishing Coats.** The finishing coats should now be applied in the same manner as for natural fabrics. It should be noted that with a properly finished polyester cover the weave of the fabric will still show through the dope film. Because the fibres are continually moving, any attempt to completely hide them will result in a finish that does not have sufficient flexibility to resist cracking.

8   APPLICATION TO GLASS-FIBRE FABRIC   Glass-fibre fabric has a loose weave which tends to make it difficult to apply to aircraft structures. To overcome this problem it is pre-treated with butyrate dope, and the covering and doping must be carried out in accordance with the manufacturer's installation instructions.

8.1 **Priming Coats.** Nitrate dope must not be used under any circumstances with this type of fabric. The first coat of clear butyrate dope is sprayed on with the dope being thinned only enough to permit proper atomisation. The atomising pressure must be set to the lowest possible that will permit proper atomisation without the dope being blown through the fabric. The coat should be heavy enough to thoroughly wet the fabric and soften the dope in the fabric, but must not be so heavy that it causes the dope to run on the reverse side of the fabric. If the dope is allowed to run in this way an orange peel finish will develop and the fabric will not tauten properly.

8.2 After the first coat has dried, further coats of butyrate dope should be sprayed on, each a little heavier than the one before it, until the weave fills and the fabric tautens; this may take as many as five coats. Tapes, drainage eyelets or grommets and inspection rings are applied in a coat of butyrate dope.

8.3 **Filling Coats.** Once the fabric is taut and the weave has been filled, two full-bodied brush coats of clear butyrate dope should be applied and allowed to dry thoroughly. The film should then be very carefully sanded, making sure that it is not sanded through to the fabric. Whilst the fabric is not damaged by ultra-violet radiation, the clear dope can deteriorate as a result of exposure and, therefore, a coat of aluminium dope should be sprayed on for protection and lightly wet-sanded smooth. After the aluminium dope has been sanded, the residue should be removed by washing with water and then the surface thoroughly dried.

8.4 **Finishing Coats.** The application of the finishing coats is carried out in the same manner as for natural fabrics. Several thin, wet coats of coloured butyrate dope will allow the surface to flow out to a glossy finish.

9   DOPING PROBLEMS   The production of a doped finish that is both sound and attractive is dependent upon a great deal of care and attention being paid to detail at each stage of the finishing process. In spite of this, problems do occur and the following paragraphs detail some common ones and their possible causes.

9.1 **Adhesion.** There are two basic areas in which adhesion may be poor; between the fabric and the first coat of dope and between the aluminium coat and subsequent coats. Adhesion to the fabric, particularly polyester fabric, is largely dependent upon the technique used to ensure the encapsulation of the fibres. Adhesion to the aluminium coat may be impaired if too much aluminium powder was used or if the surface was not thoroughly cleaned after sanding. The use of a tack rag to finally clean a surface before applying the next coat is always recommended.

9.2 **Blushing** is a white or greyish cast that forms on a doped surface. If the humidity of the air is too high, or if the solvents evaporate too quickly, the temperature of the surface drops below the dew point of the air and moisture condenses on the surface. This water causes the nitrocellulose to precipitate out. Moisture in the spray system or on the surface can also cause blushing. Blushing can be controlled by reducing the humidity in the air (raising the temperature by several degrees may achieve this) or by using a retarder in the place of some of the thinners. A blushed area can be salvaged by spraying another coat over the area using a retarder instead of some of the thinners; the solvents attack the surface and cause it to flow out.

9.3 **Bubbles or Blisters** are caused by the surface of the dope drying before all the solvents have had time to evaporate. This may happen if a heavy coat of dope is applied over a previous coat that had not fully dried.

9.4 **Dull Finish.** The gloss of butyrate dope may be improved by the addition of up to 20% retarder in the last coat. Excessive dullness may be caused by holding the spray gun too far from the surface so that the dope settles as a semi-dry mist. Small dull spots may be due to a porous surface under the area.

9.5 **Fisheyes.** These are isolated areas which have not dried due to contamination of the surface with oil, wax or a silicone product. Cleanliness is important, especially when refinishing a repair. All wax should be removed using a suitable solvent before attempting to re-dope the surface.

9.6 **Orange Peel.** This is caused by insufficient thinning of the dope or holding the spray gun too far from the surface. It can also be caused by too high an atomising pressure, use of thinners that is too fast drying or by a cold, damp draught over the surface.

9.7 **Pinholes.** These are smaller versions of a blister. Apart from the causes listed in paragraph 9.3, they can be caused by water or oil in the spray system. An air temperature that is too high can also be a cause.

9.8 **Roping.** This is a condition in which the surface dries as the dope is being brushed, resulting in an uneven surface. This is common when the dope is cold and has not been brought up to the temperature of the spray shop. When applying dope with a brush, it should not be overbrushed. The brush should be filled with dope then stroked across the surface and lifted off. The pressure applied to the brush should be sufficient to ensure the proper penetration of the dope.

9.9 **Rough Finish.** Dirt and dust on the surface, insufficient sanding and too low a working temperature can all cause a rough finish.

9.10 **Runs and Sags.** This type of defect is caused by too thick a coat, especially on vertical surfaces. This can be the result of incorrectly adjusted spray equipment or incorrect technique.

9.11 **Wet Areas.** This is a larger version of the defect described in paragraph 9.5.

BL/6-26

10   GENERAL CONSIDERATIONS

10.1 The weight of the dope applied to the fabric is an indication that the scheme has been correctly applied. In the BS X26 doping schemes the weight per unit area is given and should be checked by doping a test panel at the same time as the structure. The fabric is weighed before doping and then again after doping, the difference being the weight of the dope film. United States Military Specifications call for a minimum dope weight of 161 g/m² (4·75 oz/yd²). A tolerance of ±20% may be applied to the weights given in BS X26.

10.2 When an aircraft is re-covered and re-doped it is essential that it is re-weighed and a new Weight Schedule raised (see Leaflet **BL/1-11**).

10.3 After the re-covering, repair and doping of control surfaces it is essential that the static balance of each surface is checked against the manufacturer's requirements. Addition of weight aft of the hinge line without correction of the static balance is likely to cause flutter of the control surface.

BL/6-27

Issue 1.

1*st April,* 1972.

BASIC
ENGINEERING PRACTICES AND PROCESSES
SOLID RIVETS

1   INTRODUCTION   This Leaflet gives guidance on the various types of solid rivets used in aircraft structures.   It includes tables of the principal types of British and American rivets and gives guidance on the heat treatment of aluminium alloy rivets.   Similar information concerning hollow rivets is given in Leaflet BL/6-28 and guidance on riveting practice is given in Leaflet BL/6-29.

NOTE: This Leaflet incorporates all the relevant information previously published in Leaflet AL/7-5, Issue 4.

2   GENERAL   Rivets are designed to be strong in shear and should not be subjected to excessive tension loads.   The two main groups of solid rivets are those with protruding heads, mostly used in the interiors of aircraft, and those with countersunk heads which are used on exterior surfaces where a flush finish is required.   If protruding rivets are used externally they are usually of the mushroom (Figures 1 and 2) or universal (Figure 3) head types.

2.1   British and American rivets are not manufactured to identical specifications nor from identical materials but, since American rivets are not always available, it is often necessary to repair American-built aircraft using British rivets.   Unless there are specific instructions to the contrary the information given in paragraph 5 may be used as a guide in choosing British substitutes for American rivets.   When American rivets are available, all protruding-head rivets in American-built aircraft may be replaced by universal head rivets which have now been adopted as the standard for protruding-head rivets in that country.

NOTE: Deviations from the original repair scheme approved for an aircraft type, e.g. use of rivets of a different material, may only be made if written authority is obtained from an approved design organisation.   The possibility of electro-chemical reaction between rivets and the surrounding material must always be considered.

2.2   Both British and American rivets are identified by head or shank end markings except where a material is easily identified by its natural colour or weight.   Certain British rivets are also coloured all over to enable them to be more readily distinguished.

NOTE: Identification colouring requirements for British aluminium or aluminium alloy rivets are contained in Specification DTD 913.

2.3   Some aircraft manufacturers specify rivets made to the standards of their own companies, and may also use a different colour identification for standard rivets.

3   BRITISH SOLID RIVETS   Standards for British rivets are issued by the Society of British Aerospace Companies (AS series) and the British Standards Institute (SP series).   Rivets are identified by a Standard number and a part number.   The Standard number

identifies the head shape, material and finish, and the part number indicates the size in terms of shank diameter (thirty-seconds of an inch or millimetres × 10) and length (in sixteenths of an inch or millimetres). For example, an AS162 rivet ¼ inch diameter and ½ inch long would be AS162-408, and an SP160 rivet 4 mm in diameter and 16 mm long would be SP160-40-16.

NOTE: 'AS' close tolerance rivets are supplied in length graduations of 1/32 inch. The part number system remains the same, however, and odd 1/32 inches in length are shown by the addition of '·5' after the normal part number.

3.1 **Materials.** The materials used for the manufacture of British rivets comply with DTD or British Standards (BS) Specifications, the actual material being quoted in the relevant tables. Rivets now manufactured from BS L86 were, until September 1961, manufactured from BS L69. Where the rivets require heat treatment, i.e. all BS L37 rivets, this is also indicated in the tables by the symbol '††' and the procedures explained in paragraph 6.

3.2 **'AS' Rivets.** Table 1 gives a list of the solid rivets which conform to the Aircraft Standards of the Society of British Aerospace Companies; these rivets are made in a range of sizes from ¹⁄₁₆ inch to ⅜ inch diameter and from ⅛ inch to 2 inches long except that copper rivets to AS 469 are only made in diameters up to ¼ inch. Figure 1 illustrates the AS solid rivets and indicates the method of measuring the length 'L'. It will be seen from the Table that most of these rivets are obsolescent and have been replaced by rivets conforming to SP Standards.
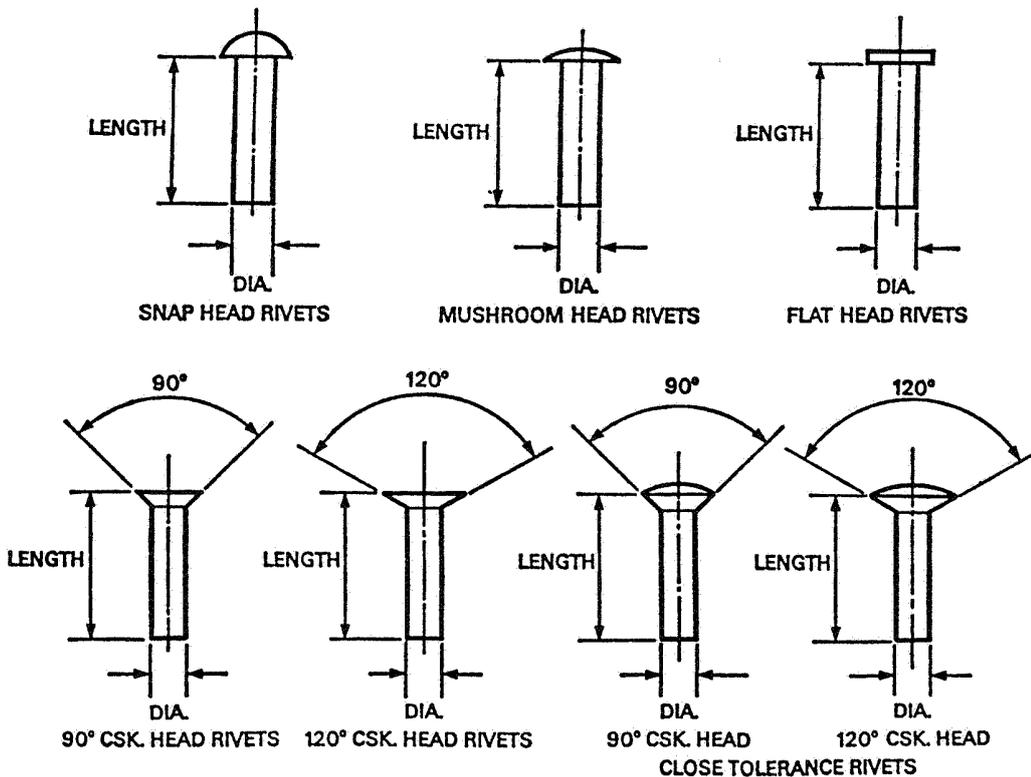

SNAP HEAD RIVETS   MUSHROOM HEAD RIVETS   FLAT HEAD RIVETS

90° CSK. HEAD RIVETS   120° CSK. HEAD RIVETS   90° CSK. HEAD   120° CSK. HEAD
CLOSE TOLERANCE RIVETS

Figure 1   'AS' RIVETS

TABLE 1

Aircraft Standard Number	Material	Material Specification	Head Type	Finish	Identification mark on end of shank	Remarks
AS 155*	aluminium	L 36	snap	black anodic	A	superseded by SP 77
AS 156*	aluminium alloy	L 37††	snap	natural	D	superseded by SP 78
AS 157*	aluminium alloy	L 58	snap	green anodic	X	superseded by SP 79
AS 455*	mild steel	BS 1109	snap	cadmium		superseded by SP 76
AS 457*.	monel	DTD 204	snap	natural	M	superseded by SP 81
AS 458*	tungum	DTD 367	snap	cadmium		
AS 459	copper		snap	natural		non-magnetic
AS 2227*	aluminium alloy	L 86	snap	violet anodic	S	superseded by SP 80
AS 4694*	monel	DTD 204	snap	cadmium	M	superseded by SP 82
AS 158*	aluminium alloy	L 37††	mushroom	natural	D	superseded by SP 83
AS 159*	aluminium alloy	L 58	mushroom	green anodic	X	superseded by SP 84
AS 2228*	aluminium alloy	L 86	mushroom	violet anodic	S	superseded by SP 85
AS 160*	aluminium	L 36	90° csk.	black anodic	A	
AS 161*	aluminium alloy	L 37††	90° csk.	natural	D	
AS 162*	aluminium alloy	L 58	90° csk.	green anodic	X	
AS 460	mild steel	BS 1109	90° csk.	cadmium		magnetic
AS 462	monel	DTD 204	90° csk.	natural	M	
AS 466*	tungum	DTD 367	90° csk.	cadmium		
AS 467	copper		90° csk.	natural		non-magnetic
AS 2229*	aluminium alloy	L 86	90° csk.	violet anodic	S	
AS 4695	monel	DTD 204	90° csk.	cadmium		
AS 4645	aluminium alloy	L 86	90° csk.	violet anodic	S	shank ₁⁄₁₆ in. oversize, "R" on head
AS 4646	aluminium alloy	L 37††	90° csk.	plain anodic	D	
AS 163*	aluminium	L 36	120° csk.	black anodic	A	
AS 164*	aluminium alloy	L 37††	120° csk.	natural	D	
AS 165*	aluminium alloy	L 58	120 °csk.	green anodic	X	

3

TABLE 1—*continued*

Aircraft Standard Number	Material	Material Specification	Head Type	Finish	Identification mark on end of shank	Remarks
AS 463	mild steel	BS 1109	120° csk.	cadmium		magnetic
AS 465	monel	DTD 204	120° csk.	natural	M	
AS 468*	tungum	DTD 367	120° csk.	cadmium		
AS 2230*	aluminium alloy	L 86	120° csk.	violet anodic	S	
AS 4696	monel	DTD 204	120° csk.	cadmium	M	
AS 4647	aluminium alloy	L 86	120° csk.	violet anodic	S	⎫ shank ₁⁄₆₄ in. ⎬ oversize,
AS 4648	aluminium alloy	L 37††	120° csk.	plain anodic	D	⎰ "R" on ⎱ head
AS 469	copper		flat	natural		non-magnetic
AS 2918	aluminium alloy	L 37††	90° raised csk.	natural		close tolerance
AS 3362	aluminium alloy	L 86	90° raised csk.	violet anodic		close tolerance
AS 2919	aluminium alloy	L 37††	120° raised csk.	natural		close tolerance
AS 3363	aluminium alloy	L 86	120° raised csk.	violet anodic		close tolerance

* Obsolescent.

†† Require heat treatment before driving.

3.3 **'SP' Inch Size Rivets.** Table 2 gives a list of the solid rivets which conform to the British Standards Institute Aerospace Standards for rivets in inch sizes. These rivets are made in a range of sizes from ₁⁄₁₆ inch to ⅜ inch in diameter and from ¼ inch to 3 inches long, and are illustrated in Figure 2.
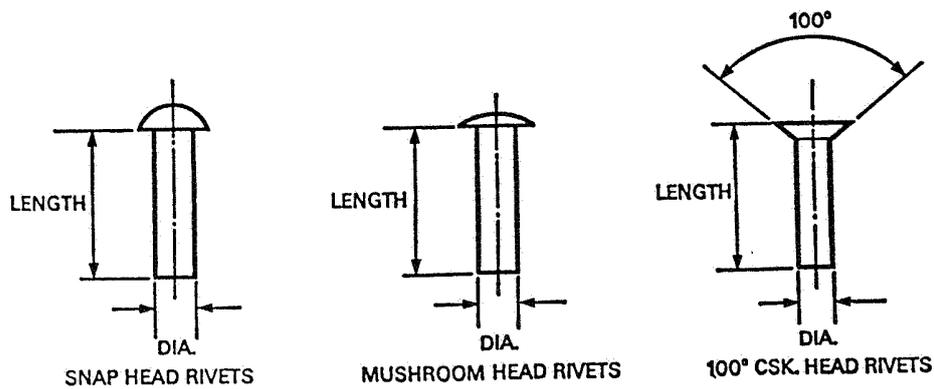

Figure 2 'SP' INCH SIZE RIVETS

TABLE 2

British Standard Number	Material	Material Specification	Head Type	Finish	Identification mark**	Remarks
SP 68	aluminium	L 36	100° csk.	black anodic	I*	
SP 69	aluminium alloy	L 37††	100° csk.	natural	7	
SP 70	aluminium alloy	L 58	100° csk.	green anodic	8	
SP 71	aluminium alloy	L 86	100° csk.	violet anodic	O†	
SP 76	steel	BS 1109	snap	cadmium		magnetic, superseding AS 455
SP 77	aluminium	L 36	snap	black anodic	I	superseding AS 155
SP 78	aluminium alloy	L 37††	snap	natural	7	superseding AS 156
SP 79	aluminium alloy	L 58	snap	green anodic	8	superseding AS 157
SP 80	aluminium alloy	L 86	snap	violet anodic	O	superseding AS 2227
SP 81	monel	DTD 204	snap	natural	M	superseding AS 457
SP 82	monel	DTD 204	snap	cadmium	M	non-magnetic, superseding AS 4694
SP 83	aluminium alloy	L 37††	mushroom	natural	7	superseding AS 158
SP 84	aluminium alloy	L 58	mushroom	green anodic	8	superseding AS 159
SP 85	aluminium alloy	L 86	mushroom	violet anodic	O	superseding AS 2228
SP 86	steel	BS 1109	100° csk.	cadmium		magnetic
SP 87	monel	DTD 204	100° csk.	natural	M	non-magnetic
SP 88	monel	DTD 204	100° csk.	cadmium	M	non-magnetic

* SP 68 rivets, prior to Amendment No. 1 to the Standard, published in September, 1959, bore no identification marks.

† SP 71 rivets, prior to Amendment No. 1 to the Standard, published in September, 1959, bore the identification mark '9' to signify manufacture from L 69 material.

†† Require heat treatment before use.

** May be on head or shank end, depending on rivet size.

3.4 **'SP' Metric Size Rivets.** Table 3 gives a list of rivets which conform to the British Standards Institute Aerospace Standards for rivets in metric sizes. These are confined, at present, to universal head and 100° countersunk truncated radiused head rivets in diameters of 2·4 to 9·6 mm and lengths of 4 to 60 mm. The identification marks listed in the table are applied to the shank end only. Figure 3 illustrates the shape of these rivets.
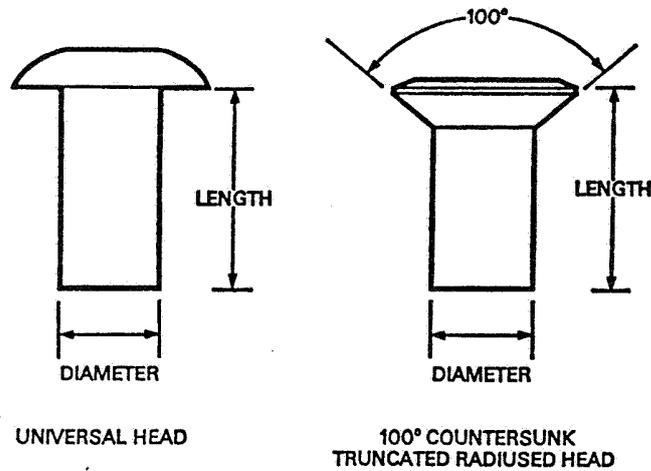
UNIVERSAL HEAD

100° COUNTERSUNK
TRUNCATED RADIUSED HEAD

Figure 3   'SP' METRIC SIZE RIVETS

TABLE 3

British Standard Number	Material		Head Type	Finish	Identification
	Type	Specification			
SP 142	al. alloy	L 86	100° csk.†	violet anodic	indented dot
SP 157	al. alloy	L 86	universal	violet anodic	indented dot
SP 158	monel	DTD 204	universal	natural	two indented dots
SP 159	monel	DTD 204	universal	cadmium	nil
SP 160	al. alloy	L 58	universal	green anodic	raised cross
SP 161	al. alloy	L 58	universal	plain anodic	raised cross
SP 162	al. alloy	L 37††	universal	natural	raised broken line and centre point
SP 163	al. alloy	L 86	universal	plain anodic	indented dot

† 100° countersunk, truncated radiused head.

†† Require heat treatment before driving.

4   AMERICAN SOLID RIVETS   American rivets in general use are listed in Table 4, together with the means of identification which, since all the aluminium alloy rivets are anodised, is by means of head markings rather than colour.   The code used for the classification of American rivets is similar to that used for British rivets and is best illustrated by an example such as MS 20470 AD 5-12, which has the following meaning:—

(i) MS signifies Military Standard

(ii) 20470 is a code for the head shape and basic material (aluminium universal head in this instance)

(iii) AD is a code for the rivet material (2117 aluminium alloy in this instance, see paragraph 4.1)

(iv) 5 is the diameter in thirtyseconds of an inch

(v) 12 is the length in sixteenths of an inch.

TABLE 4

Rivet and Material Code	Material	Material Specification	Head Type	Identification mark on head	Remarks
MS 20426A	aluminium	1100	100° csk.	nil	supersedes AN 426A
MS 20426B	aluminium alloy	5056	100° csk.	raised cross	supersedes AN 426B
MS 20426AD	aluminium alloy	2117	100° csk.	dimple	supersedes AN 426AD
MS 20426DD	aluminium alloy	2024††	100° csk.	raised double dash	supersedes AN 426DD
MS 20426D	aluminium alloy	2017††	100° csk.	raised dot	supersedes AN 426D
MS 20427	carbon steel	QQ-W-409 or QQ-S-633	100° csk.	recessed triangle	supersedes AN 427
MS 20427F	corrosion resistant steel	QQ-W-423	100° csk.	recessed dash	supersedes AN 427F
MS 20427M	monel	QQ-N-281	100° csk.	nil	supersedes AN 427M
MS 20427C	copper	QQ-W-341	100° csk.	nil	supersedes AN 427C
MS 20470A	aluminium	1100	universal	nil	supersedes AN 470A
MS 20470B	aluminium alloy	5056	universal	raised cross	supersedes AN 470B
MS 20470AD	aluminium alloy	2117	universal	dimple	supersedes AN 470AD
MS 20470DD	aluminium alloy	2024††	universal	raised double dash	supersedes AN 470DD
MS 20470D	aluminium alloy	2017††	universal	raised dot	supersedes AN 470D
MS 20613 P/Z	carbon steel	QQ-S-633	universal	recessed triangle	supersedes MS 20435
MS 20613 C	corrosion resistant steel	QQ-W-423	universal	nil	supersedes MS 20435
MS 20615 M	monel	QQ-N-281	universal	double dimple	supersedes MS 20435
MS 20615CU	copper	QQ-W-341	universal	nil	supersedes MS 20435

NOTE: For MS 20613 rivets the letter P is added to indicate cadmium plated carbon steel and the letter Z to indicate zinc plated carbon steel.

†† Require heat treatment before use.

4.1   American wrought aluminium and aluminium alloys are identified by a four digit index system. The first digit indicates the main alloying element, the second indicates modifications to the original alloy and the last two indicate the aluminium purity or the specific alloy. These numbers are followed by a letter indicating the temper condition. Table 5 shows the aluminium and aluminium alloys used in the manufacture of rivets and the condition in which they are normally supplied to the user. Further information on temper designations is contained in paragraph 4.3.

7

4.2 MS Standards provide for two types of rivets, i.e. the universal head which is standard for protruding head rivets, and the 100° countersunk head which is standard for all flush head rivets.

TABLE 5

Specifications of aluminium/alloy	Condition in which normally supplied
1100	— F as fabricated
2017	— T4 solution heat-treated
2024	— T4 solution heat-treated
2117	— T4 solution heat-treated
5056	— H32 strain hardened and then stabilised

4.3 **American Temper Designations.** American aluminium alloy rivets are given a temper designation to signify their condition. Non heat-treatable alloys such as 5056 have attained their maximum strength by working and are driven in the 'as received' condition. Of the heat-treatable alloys, 2117 does not benefit from further heat treatment and is driven in the 'as received' condition, 2024 must be solution treated before use and it is recommended that 2017 rivets of $\frac{3}{8}$ inch diameter and larger are also solution treated to prevent cracking. Heat-treatable alloy rivets are supplied in the T4 condition (solution treated by the rivet manufacturer); when solution treated by the user before driving the final temper is T31 and when driven 'as received' the final temper is T3.

5 SELECTION OF RIVETS The following paragraphs give general guidance on the factors which must be considered when rivets of either British or American manufacture are specified for a particular application.

5.1 The rivet material must be compatible with the material in which it is to be used, for reasons of strength and resistance to corrosion. L 58 (or 5056) rivets must be used in magnesium structures, monel rivets in titanium and stainless steel, and aluminium or copper rivets in parts of similar or non-metallic materials in non-structural applications. The type of aluminium alloy rivets to be used for a particular repair depends on the strength of the alloy with which it is used. Table 6 indicates the shear strengths of various rivet materials. Rivets of less shear strength than those specified in a Repair Manual c · drawing should not be used without the approval of the manufacturer. L 37 (or 2024) rivets require heat treatment before use and if they are to be replaced by L 86 (or 2117) rivets through lack of treatment facilities, the number of rivets must be increased to provide the same shear strength. Cadmium plated rivets should not be used in areas where temperatures of 250°C or more are likely to be encountered.

5.2 The shear strength of the rivets used is not the only factor which determines the strength of a riveted joint. Generally, if the thickness of the sheets is less than half the diameter of the rivets used, failure of the joint will depend on the bearing stress rather than on the shear stress in the rivets.

5.3 The diameters and types of rivets to be used in repairs are normally specified either in the Repair Manual or in the repair scheme, but in the absence of specific instructions, $\frac{3}{32}$ inch rivets should be used for 24 and 22 s.w.g. material, $\frac{1}{8}$ inch rivets for 20 and 18 s.w.g. material and $\frac{5}{32}$ inch for 16 s.w.g. If rivets of reduced diameter have to be substituted during repair work, the total number of rivets must be increased to provide equivalent cross-sectional area. Where 22 s.w.g. and thinner material is concerned, and there are no specific instructions regarding repair after a riveting failure, the substitution of mushroom head rivets for snap head rivets should be considered.

NOTE: Shear strength of a rivet is proportional to its cross-sectional area and not its diameter. Thus four rivets 1/16th inch diameter must be used to replace one rivet $\frac{1}{8}$ inch diameter.

5.4 Where a large diameter rivet is used with thin sheet metal, the pressure required to close the rivet generally causes an undesirable bulging of the sheet around the rivet head. A diameter/thickness ratio not exceeding 3 is satisfactory for protruding head rivets but for countersunk rivets this ratio should not exceed 1·5.

5.5 When British rivets have to be used in American-built aircraft, rivets of the material with the nearest equivalent shear strength to the material of the original American rivets should be selected. If, as occurs in some instances, the available British rivets have lower shear strengths than the American rivets, either the total number of rivets should be increased or rivets of larger diameter should be used to make the strength of the joint in bearing and shear not less than it was originally. However, it should be borne in mind that an increase in the size of the rivets does not necessarily increase the strength of a joint; indeed, if the rivet sizes are increased beyond a certain amount, a reduction in strength will result.

TABLE 6

American Rivet Materials			British Rivet Materials		
Material Specification	Tensile Strength lb/in^2	Shear Strength lb/in^2	Material Specification	Tensile Strength lb/in^2	Shear Strength lb/in^2
5056–H32	38000	24000	L 58	35500	28500
2117–T4	38000	26000	L 86	38000	29500
2017–T4	55000	33000	L 37	56000	36000
2024–T4	62000	37000	L 37	56000	36000

5.6 To ensure correct seating, countersunk head rivets should always be installed in dimples or countersunk holes of the same angle as the rivet head. Rivets with countersunk heads of 70° or 82° included angle are often used in positions where sealing is of primary importance, such as in integral fuel tanks, and when these rivets require replacement care is necessary to ensure that rivets with the correct angle heads are selected.

6 **HEAT TREATMENT** Rivets which require heat treatment prior to driving should be treated in accordance with the requirements of the relevant specification.

6.1 Generally the most satisfactory way of heating rivets is to immerse them in a salt bath, although muffle furnaces of the circulating hot air type are also used. The rivets should be placed in wire baskets or perforated containers and immersed in the salts for 15 minutes, then quenched in water at a temperature of not more than 40°C. The time between removal from the bath and quenching must be not more than 10 seconds to achieve satisfactory properties. The temperature of the bath must be 495 ± 5°C

(maximum 496°C for 2024 rivets) and if the maximum is exceeded at any time the rivets should be rejected. Rivets which have been heated in a salt bath must be thoroughly washed after quenching to remove all traces of salt.

6.2   BS L37 rivets commence to age harden immediately after quenching and should normally be used within 2 hours of treatment (a period of 20 minutes is specified for 2024 rivets). Age hardening can be delayed by storing the rivets at a low temperature immediately after quenching. At a temperature of 0°C to −5°C they will keep satisfactorily for 45 hours and at a temperature of −15°C to 20°C for 150 hours, but must be used within 2 hours of removal from cold storage.

6.3   If the treated rivets have not been used within the prescribed time after solution treatment they may be re-treated up to a maximum of three times. Further heat treatments would increase the grain size and result in low strength even after ageing. Further guidance on the heat-treatment of wrought aluminium alloys is given in Leaflet BL/9–1.

6.4   Precautions must be taken to prevent the accidental use of aged rivets. A satisfactory method of ensuring this is to use the rivets from trays or boxes which are coloured to indicate the periods during which the rivets may be used. Thus a suitable colour code might permit only rivets from green trays to be used during the first two hours of a working day, after which only rivets from blue trays should be used for the next two hours and so on. American 2024 rivets could be controlled in a similar manner but the elapsed time should not exceed 20 minutes.

BL/6-28

Issue 1.

1st April, 1972.

BASIC

ENGINEERING PRACTICES AND PROCESSES

HOLLOW RIVETS AND SPECIAL FASTENERS

1   INTRODUCTION   This Leaflet gives general information on the various types of hollow rivets used in aircraft structures.   It lists the principal types of British and American tubular, hollow and self-sealing rivets and also includes information on other types of fasteners which are widely used as replacements for nuts and bolts.   Information on solid rivets is given in Leaflet BL/6-27 and guidance on the appropriate riveting practices in Leaflet BL/6-29.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet AL/7-6, Issue 1, dated 1st July, 1956.

2   GENERAL   Hollow rivets may be broadly classified into two main groups, those which are closed by drawing a mandrel through the bore and those which are closed by hammering.   The first group are known as 'blind' rivets, because they may be installed when only one side of the rivet hole is accessible.

2.1   It is most important that the correct tools are used, with the types of rivets mentioned in this Leaflet, a variety of tools being available for each type of rivet.   Power tools are normally used by aircraft manufacturers, but hand tools are often used with the smaller rivet sizes for repair work.

2.2   Blind rivets may only be used to replace solid rivets when this is permitted by the repair scheme.   In the absence of specific instructions it is important to ensure that the rivet is either of the same material as the original solid rivet or, if dissimilar, has the minimum potential difference with the material being riveted, otherwise there may be a risk of corrosion (see Leaflet BL/4-1).   The blind rivet must also possess equivalent shear strength and this may be achieved by plugging the rivet bore.

3   BLIND RIVETS   The blind rivets discussed in this paragraph are all closed by pulling a mandrel through the bore.   In some cases the mandrel also plugs the rivet, but in others a separate sealing pin must be driven in after the rivet has been closed.

3.1   **Chobert Rivets.**   Chobert rivets are manufactured with either snap or countersunk heads and are normally supplied in tubes for ease of assembly on the mandrel.   The action of closing a Chobert rivet is shown in Figure 1, initial movement of the mandrel down the tapered bore forming the head and subsequent movement expanding the shank to fill the rivet hole.   Sealing pins are an interference fit in the rivet bore and, apart from increasing shear strength, will prevent the ingress of moisture.

3.1.1   The Chobert rivets which have been given AGS numbers by the Society of British Aerospace Companies are shown in Table 1, but many other types are suitable for
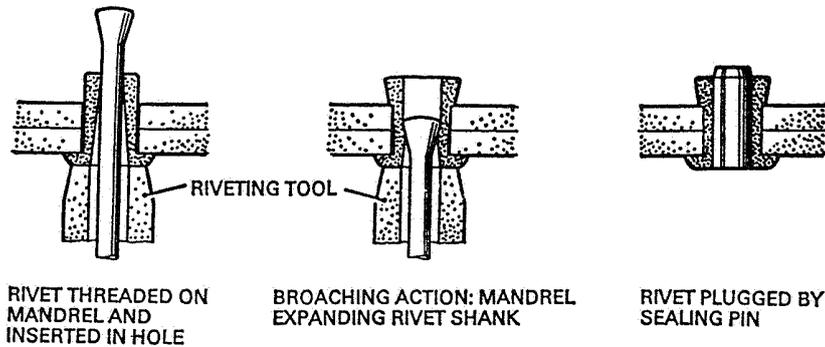
1

RIVET THREADED ON
MANDREL AND
INSERTED IN HOLE

BROACHING ACTION: MANDREL
EXPANDING RIVET SHANK

RIVET PLUGGED BY
SEALING PIN

Figure 1 CLOSING CHOBERT RIVETS

use on aircraft, full details of materials, size and grip lengths being quoted in the manufacturer's literature. For ordering purposes Chobert rivets may be identified by either the AGS number or a four figure code number assigned to it by the manufacturer. This is followed by a further four figures indicating the size of the rivet. The first two figures of the size code indicate the diameter and the second two the length (both in thirtyseconds of an inch), except that if the AGS number is being quoted a zero in the diameter code is disregarded. As an example, a steel snap head rivet, $\frac{5}{32}$ inch diameter and $\frac{3}{8}$ ($\frac{12}{32}$) inch long, would be known by the manufacturer as 1201-0512, but the same rivet could also be ordered as AGS 2040/512.

NOTE: The length referred to for ordering purposes is the length of the rivet as supplied (i.e. shank length of snap head rivets and total length of countersunk rivets) and not the thickness to be riveted (i.e. grip).

3.1.2 The size code used for sealing pins fitted to snap head rivets is the same as the code used for the rivet itself, but if a sealing pin is to be fitted to a countersunk rivet the preceding length should be quoted. For example, a sealing pin for an AGS 2045/512 rivet (snap head) would be AGS 2047/512, but a sealing pin for an AGS 2068/512 rivet (100° countersunk) would be AGS 2047/510.

TABLE 1
CHOBERT RIVETS

AGS Number	Maker's Code	Head Type	Material Spec.	Anti-corrosive treatment	Identification
2040	1201	snap	DTD 720	cad. plated	magnetic
2045	1211	snap	L86	anodised	dyed violet
2041	1203	120° countersunk	DTD 720	cad. plated	magnetic
2046	1213	120° countersunk	L86	anodised	dyed violet
2067	1204	100° countersunk	DTD 720	cad. plated	magnetic
2042	1281	sealing pin	DTD 904	cad. plated	magnetic
2047	1282	sealing pin	L64	anodised	plain

3.1.3 A range of Chobert rivets with oversize shanks is also available and may be used for repair work on aircraft. This is an advantage when rivets have been removed, since the increase in diameter is of the order 0·015 to 0·020 inches, depending on rivet size, so that repositioning of holes or re-stressing of joints is unnecessary.

3.2 **Avdel Rivets.** These rivets are similar to Chobert rivets, but each is fitted with its own stem (mandrel), the component parts being referred to as the body and stem respectively. The stem is pulled into the body to close the rivet and, at a predetermined load, breaks proud of the manufactured head, leaving part of the stem inside the body in the form of a plug. Excess stem material may be nipped off and milled flush with the rivet head when required, e.g. on external surfaces, but stainless steel and titanium rivet stems break flush with the rivet head at the maximum grip range limit, and milling may not be necessary. The action of closing an Avdel rivet is shown in Figure 2.
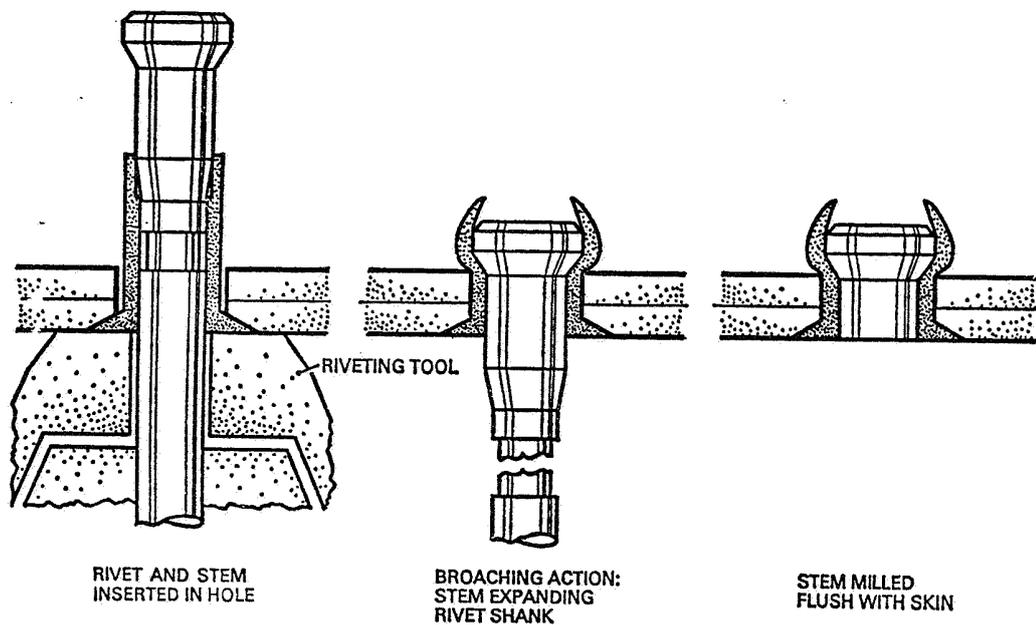
RIVET AND STEM INSERTED IN HOLE

RIVETING TOOL

BROACHING ACTION: STEM EXPANDING RIVET SHANK

STEM MILLED FLUSH WITH SKIN

Figure 2 CLOSING AVDEL RIVETS

3.2.1 The Avdel rivets which have been given AGS numbers are shown in Table 2, and some of the more common rivets which may be used on aircraft, but do not have AGS numbers, are also included.

3.2.2 The code used for the identification of Avdel rivets is the same as that used for Chobert rivets, i.e. the AGS number or the manufacturer's product code, followed by the size code.

3.2.3 The oversize rivets listed in Table 2 are used for repair purposes. The increase in diameter is similar to that quoted in paragraph 3.1.3 for Chobert rivets, and the same advantages apply.

3.2.4 Avdel rivets are lubricated by the manufacturer to facilitate forming the rivet and on no account should the rivets be cleaned in solvent before use. The lubricants used are specially prepared for each type to obtain consistent results.

TABLE 2
AVDEL RIVETS

AGS Number	Maker's code	Head Type	Material spec.		Finish	Remarks
			Body	Stem		
2065	4022	snap	L86	DTD 5074	anodised	—
2066	4032	100° countersunk	L86	DTD 5074	anodised	stem dyed red
—	4102	snap	L86	DTD 5074	anodised	oversize rivet, stem dyed violet
—	4132	100° countersunk	L86	DTD 5074	anodised	oversize rivet, stem dyed green
3920	4051	snap	DTD 189	FV 448	plain	stainless steel
3921	4057	100° countersunk	DTD 189	FV 448	plain	stainless steel
3922	4061	snap	DTD 189	FV 448	body cad. plated	stainless steel
3923	4067	100° countersunk	DTD 189	FV 448	body cad. plated	stainless steel
—	4074	universal	I.M.I. 230	I.M.I. 138A	plain	titanium
—	4077	100° countersunk	I.M.I. 230	I.M.I. 138A	plain	titanium

NOTE: Until recently all Avdel rivets manufactured from L86 were dyed violet. This practice has been discontinued because of the frequent need to use these rivets in exterior aluminium surfaces which are not subsequently painted. The stems only are now dyed for identification purposes.

3.2.5 The shear strength of Avdel rivets is similar to that of solid rivets and is somewhat greater than that of Chobert rivets of similar material and size.

3.3 **Tucker 'Pop' Rivets.** Tucker 'Pop' rivets are manufactured with either domed or countersunk heads, and are supplied threaded on individual mandrels. There are, basically, two different types of rivets, known as 'standard' (open) and 'sealed'. The action of closing both types of rivet is shown in Figure 3.

3.3.1 The mandrels of standard type rivets are of two types, namely break head and break stem. With the former type the mandrel head separates from the formed rivet, but with the latter the head is retained in the rivet bore and provides a measure of sealing. The break head rivets are not widely used on aircraft due to the difficulty of recovering broken mandrel heads.

3.3.2 The mandrels of sealed type rivets are also of two types, the short break and the long break. The short break mandrel breaks immediately under the head, but the long break mandrel breaks outside the rivet thus greatly increasing shear strength of the rivet and providing a flush finish when the protruding stem is nipped off.

3.3.3 A wide variety of tools is available for closing 'Pop' rivets, ranging from plier type hand tools to pneumatically or hydraulically operated power tools. A range of interchangeable heads for these tools permits closing the rivets where access is restricted.
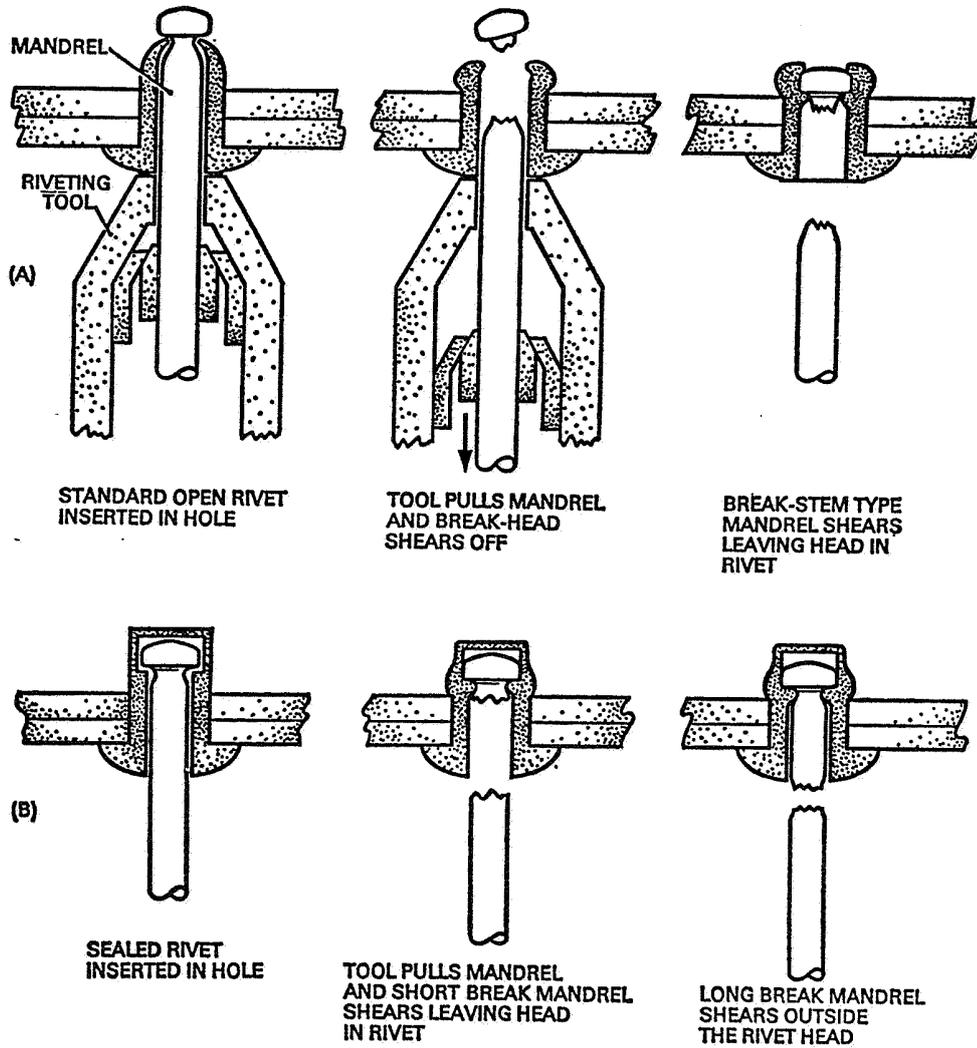
MANDREL

RIVETING
TOOL

(A)

STANDARD OPEN RIVET
INSERTED IN HOLE

TOOL PULLS MANDREL
AND BREAK-HEAD
SHEARS OFF

BREAK-STEM TYPE
MANDREL SHEARS
LEAVING HEAD IN
RIVET

(B)

SEALED RIVET
INSERTED IN HOLE

TOOL PULLS MANDREL
AND SHORT BREAK MANDREL
SHEARS LEAVING HEAD
IN RIVET

LONG BREAK MANDREL
SHEARS OUTSIDE
THE RIVET HEAD

Figure 3   CLOSING TUCKER 'POP' RIVETS

3.3.4 The manufacturer's identification code varies according to the type or rivet (i.e. standard or sealed) but similar letters are used to indicate material and head shape as follows:—

(i) Standard rivets,

T = Tucker

L, A, S or C = Monel (DTD 10B), L58, steel (E.N.2a) or copper respectively.

5

P = 'Pop' rivet

D or K = domed or countersunk head (120°) respectively.

BH or BS = break head or break stem respectively.

Size is indicated by three figures, the first indicating diameter and the last two the length of shank.

Thus a rivet coded TAP/K412 BH would be a Tucker, L58, 'Pop' rivet, with a countersunk head, $\frac{4}{32}$ ($\frac{1}{8}$) inch diameter with a shank length of 0·12 inch and a break head mandrel.

(ii) Sealed rivets,

A or C = L58 or copper respectively.

D or K = Domed or countersunk head (120°) respectively.

R = Reinforced (i.e. long break mandrel). Size is indicated by two or three figures, the first indicating diameter and the remainder the maximum riveting thickness.

Thus a rivet coded AD 48R would be an L58, domed head rivet, $\frac{4}{32}$ ($\frac{1}{8}$) inch diameter, capable of riveting material up to $\frac{8}{32}$ ($\frac{1}{4}$) inch thick and having a long break mandrel.

NOTE 1: The above details apply to the majority of aircraft rivets but rivets of different materials and head shapes are also available.

NOTE 2: Mandrels are normally of steel but are also available in different materials.

3.3.5 AGS numbers have been given to some of the standard 'Pop' rivets and the most common are as follows:—

AGS 2048, L58 domed head

AGS 2049, L58 120° countersunk head

AGS 2050, Monel (DTD 10B) domed head

AGS 2051, Monel (DTD 10B) 120° countersunk head

AGS 2070, Monel (DTD 10B) 100° countersunk head

The AGS number is followed by the manufacturer's coding for size and mandrel type as given in paragraph 3.3.4 (i).

3.4 **Cherry Rivets.** These are rivets of American manufacture and are very similar to Avdel rivets, except that the stem is positively locked in the rivet bore. During the final stages of forming, a locking collar, located in a recess in the rivet head, is forced into a groove in the stem, and prevents the stem from further movement. Alternative types of blind head may be formed, and these are known as 'standard' and 'bulbed'. The only practical difference between these types is that the bulbed rivet stem has a stepped head, and the finished blind head is flatter and broader than the standard head. The action of closing a Cherry rivet is shown in Figure 4.

3.4.1 After forming, the stem protrudes slightly beyond the rivet head and this excess, plus part of the locking collar, may be milled off to provide a flush finish.

3.4.2 Cherry rivets are installed using hand or power operated tools, and it is important that the tools are fitted with the correct type of head for the particular size or type of rivet. Details are normally supplied by either the aircraft or tool manufacturer.

3.4.3 Cherry rivets are identified by a four figure number followed by a figure indicating the diameter in thirtyseconds of an inch, and a further figure indicating the maximum grip in sixteenths of an inch. As an example, CR 2162-3-6 refers to a Cherry rivet in aluminium alloy, with a countersunk head and standard stem, $\frac{3}{32}$ inch diameter and a maximum grip of $\frac{3}{8}$ inch. Table 3 shows some of more common Cherry rivets, together with identification details.
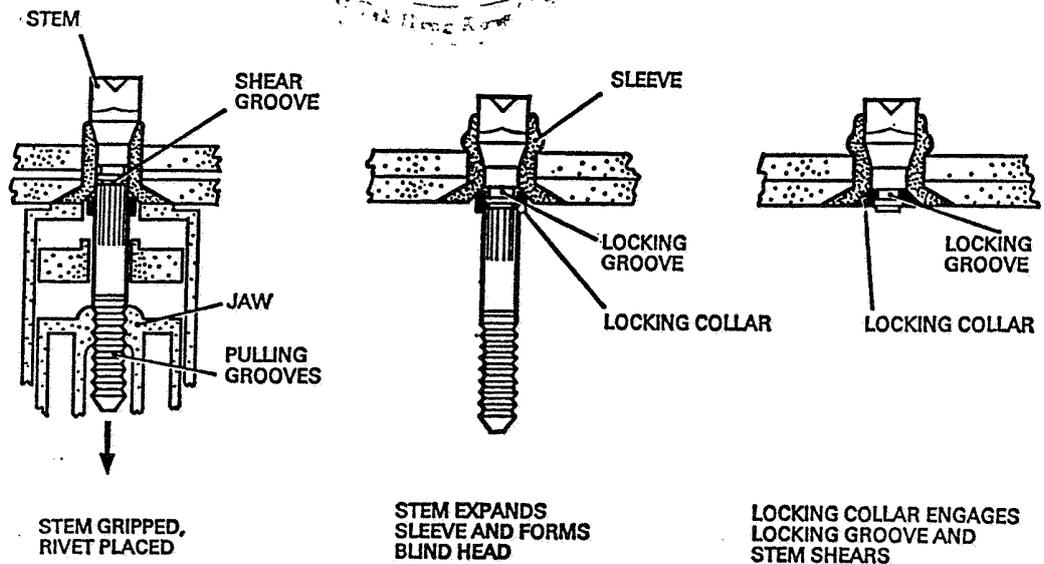
| STEM GRIPPED, RIVET PLACED | STEM EXPANDS SLEEVE AND FORMS BLIND HEAD | LOCKING COLLAR ENGAGES LOCKING GROOVE AND STEM SHEARS |

Figure 4 CLOSING CHERRY RIVETS

TABLE 3
CHERRY RIVETS

			Material		Finish	
Code	Type	Head	Rivet	Stem	Rivet	Stem
CR 2162	standard	countersunk	2017	7075	205 Alumite	1200 Alodine
CR 2163	standard	universal	2017	7075	205 Alumite	1200 Alodine
CR25625	standard	countersunk	monel	monel	silver plate	natural
CR25635	standard	universal	monel	monel	silver plate	natural
CR 2662	standard	countersunk	st. steel	st. steel	dry film	natural
CR 2663	standard	universal	st. steel	st. steel	dry film	natural
CR 2248	bulbed	countersunk	5056	steel	anodised	cad. plate
CR 2249	bulbed	universal	5056	steel	anodised	cad. plate

NOTE: A figure indicating maximum grip is marked on the rivet head.

4   TUBULAR RIVETS   Tubular rivets were, at one time, quite often used on tubular structures, such as engine mountings or fuselage frames, for joining tubes to fittings, or for repair work.   These parts are now more often welded or fixed with taper pins, but tubular rivets may still be found on a number of aircraft.   These rivets are closed by hammering, using specially shaped punches and snaps, and care is necessary to prevent buckling the rivet or tube.   To prevent buckling and to maintain the tube shape, distance tubes are often used.

4.1   The most common type of tubular rivet is the one manufactured in accordance with AGS 501, and is obtainable in various materials, diameters and gauges.   Another type of tubular rivet (covered by AGS 513, 514, 515 and 516) is the 'split' or 'Cox' rivet, which is formed from sheet material and may have a straight or serrated joint running axially along the rivet length.   This type of rivet is only used in non-structural applications.

7

5   SPECIAL FASTENERS   The special fasteners discussed in this paragraph are closed by means of a collar which is swaged into grooves in the fastener shank or expanded over the shank to form a blind head. The fasteners are generally used instead of bolts and present a considerable saving in weight.

5.1   **Hi-shear.** The Hi-shear fastener consists of a pin of high shear strength and a collar of softer material which is forced into the pin groove by the riveting action (see Figure 5). The pins are supplied with standard or close tolerance shanks and may have either of two differently shaped grooves (the '100' series which uses aluminium alloy collars only, and the '200' series which uses collars in a variety of materials). Some pins are supplied with oversize shanks for repair work.
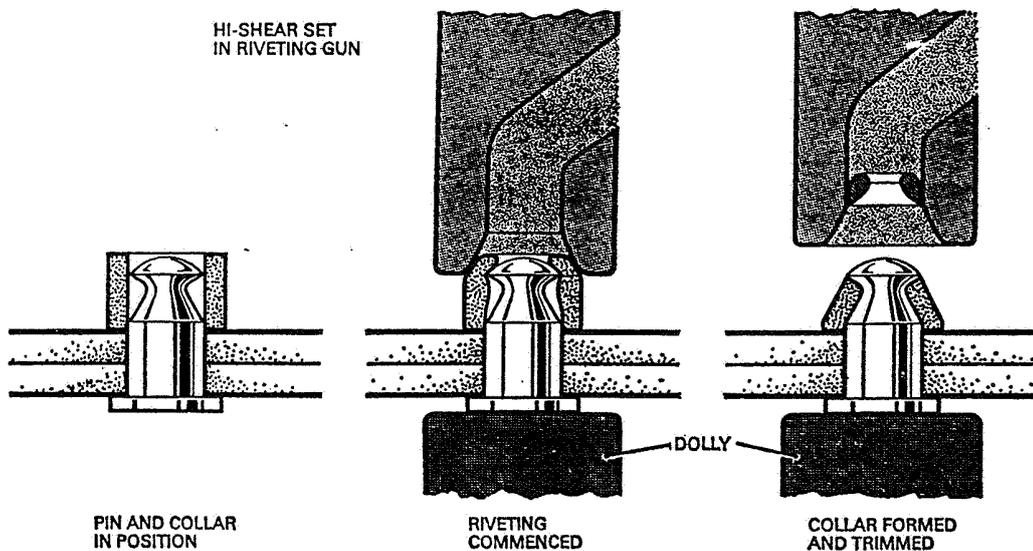
HI-SHEAR SET
IN RIVETING GUN

PIN AND COLLAR
IN POSITION

RIVETING
COMMENCED

DOLLY

COLLAR FORMED
AND TRIMMED

Figure 5 CLOSING HI-SHEAR FASTENERS

5.1.1   For ordering purposes Hi-shear pins and collars are identified by a prefix (BBH), followed by a series of numbers or letters indicating type, material and size. Pins and collars are ordered separately from the following codes:—

(i) A three figure number indicating shank tolerance and collar material.

(ii) A letter indicating head shape (C=countersunk, F=flat).

(iii) A letter indicating pin material (N=55/65 ton steel, H=75/85 ton steel, S= stainless steel, K=monel, T=titanium and A=aluminium alloy).

(iv) Two figures indicating nominal diameter in thirtyseconds of an inch (in addition the letters C & D may be used for pins the same size as No. 8 and No. 10 Unified bolts).

(v) Two figures indicating maximum grip length in sixteenths of an inch.

As an example, a close tolerance flat head pin in stainless steel, ¼ inch diameter, with a grip length of ½ inch and for use with an aluminium alloy collar, would be BBH/101/ FS/04/08; the matching collar would be BBH/104/04.

5.1.2 For recognition purposes symbols are marked on pin heads, or a dyed finish is added, as shown in Table 4. In addition the letter 'P' is added to precision (close tolerance) pins, and '$\frac{1}{32}$' or '$\frac{1}{64}$' added to oversize pins as appropriate.

TABLE 4
HI-SHEAR RECOGNITION FEATURES

Material	Marking	Finish
Pins		
55/65 ton steel	B+	cadmium plated
75/85 ton steel	Ⓑ	cadmium plated
stainless steel	. B .	natural
monel	BM	natural
titanium	BT	natural
aluminium alloy	nil	anodised and dyed blue
Collars		
(a) for '100' series pins:—		
aluminium alloy	nil	anodised and dyed mauve
(b) for '200' series pins:—		
aluminium alloy	nil	anodised and dyed green
stainless steel	nil	natural
mild steel	nil	cadmium plated
annealed monel	nil	natural

5.1.3 Hi-shear pins are placed using a special hi-shear rivet set which forms and trims the collar. Collars are pre-lubricated and should not be washed in solvent before use.

5.1.4 Some Hi-shear pins were produced with a grooved shank to release trapped jointing compound; in all other cases where wet-assembly is called for the exposed pin shank must be wiped clean to ensure correct forming of the collar.

5.2 **Avdelok Fasteners.** These fasteners are typical of a wide variety of proprietary fasteners available in America and the United Kingdom. The bolt portion of the fastener is solid and a collar is swaged onto grooves in the bolt shank as shown in Figure 6. When swaging is complete the bolt shears flush with the collar. Avdelok fasteners are manufactured with a number of different head shapes, in steel or aluminium alloy, with diameters of $\frac{1}{16}$ inch to $\frac{1}{2}$ inch. They are normally placed with power operated tools.

5.2.1 Some aircraft manufacturers recommend that the holes for Avdelok fasteners should be reamed to an interference fit, and lay down the tolerances to be achieved. This practice requires a different technique for placing the fasteners, the bolt first being inserted without its collar and pulled into place by use of the riveting gun, then the collar is fitted and swaged by a second operation of the gun.

5.2.2 As with other similar fasteners the Avdelok is pre-lubricated and should not be de-greased before assembly except that, if an interference fit is specified, lubricant must be removed from the bolt. If wet assembly is specified the sealant must be removed from the bolt shank before swaging.
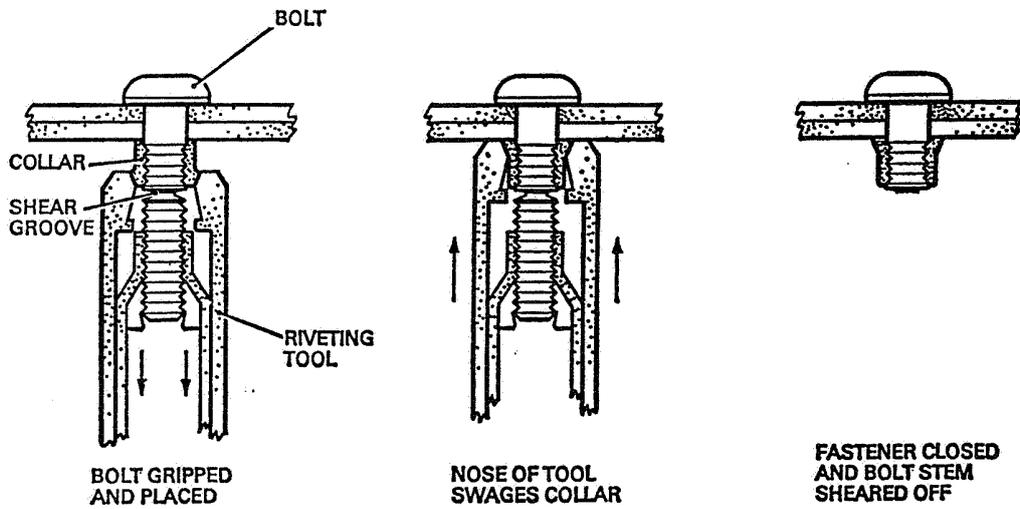
Figure 6   CLOSING AVDELOK FASTENERS

5.2.3   Avdelok fasteners are identified by a code system similar to that used for Chobert and Avdel rivets, namely a four figure product code and a four figure size code.

5.3   **Jo-bolts.**   Although Jo-bolts may be classified as blind rivets, the method of closing is different from the methods previously discussed. The complete item consists of a threaded bolt with a round head, a rivet shaped nut and a sleeve, assembled as illustrated in Figure 7.   Rotation of the bolt forces the sleeve up the tapered nut shank, clamping the materials to be joined, and at a predetermined load the bolt shears just inside the nut head leaving, virtually, a solid steel rivet in the hole.
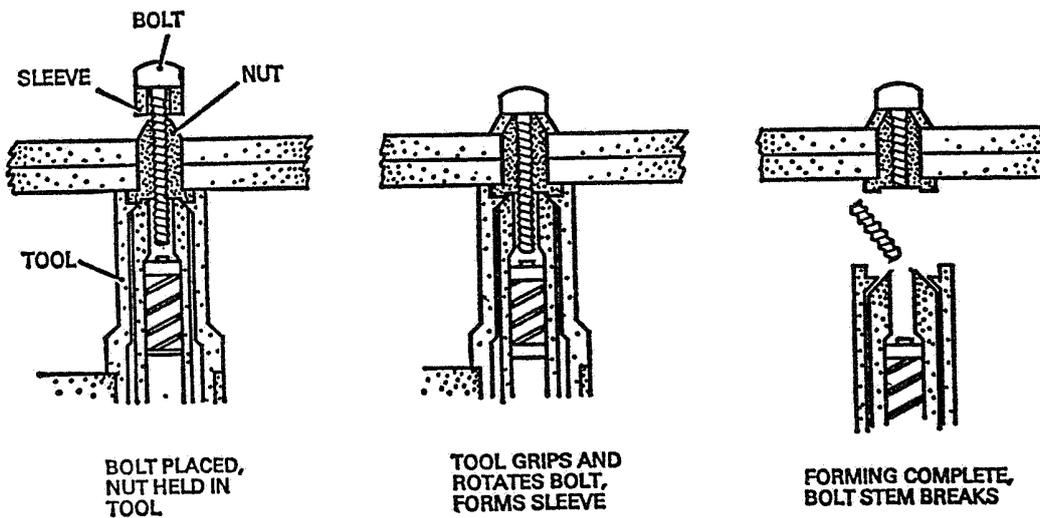

Figure 7   CLOSING JO-BOLTS

5.3.1 Jo-bolts are manufactured with hexagon or 100° countersunk heads, in either stainless or alloy steel, and have a shear strength almost equal to a bolt of equivalent size and material. The bolts are pre-lubricated and must not be washed in solvent, since this would alter the gripping strength at which the bolt breaks.

5.3.2 The tools used for placing Jo-bolts are in two concentric parts, the outer part holding the nut and the inner part gripping the bolt shank. Different adaptors must be fitted to the tools to accommodate the different size hexagon heads, or cruciform slots of countersunk bolts.

5.3.3 Jo-bolts are identified by an eight figure code number, the first four figures indicating type and material, and the remainder the size, in a similar way to Avdel rivets. As an example the code 2103-0607 indicates a 100° countersunk bolt in cadmium plated alloy steel, with a diameter of $\frac{6}{16}$ inch and nominal grip of $\frac{7}{16}$ inch.

5.4 **Rivnuts.** Rivnuts were originally developed for securing rubber de-icing boots to the leading edges of aerofoil sections but they are now also used, for example, for securing floor coverings and other non-structural parts. They are a form of blind rivet which can be used as an anchor nut, the internal bore being threaded to receive a bolt or screw. Rivnuts used on de-icing boots have a 6-32 thread and have either flat or countersunk heads. The countersunk head types are open ended and may or may not have a locating key, but the flat head types all have a locating key and are supplied with either a closed or open end. Marks on the head indicate length in accordance with a manufacturer's code. Rivnuts are installed with a special tool fitted with a threaded mandrel; the mandrel is screwed into the rivnut, and when the gun is operated the shank expands as shown in Figure 8.
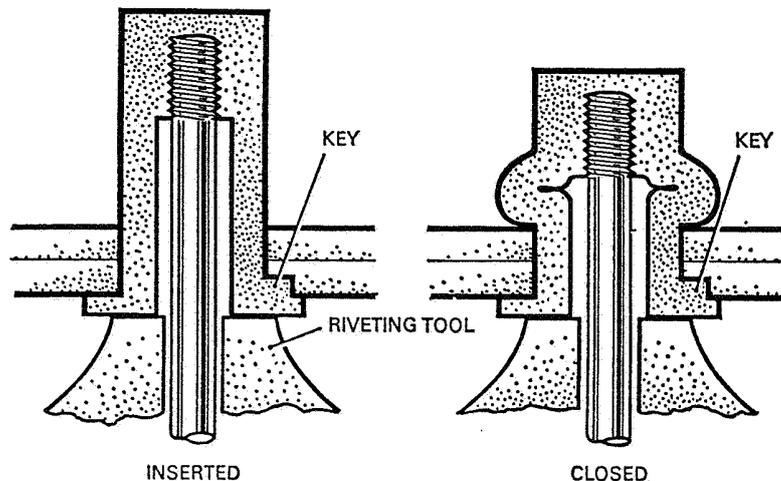

Figure 8 CLOSING RIVNUTS

BL/6-29

Issue 1.

1*st April*, 1972.

BASIC ENGINEERING PRACTICES AND PROCESSES
RIVETING

I   INTRODUCTION   This Leaflet gives guidance on the riveting of aircraft struc-
tures, particularly from the repair aspect.   It also outlines some of the factors involved
in preparing work for riveting and gives the procedures for closing various types of rivets.
Information on the classification and identification of the main types of British and American
rivets is given in Leaflets BL/6-27 and BL/6-28, which should be read in conjunction with
this Leaflet.   Further information on the repair techniques applicable to riveted structures
is contained in Leaflet AL/9-1.

NOTE: This Leaflet incorporates the relevant information previously published in Leaflet AL/7-7, Issue 1,
1st July, 1956.

2   GENERAL   Information on the size and type of rivets to be used, and the spacing
to be employed for a particular repair, is normally specified in an approved repair scheme
for a particular aircraft type.   Unless otherwise stated the repair should follow the system
of riveting used elsewhere on that aircraft at similar locations.   It must be appreciated
that the original pattern of riveting will have been deliberately selected and on all modern
aircraft will have been proven in both static and fatigue structural test programmes.   In
carrying out any repair of major structural components, such as pressurised cabins and
integral fuel tanks, the same type of riveting and a comparable quality of riveted assembly
are vital to the integrity of the structure.   If departure from the normal methods of
construction is necessary, for example, different rivets or rivet spacing, approval of the
manufacturer should be sought, since the strength of the repair might be affected.   Provided
that the approved repair scheme is followed in every detail, and that drilling and riveting
techniques are of a high standard, the integrity of the structure will not be degraded.   On
completion, the repair should be inspected as outlined in paragraph 9 and any exposed
metal reprotected.

3   RIVET SELECTION   A number of factors must be taken into account when selecting
the rivets to be used for a particular application.   Generally the strength of the rivets
must be similar to that of the material in which they are used; the size, number and spacing
of rivets is calculated from the tensile strength and bearing strength of the sheet material
and the shear strength of the rivets.   The rivet diameter should be approximately three
times the thickness of a single sheet of the material being joined, for example, $\frac{1}{8}$ inch diameter
rivets should normally be used with 20 s.w.g. (0·036 inch) sheet, and $\frac{5}{32}$ inch diameter
rivets with 18 s.w.g. (0·048 inch) sheet, but this may be unsuitable when holes are cut-
countersunk (see paragraph 5.1).

3.1   Figure 1 shows the spacing normally applied to double chain and staggered lap
joints to obtain maximum strength; in other types of riveted structures a rivet pitch
(i.e. distance between rivets in a row) of four times rivet diameter (D) and distance from
sheet edge (land) of 2D are typical.   Where a rivet is used to fasten an angled member,
the rivet must not be so close to the bend that the rivet cannot be properly closed when
using the appropriate dollies or special tools.
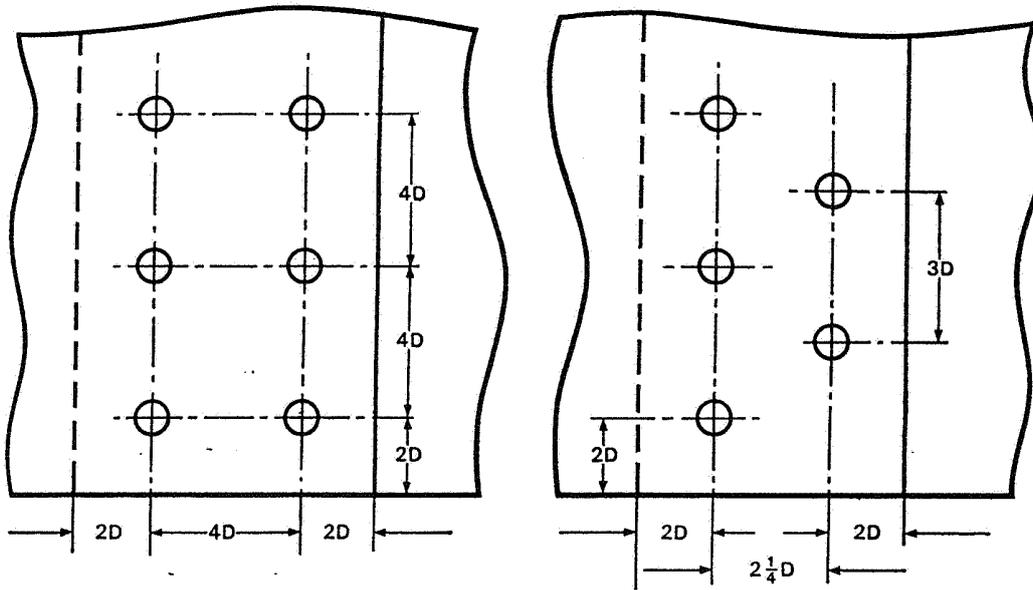
(D = DIAMETER OF RIVET SHANK)

Figure 1   MINIMUM SPACING FOR RIVETED JOINTS

4   HOLE PREPARATION

4.1   Marking Out.   Careful marking out is a prerequisite for accurate drilling.   Aluminium alloy parts used on aircraft should not be marked out with a scriber or other tool which will scratch the surface, unless the marks are subsequently machined off or otherwise removed.   A thin coat of zinc chromate primer makes a suitable background for pencil lines, but it may be preferable to manufacture a template which can be used as a drilling jig on the aircraft.

4.2   Hole Size.   The size of the rivet holes has a positive bearing on the strength of a riveted joint.   A clearance must exist between the rivet and the hole in which it is fitted to accommodate expansion of the shank during forming.   If the clearance is too small the sheets will tend to buckle, whereas if the clearance is too large separation of the sheets may occur (see Figure 4).   The selection of the correct size rivet countersink, dimple and rivet hole, should be made by reference to tables published by the aircraft manufacturer.   The recommended sizes vary according to the gauge of the structural materials being joined and the size, form, length and material of the rivets being used.   In general the harder and longer the rivet the smaller the clearance, but close tolerance holes and interference fits are often a requirement.

4.2.1   As a result of laboratory tests and engineering development at the design stage, carefully controlled hole sizes and rivet fits are used in critical fatigue-prone locations.   Should it be necessary to disturb structure of this type it is imperative that reassembly be carried out in accordance with the original drawings or repair schemes, or as advised by the aircraft manufacturer.

4.2.2 In order to allow for slight misalignment during assembly work, it is usual to drill pilot holes at positions where rivets are to be fitted. When the assembled structure is ready for riveting, the holes should then be opened out to the required size.

4.2.3 When a structure has to be dimpled to accommodate countersunk rivets, the holes should first be drilled undersize, since the dimpling action enlarges the hole. After the dimple is formed the hole may then be drilled or reamed out to the appropriate size; this action must also remove any small radial cracks which have formed round the hole during the dimpling operation. Some aircraft manufacturers may permit dimpling to be carried out from final size holes, but this practice is normally only applicable to lightly loaded structures.

4.3 **Drilling Technique.** It is always important to use a drill which is sharp and accurately ground, and to prevent the drill 'wandering off' it is advisable to mark the drilling position with a centre punch. Care must also be taken to ensure that the drill is held perpendicular to the work surface, and it may be advisable in certain circumstances to use a drilling jig to prevent error. A badly drilled hole will prevent accurate riveting and may result in failure to meet the design strength requirements of a joint.

NOTE: When drilling out rivets on complete aircraft care must be taken to prevent damage to pipes, wiring looms or subsidiary structure, and precautions taken to prevent the ingress and facilitate recovery of swarf and pieces of rivets.

4.4 **Deburring of Holes.** One aspect of riveting which often receives insufficient attention is the deburring of holes. It is most important that all rough edges and swarf are removed after drilling or reaming operations, for example, where holes are finally drilled on assembly, the structure must be disassembled for deburring and swarf removal before final assembly and riveting. A special deburring tool must be used for removing rough edges, an ordinary drill larger than the rivet hole being considered unsuitable. A power driven cutter with a locating spigot and concentric stop sleeve is normally used when a large number of holes have to be deburred. Burrs should not be removed with files or emery paper.

5   COUNTERSINKING When countersunk rivets are to be fitted, there are two methods of accommodating the rivet head to ensure a flush fit. Cut-countersinking is employed where sheet thickness is greater than the depth of the rivet head, but for thinner sheets dimpling is necessary. Where sheets of different thicknesses are joined together it may be found that both methods are used, a thin outer sheet being dimpled into a countersunk thick inner sheet.

5.1 **Cut-countersinking.** Table 1 shows the minimum sheet thickness which may be countersunk for particular rivet diameters, and is applicable where 100° or 120° countersunk head rivets are used. Where special rivets with different head angles are used the aircraft manufacturer may specify a different minimum sheet thickness, and when oversize rivets are being fitted it may be recommended that the rivet heads are milled in preference to cut-countersinking into supporting structure.

TABLE 1   MINIMUM SHEET THICKNESS FOR COUNTERSINKING

Rivet diameter (inch)	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$
Minimum sheet thickness (s.w.g.)	18	16	14	12

5.1.1. Special countersinking tools should be used for cut-countersinking. The tools should have a centralising spigot and an adjustable depth stop which will limit the depth of cut.   The rivet head should always be slightly proud of the work before riveting, and this can be set by trial drilling in scrap material.   Aircraft manufacturers usually specify a tolerance on head protrusion after riveting, and this is usually of the order of 0·005 inch above the skin surface.   It is not normally permissible for the rivet head to be below the skin surface.

5.2   **Dimpling.**   This is a process for indenting thin sheet material (not normally thicker than 16 s.w.g.) around a drilled hole to accommodate a countersunk rivet.   If correctly preformed, dimpling has a beneficial effect on the strength of a joint, but the method of dimpling must be related to the ductility of the material to prevent overstressing and cracking.

5.2.1   **Dimpling Characteristics.**   The aluminium alloy skin panels commonly used for stressed skin structures are either solution treated and naturally aged or solution treated and artificially aged.   The naturally aged materials and some of the artificially aged clad materials may be satisfactorily dimpled at room temperature, although if dimples of 90° or less are required, hot dimpling may be specified.   Carefully controlled spin dimpling processes are considered suitable for L70, L72, L73, DTD 746 and 2024–T4 aluminium material and stainless steel, but hot dimpling should be used for the stronger but less ductile L71, DTD 687, 2014–T6 and 7075–T6 aluminium alloys, and for titanium.

5.2.2   **Control Tests for Dimpled Sheet.**   Before dimpling any aircraft material of which the dimpling characteristics are uncertain, either because of lack of familiarity with the material itself or because of the use of a new dimpling technique or tool, tests should be made on sample material of the same gauge, specification and heat treatment condition.

(i) Specimens of the material should be cut approximately 8 inches long and 1 inch wide, and dimpled along the centreline of the strip at the pitch to be used on the aircraft.   When the strip is bent across the dimples as shown in Figure 2, cracks across the dimples at the bend may be expected and are acceptable, but if other radial or circumferential cracks develop the process must be considered unsatisfactory.

(ii) Before any method of dimpling is approved for production, its suitability for the particular combination of material, gauge, dimple and rivet size should be assessed by the Design Department.   A number of dimpled and riveted specimens should be sectioned to check the nesting of the dimples and the fit of the rivet.
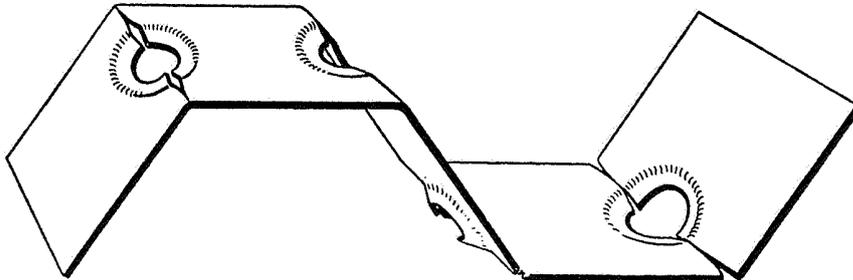

Figure 2   DIMPLE TEST SPECIMEN

5.2.3. **Punch Dimpling.** This is the simplest method of dimpling but is generally only suitable for minor repairs in sheet steel or soft aluminium alloys. The type of tool used is similar to a centre-punch but has a spigot which engages in a female tool of the same form. The hole should first be drilled to the spigot size and then the male die should be driven or squeezed into the female die to form the dimple.

5.2.4. **Spin Dimpling.** This is the most widely used method of cold-dimpling. The sheet is first pre-drilled and backed by a female die as for punch dimpling, then a rotating male die is pressed into the hole. The metal around the rivet hole is stretched over the edge of the female die and, if the material is clad, the aluminium cladding is spread by the spinning action. The cladding may form a ridge around the outside of the dimple but this will only be slight, and should not be removed.

5.2.5 **Hot Dimpling.** There are basically two methods of hot dimpling. In the first method, sometimes known as 'coin dimpling', electrically heated dies are used; in the second, the sheet is heated by its resistance to the passage of an electric current. Each material has a different rate of conducting heat, or a different electrical resistance, and the applied current or time and temperature will be different for different materials and gauges. These details are normally found by experiment and the instructions given by the aircraft manufacturer should be followed.

NOTE: In order to obtain consistent results during aircraft construction, large static machines with automatically controlled temperature, current and tool pressure are often used but for repair work portable hot squeeze-dimpling tools are generally satisfactory.

5.2.6 **Dimpling Technique.** To ensure that rows of dimples fit satisfactorily together, the pilot holes should be drilled with the structure fully assembled. The structure may then be disassembled and the individual components deburred and dimpled separately. However, if sheets are to be bonded together, it may be recommended that dimpling is carried out after bonding.

(i) To produce dimples which are free from cracks around the holes it is essential that the pilot holes are free from burrs or other defects and that the correct lubricant is used. The ideal procedure is to drill the holes undersize, ream to suit the size of dimpling tool spigot, then deburr on both sides before dimpling. For maximum shear strength the hole should be finally drilled or reamed to give a hole with parallel sides and ideal rivet clearance. This second drilling should start from the dimpled side so that any burrs are on the raised edge and easily removed with a deburring tool.

(ii) When countersunk rivets are used to join several thin sheets of material there are two ways in which dimples may be formed. If the same tools are used for successive sheets the dimples will be identical, but will not nest satisfactorily. This may be acceptable when joining two sheets of ductile material but, for stiffer materials and when joining more than two sheets, the dimples may be overstressed by the riveting action. A more satisfactory method is to use tools of a slightly larger diameter and shallower angle with successive sheets, the innermost sheet having the largest and shallowest dimple.

6 USE OF SEALANTS After components have been prepared for riveting the mating surfaces are normally given a coat of jointing compound or sealant before final assembly. The purpose of the jointing compound is to inhibit electrolytic action between materials of different electrical potential and prevent the ingress of moisture, whereas a sealant (normally a polysulphide type synthetic rubber) is used to seal joints in fuel tanks and pressurised compartments. Jointing compound should be applied in a thin even film, just sufficient to ensure that all mating surfaces, including rivets, are adequately covered, but sealant should normally be applied in a layer approximately 0·030 inch thick so that it exudes

from the joint when the rivets are closed. It may be recommended that rivets are dipped in the compound before use but the exposed shanks of some types of rivets should, after insertion, be carefully wiped clean to ensure correct closing of the rivet (see Leaflet BL/6-28). Riveting must be completed before the compound or sealant has set and any excess material on external surfaces should be wiped off or to a prescribed fillet while still wet.

7 **SUPPORT AND ALIGNMENT OF STRUCTURE** During the manufacture of an aircraft extensive jigging is used to locate detail parts in accurate relationship to one another while they are being secured by rivets or other types of fasteners. This provides not only for interchangeability of structural components but for correct external contour. When carrying out repairs on riveted structures, adequate support must be provided to maintain the original size, contour and alignment (see also Leaflet AL/9-1); this is particularly important in the case of extensive repairs. On high speed aircraft the achievement of correct external contour is vital, but on all aircraft care should be taken to prevent an increase in aerodynamic drag through poor shape or finish.

7.1 Major stress concentrations are spread from principal transport joints into the lighter structure through progressively reduced reinforcing fittings. Such assemblies involve the use of bushes, taper pins, bolts and rivets, each designed to take a share of the load. The sequence of assembly during repair or replacement may be vital to ensure correct alignment and the use of jigs may be required when drilling or reaming holes for rivets.

7.2 During the assembly of sheet metal fabricated structure each mating part must fit snugly together. This accuracy of fit must be achieved before the application of interfaying material and any forming or packing necessary must be carried out before final assembly. Panel shape should be adjusted to achieve perfect fit against supporting frames, stringers or ribs.

7.3 On high speed aircraft embodying heavy riveted skins or bonded laminated reinforcements which are extremely rigid, the design may call for the use of sophisticated skin grips to hold the skin in contact with the structure during riveting. Certain forms of interfaying sealant require a specific torque loading to be applied to such grips, with a minimum time of clamping and a maximum time between releasing the grips and closing the rivets. Such precautions as these should be obtained from the manufacturers process sheets or the aircraft Repair Manual.

8 **CLOSING RIVETS** When the appropriate actions of drilling, countersinking, dimpling, deburring, cleaning and adjustment have been completed, the work to be riveted should be assembled, sealant applied, and mating surfaces brought tightly into contact by use of skin grips, care being taken not to damage the skin surface. It is important that no gaps are present between layers, as this will prevent the correct forming of the rivet and reduce shear strength. Riveting may stretch thin sheets slightly, particularly with minimum rivet clearances, and this should not be allowed to accumulate by riveting, for example, straight along a line of rivets. The correct sequence of closing rivets can only be obtained by experience, and with each type of joint the order of riveting may vary slightly.

8.1 **Solid Rivets.** The length of protruding shank which is flattened to close a rivet is known as the 'allowance', and is expressed in terms of the rivet diameter 'D'. For normal reaction riveting the allowance is 1·5D, and this is sufficient to form a flat head 1·5D in diameter and 0·5D thick; for this type of riveting these are the dimensions to be aimed at. On the rare occasions on which hand riveting may be required, an allowance of 1·5D is sufficient to form a snap head and 0·75D is sufficient to form a countersunk head. Rivets should always be used which are manufactured to the length required; cutting rivets to length is not recommended, since any tool marks in the rivet tail are possible sources of cracks when the tail is hammered.

8.1.1 Hand Hammering. Riveting by hand is only appropriate to certain types of older aircraft and elementary repairs to simple structures. When solid rivets are closed with a hand hammer, the manufactured (pre-formed) head should be supported by a suitably shaped dolly and the tail hammered to a thickness of $0·5D$; if a snaphead is required on the shank end, the tail should first be partly formed by hammer blows, then finished with a suitably shaped snap. It is most important that the dolly is backed by a heavy block or holder, and as few hammer blows as possible used. A large number of light blows will work-harden the rivet and result in cracks in the tail or difficulty in forming.

8.1.2 Pneumatic Hammering. In some instances it may be specified that a similar procedure should be used for pneumatic hammering as is described in paragraph 8.1.1. However, since the preformed rivet head is invariably on the outside of the aircraft and access to the interior often restricted, a type of riveting known as reaction riveting is more generally used. A suitably shaped snap (or 'set') is held in the riveting gun and a dolly (or 'bucking bar') held against the tail end. When the riveting gun is operated the tail is spread by the reaction of the dolly.

(i) To prevent damage to the surface of the work when protruding head rivets are being closed, the radius of the recess in the snap should be slightly greater than the radius of the rivet head. For this reason, since rivets to different specifications (e.g. SP or AS) have slightly different shaped heads, use of the correct snaps is imperative.

(ii) When flush rivets are being closed a flat snap should be used, but it may be found advantageous to use one with a slightly convex surface to prevent damaging the surrounding skin.

(iii) The dolly should be as heavy as practicable, bearing in mind the space available, and should have a smooth surface to prevent damage to the rivet tail.

(iv) The type of gun to use will depend on the size and type of rivets, but generally on aircraft work a fast-hitting type is used on rivets up to $\frac{1}{4}$ inch diameter and a single-blow or slow, long-stroke type for larger rivets. As with hand hammering a few heavy blows are preferable to a large number of light blows.

8.1.3 Squeeze Riveting. On large modern aircraft, extensive use of squeeze riveting is made when securing spanwise stringers to preformed wing skins. It is part of an automatic process using large tape-controlled machines which drill, countersink, deburr, rivet and mill flush in one continuous action. This method of riveting is also used for the production of small assemblies or, when both sides of the work are accessible, during repair work. Squeeze riveting is also preferred when bonded laminated structures are to be riveted since, unless skill and care are exercised, reaction riveting tends to damage the bond. The rivets are closed by hydraulically or pneumatically operated machines, of which both static and portable types are available.

(i) Before riveting with squeeze tools the working pressure should be adjusted, by experiment, to obtain the optimum value for the work in hand. Test pieces of the same materials, thickness and rivet diameter as the work in hand should be used and may be sectioned across the rivets to study the plastic distortion to which the rivets and sheets have been subjected. Once adjusted the tools may be used for all work for which similar conditions apply, but must be readjusted if any changes occur in material, thickness or rivet size.

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8.2 **Blind Rivets.** Special tools are required to close blind rivets, and it must be ensured that the correct types of nose piece and gripping jaws are fitted for the type and size of rivet to be closed.

8.2.1 **Chobert Rivets.** A different sized mandrel is used with each diameter of rivet and it is important that the correct mandrel is selected. Before use it should be checked for diameter using an approved gauge, inspected for scratches or other damage likely to mark the rivet bore, and must be clean and lightly lubricated. Mandrels are subject to wear during use, and should normally be replaced when the head diameter has been reduced by approximately 0·002 inch. Use of a mandrel worn beyond these limits may result in incomplete closing of the rivet.

(i) The correct length rivet must be chosen for the work in hand, and it should be noted that the size code for the rivet indicates the rivet length and not the grip range; this is approximately ⅛ inch less that the rivet length, but reference should be made to the manufacturer's literature or the appropriate aircraft manual for exact details.

(ii) In the case of single action tools the mandrel should be threaded through the rivet and inserted into the tool until the rivet head contacts the tool nose piece. The rivet should then be pushed into the hole and steady pressure applied at right angles to the work while the broaching action is completed.

(iii) It is advisable to use a repetition gun when a large number of rivets have to be closed. The mandrels in these tools may be threaded into a tube containing approximately thirty rivets, and these are automatically positioned as each rivet is closed. High rates of closing are easily obtained.

(iv) When sealing pins are used it must be ensured that they are the correct diameter for the particular rivet.

8.2.2 **Avdel Rivets.** Avdel rivets are coded according to diameter and length, the grip, like Chobert rivets, being approximately ⅛ inch less than the length. They are pre-lubricated and must not be washed in solvent before use, but surplus sealant or jointing compound could be detrimental to the forming process and should be wiped off.

(i) Each rivet should be assembled individually into the riveting gun, then inserted into the prepared hole and steady pressure applied at right angles to the work whilst the gun is operated.

(ii) Milling of the sheared ends of stems is quite often specified and this normally involves the use of a special milling attachment on a standard air-operated drill, an adjustable stop being set to prevent cutting the rivet head or adjacent skin.

(iii) When the rivets have been closed, the tightness of the stem should be checked with an Avdel Pin Tester, which is a tool having a retractable spring-loaded pin. The pin is pushed against the stem, and tightness may be considered satisfactory if there is no stem movement when the spring is fully compressed.

8.2.3 **Cherry Rivets.** A gauge is supplied by the manufacturer of these rivets, which may be inserted into the rivet hole to measure the thickness of material to be riveted. The maximum grip of each rivet is marked on the rivet head, in sixteenths of an inch, and this figure should correspond to the gauge reading.

(i) It is important that the appropriate pulling head for the riveting tool should be used, in accordance with the type and size of rivet. The rivet should be inserted into the prepared hole and the gun pressed over the stem until firm resistance is felt. The gun should then be operated while light pressure is applied towards the rivet.

(ii) To check the stem locking, a stem tester should be pressed against the sheared end of the stem; as with Avdel rivets, the stem locking may be considered satisfactory if no movement results when the tester is fully compressed.

(iii) The sheared stem and locking collar may be milled to maintain specified protrusion limits, but care must be taken not to remove material from the rivet head or surrounding skin.

(iv) On aircraft which have a bare metal exterior finish, it is sometimes specified that clear varnish should be applied to the heads of these rivets.

8.2.4 **'Pop' Rivets.** These rivets are most often closed by hand tools of the 'lazy tong' type when used for repair work, although other types of hand and power tools are also available. The mandrel should be inserted while the tool is extended, the rivet placed in position and the tool operated by pressing firmly towards the rivet until the mandrel shears. If break-head type rivets are used the sheared heads should be collected, and not allowed to fall inside the aircraft structure. Long-break mandrels are specified where increased shear strength is required and should not be replaced by break-head or short-break types.

8.3 Special Fasteners

8.3.1 **Hi-shear.** With these fasteners a simple check may be carried out to ensure that the pin is the correct length for the work to be joined. With the pin inserted in the hole, the edge of the pin groove should be proud of the work surface and with the collar fitted the pin trimming edge should be inside the collar as shown in Figure 3. The fasteners are normally closed by hammering a special Hi-shear set against the collar, the pin head being supported by a dolly, but squeeze or reaction riveting may also be used if the normal method is impracticable.
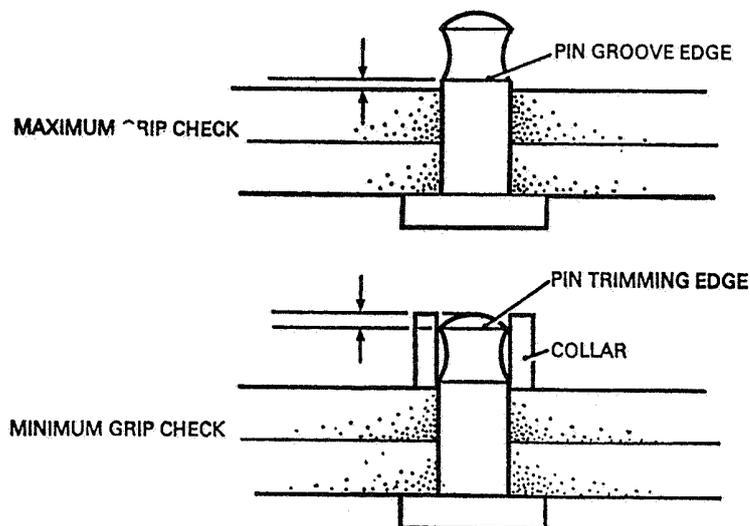

Figure 3   HI-SHEAR PIN LENGTH CHECK

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8.3.2 **Avdelok.** The plain shank of these fasteners should be approximately equal to the thickness to be joined. The fasteners are normally closed by power operated tools, the gripping jaws pulling on the shank and the nose piece pushing against the collar, first clamping the plates together then swaging the collar into grooves on the shank. When swaging is complete the pin shears approximately level with the collar. If an interference fit is specified, closing should be in two operations, the first (without the collar fitted) pulling the pin into place and the second (with the collar fitted) completing the swaging operation.

8.3.3 **Jo-bolts.** Due to the method of closure of these fasteners it is particularly important that the nut length is suitable for the thickness of the work. If the maximum grip of the fastener exceeds the thickness of work by more than $\frac{1}{16}$ inch then the sleeve may not be properly expanded and a loose fastener could result.

(i) The tool used to close these fasteners consists of an outer portion to prevent the nut from turning and an inner portion by means of which the bolt is rotated. Rotation of the bolt (which has a left-hand thread) forces a sleeve up the tapered nut shank to form a blind head; when the work is securely clamped, continued rotation shears the bolt inside the nut head. Grip of the bolt may be checked by attempting to turn the nut anti-clockwise (i.e. tightening further).

(ii) Different adaptors for the tools must be used for each size and type of Jo-bolt.

8.3.4 **Rivnuts.** When Rivnuts have a locating key to prevent rotation, the keyway should be cut with a special tool supplied by the nut manufacturer. To close Rivnuts the threaded mandrel of the special tool is screwed into the nut, and when the tool is operated the nut shank bulges towards the far side of the work to form a blind head. When the mandrel is removed a fixed nut is left in the structure and may be used for the attachment of de-icing boots, etc.

9 INSPECTION Riveted structures should be inspected after each of the following operations:—

(i) After marking-out, to ensure conformity with the repair scheme or the riveting methods used elsewhere on the aircraft.

(ii) After drilling, to confirm the position of holes and ensure that hole size and condition are suitable for the type of rivets to be used.

(iii) After countersinking or dimpling, to check the mating of the parts involved, the condition of the countersink or dimple, and the flushness of rivet heads.

(iv) After final assembly prior to riveting, to confirm the fit of the component and condition of any protective treatments.

(v) After riveting, to ensure that rivets are satisfactorily formed, that there has been no significant distortion of the parts and, where specified, that jointing compound has been correctly applied.

9.1 It is important to ensure that techniques used for dimpling, countersinking, deburring, etc. are satisfactory, having regard to the type of materials and the tools available. As an example, the tools used to countersink aluminium alloys might be quite unsuitable for use with titanium, which work-hardens very quickly. Satisfactory techniques are best established by the manufacture of test pieces in similar materials, and using the same tools that will be used in the final work. Test pieces can be inspected by both destructive and non-destructive methods, and any faults eradicated by variation of the technique, until satisfactory samples are produced.

9.2   Pre-riveting Inspections.   Particular attention should be paid to the following points when inspecting parts prior to riveting.

(i)   Holes should be round, drilled at right angles to the work surface, have a diameter within the limits quoted by the aircraft manufacturer for the type of rivet, and sharp corners should be removed but not excessively chamfered. In certain instances a surface roughness may be specified by the manufacturer, and this should be checked by accepted methods. Normally, a finish consistent with good workshop practice and without axial scores, is satisfactory.

(ii) A countersunk surface must be coaxial with the hole and cut to the required angle. The depth must be such that the rivet will comply with the flushness requirements of the aircraft manufacturer and on no account may the rivet head be below the skin surface. As with ordinary holes a surface roughness may be specified, but provided the countersunk surface is free from 'chatter' marks a finish consistent with good workshop practice is normally adequate.

(iii) Dimples should be free from scores and should be of the correct angle. In this respect it should be noted that if several sheets are dimpled for a countersunk rivet, the angle of the dimples in successive sheets should vary to ensure correct nesting. Small radial cracks round the hole are generally acceptable in tertiary structures which have been dimpled from final size holes, but circumferential cracks round the dimple are cause for rejection.

(iv) Mating parts should fit snugly without bending or forcing and should conform to the shape of the surrounding area.

(v)   Before final assembly all parts should be separately deburred and swarf removed. The final protective treatment should be checked and, if necessary, rectified before application of jointing compound.

9.3   Inspection of Rivets.   After the rivets have been closed they should be inspected to ensure that they are tight and fully formed. Rivet heads must not be deformed or cracked, and the surrounding area should be free from distortion and undamaged by the riveting tools. Rivets which are obviously not performing their function should be replaced, but replacement of rivets which are found to be only slightly below standard might do more harm than leaving them in position, particularly in thin materials. Before rejecting such rivets, the strength requirements of the particular joint and the effectiveness of the rivets in question, should be considered. When a flushness tolerance is specified for countersunk rivets, this is normally checked before riveting is commenced; however, the milling of solid rivet heads may sometimes be permitted after riveting to obtain a uniform protrusion. In this case protective treatments must be re-applied after milling.

9.3.1 Solid Rivets.   Figure 4 shows some of the faults which may be found with solid rivets. Superficial cracks round the periphery of the head are usually acceptable, but not if intersecting cracks could lead to part of the head breaking off. Cracks in the inner area of the head, corresponding to the shank diameter, are not permitted. If snap heads are formed on the tail of the rivet a number of further faults may occur. These include a 'flash' round the rivet head if the shank was too long, and a small head, possibly accompanied by snap marks on the skin, if the shank was too short.
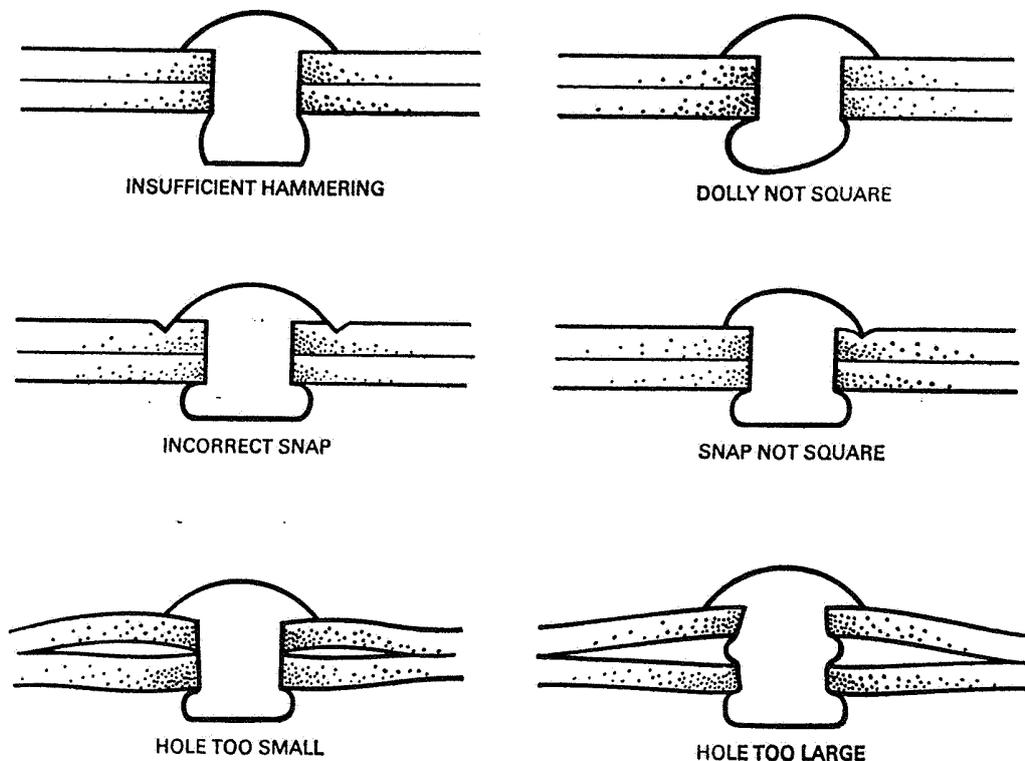
INSUFFICIENT HAMMERING   DOLLY NOT SQUARE

INCORRECT SNAP   SNAP NOT SQUARE

HOLE TOO SMALL   HOLE TOO LARGE

Figure 4   TYPICAL RIVETING FAULTS

9.3.2 Blind Rivets. The blind heads formed when these rivets are closed are not usually accessible for visual inspection and in some cases radiological examination may be specified. Visual inspection is normally limited to ensuring that the head is square to and in contact with the skin surface, that the locking collar (Cherry rivets) is properly engaged, and that no damage or buckling has been caused to the surrounding area. Where required, the flushness of countersunk rivets should also be checked.

9.3.3 Special Fasteners. These should be inspected to ensure that the axis of the fastener is at right angles to the work, that the head or collar, as appropriate, is correctly formed in accordance with the manufacturer's instructions, and that the work is not cracked or otherwise damaged around the hole.

9.4 Post Repair Inspections. When a riveted repair has been completed and finally checked for freedom from swarf and foreign matter, consideration should be given to the necessity for tests or inspections to determine whether the component is fit once again for service. The nature of the test or inspection will depend on the type of component repaired, but one or other of the following examples may be applicable:—

(i) Flying control surfaces should be checked for balance and operation.

(ii) Pressure cabins may require a pneumatic inflation and leak test or proof pressure test in accordance with the approved aircraft manual.

(iii) Integral fuel tanks should be given a pressure test, followed by a flow test or other test relevant to the repair.

(iv) Structure adjacent to moving mechanisms. The moving parts should be operated through their complete range of movement to ensure freedom from fouling. In some cases a minimum clearance may be specified to allow for flexing during aircraft operation.

10   REMOVAL OF RIVETS There are several methods of removing the rivets and fasteners described in this Leaflet, and these are outlined in the following paragraphs. For any particular situation the thickness and strength of the structure should be considered and the method likely to cause the least damage should be used. Before refitting a rivet of the same diameter, the hole should be checked to ensure that its diameter is within the limits specified by the aircraft manufacturer. If it is not within limits, an approved oversize rivet must be fitted and the hole enlarged accordingly.

10.1   The usual method of removing solid rivets is as follows:—

(i) Centre punch the manufactured head.

(ii) Drill down to the depth of the head with a drill slightly smaller than the rivet shank.

(iii) Carefully tap off the head with a flat chisel or prize off with a pin punch.

(iv) Punch out the remainder of the rivet with a parallel punch of the same diameter as the rivet shank, supporting the underside with a hollow dolly as necessary.

10.1.1   The utmost care should be taken when drilling and punching, to ensure that the original hole is not enlarged.

10.1.2   When removing rivets from assemblies which include bonded laminations or reinforcements it is essential not to apply shear loads liable to part the bond.

10.2   A different method of removing solid rivets, which is specified by some aircraft manufacturers, is to drill off the tail of the rivet with a drill slightly larger than the rivet shank and then punch out the shank and manufactured head.

10.3   Cherry rivets may be removed by punching out the stem from the locked end, then drilling off the head and punching out the shank with a parallel punch. If the rivets are installed in thin sheet, however, the locking collar should be removed first by drilling into the stem with a pilot drill, then opening up the hole to shank diameter and prizing out the collar.

10.4   Other types of blind rivet may be removed by drilling off the head with a drill the same size as the hole and punching out the remainder of the rivet.

10.5   Fasteners which have collars swaged onto the shank (i.e. Hi-shear and Avdelok) may be removed by either of two methods:—

(i) Using a hollow mill with an internal diameter slightly larger than the fastener shank, the collar should be milled off to just above the skin surface. The fastener may then be driven out, using a hollow dolly to support the structure.

(ii) The head should be removed by the method described in paragraph 10.1 and the remaining pin and collar punched out.

10.6   In some instances a drill-out bushing is available for use with particular fasteners and this may be used as a guide when drilling out the head or shank.

NOTE: When drilling out loose rivets, care must be taken to prevent the rivet from rotating with the drill, as this would tend to enlarge the hole and damage the skin surface under the head.

BASIC

ENGINEERING PRACTICES AND PROCESSES

TORQUE LOADING

1   INTRODUCTION

1.1   The purpose of this Leaflet is to provide guidance and advice on the torque loading of threaded fasteners to ensure efficient clamping of mating parts and prevent overstressing.

1.2   The subject headings are as follows:—

1.3   Related Leaflets:—

2   GENERAL

2.1   The majority of nuts, bolts and set screws on an aircraft are subject to a standard torque value, depending on their material, finish, lubrication, thread type and size, but particular applications may necessitate a different torque loading and this will be specified in the Appropriate Maintenance Manual. The normal method of applying a torque loading to a fastener is by means of a torque wrench, but in some critical bolted joints the use of pre-load indicating (PLI) washers may be specified and these are discussed in Leaflet AL/7-8.

2.2   'Standard' torque loading values are those generally applied to steel fasteners used in tension applications on aircraft, and lower values are generally quoted for shear nuts or nuts used in shear applications. Lower torque values are also necessary for union nuts (bearing in mind the actual thread size and not the pipe diameter). 'Special' torque loadings may be used for a variety of reasons, examples of which are the loadings applied to the bolts fitted to flexible engine mountings and those applied to non-standard fasteners such as cylinder holding-down nuts.

BL/6-30

3   RECOMMENDED TECHNIQUES

3.1   Torque loading instructions in Aircraft Maintenance Manuals will be found to vary slightly between different aircraft and engines. Most manufacturers specify lubricated torque values, i.e. the threads and all mating surfaces lightly lubricated with oil, sealant or anti-seize compound as appropriate, but some manufacturers specify dry torque values, i.e. parts clean and dry or as pre-lubricated during manufacture. Due to the varying effects of friction under different conditions of assembly, it is important that the torque applied to any particular fastener should be in accordance with the manufacturers instructions; the pre-load applied to a fastener at a specified lubricated torque would be considerably higher than if the same torque were applied dry.

3.2   **Initial Assembly.**   In order to remove the roughness from threads and mating surfaces when assembling new components which require high torque loadings, the following procedure should be followed:—

     (a)   Clean and, where specified, lubricate threads and mating surfaces of nut, bolt and washer.

     (b)   Tighten nut to approximately half the specified torque value.

     (c)   Slacken nut then finally re-tighten to specified torque value.

NOTE: Where cadmium plated fasteners are used in locations subject to fluctuating loads the manufacturer may recommend a different procedure.

3.3   Wherever possible, in a bolt-nut or screw-nut combination, the bolt or screw must be held stationary and the nut turned. When it is necessary to tighten a fastener from the bolt or screw side, the torque value must approach the high side of the specified range. Whenever torqued fasteners are to be secured by means of split pins or lock wire, the low side of the torque range must be used for tightening. If necessary, tighten the fastener so that the next slot aligns with the hole, provided the maximum torque value is not exceeded. If the maximum torque value is reached, and the slot in the nut does not line up with the hole in the bolt, the nut and washer must be changed.

3.4   **Sealants.**   When sealant is used in a joint the torque loading of fasteners should be carried out within the application time of the sealant. After ten minutes, but within twice the application life of the sealant, the loading should be checked and re-applied as necessary.

3.5   **Union Nuts.**   The component parts of a flared pipe coupling require bedding-in to ensure freedom from leaks, and the following procedure should be adopted when tightening union nuts:—

     (a)   Assemble the component parts of the joint and run-up the nut by hand.

     (b)   Tighten to specified torque value.

     (c)   Slacken the nut half a turn, then re-tighten to specified torque value.

NOTES: (1)   Torque loading is not usually specified for flareless couplings. The procedure normally recommended is to tighten the nut using finger pressure until positive resistance is felt, then tighten a further one sixth to one third of a turn.

          (2)   Lubrication of components is usually by the type of fluid used in the system but connections in oxygen systems must be dry unless a special preparation is recommended, see Leaflet AL/3-25.

3.6 **Stiffnuts.** In order to check the effectiveness of the friction element of a stiffnut it is general practice to turn the nut onto its mating thread by hand. If it is possible to pass the thread through the friction element by hand, then the locking is unsatisfactory. However, certain manufacturers specify acceptable limits of 'in-built' or frictional torque for various thread types and sizes, and in these instances each stiffnut should be checked with a torque wrench before re-use.

3.7 **Torque Tables**

3.7.1 Tables of standard torque values for different thread types and sizes, and for special applications, are normally found in the appropriate Maintenance Manual, separate tables often being included for ordinary nuts, stiffnuts, union nuts and studs. Manuals for older types of aircraft may be found to contain only special torque loading requirements and a single table applicable to non self-locking nuts; in these cases the frictional torque of a stiffnut must be added to the torque quoted for the type and size of thread.

3.7.2 Torque tables usually specify the upper and lower limits of torque for different types and sizes of fasteners, but if a single figure is quoted, it is generally accepted that this may be exceeded for the purpose of lining up a split pin hole, tab washer or locking plate. However, an upper torque limit should not be exceeded, and nuts should never be slackened to line up these locking devices.

4 TORQUE WRENCHES

4.1 There are basically two types of torque wrenches. One type contains a flexible beam which bends under load, the amount of bend being recorded on a dial which is graduated in units of torque. The second type contains a spring loaded ratchet device which may be preset before use, and when this preset torque is reached the wrench 'breaks' to prevent further tightening.

4.2 The torque applied to a nut is a function of the force applied to the wrench handle multiplied by the distance between the point of application of the force and the centre of the nut. This may be measured in appropriate units such as pounds inches (lb in), kilogramme centimetres (kg cm) or newton metres (Nm). The scale on the wrench is marked to show the torque applied to its driving tang, i.e. force applied to the handle multiplied by the distance between its driving tang and the centre of the hand grip.

4.3 If a torque wrench is used in conjunction with a socket type of spanner, the nut and tang centres will coincide and the torque applied to the nut may be read directly from the wrench scale. However, in some cases an extension spanner is used in conjunction with a torque wrench and the torque applied to the nut will be different from the torque shown on the wrench scale.
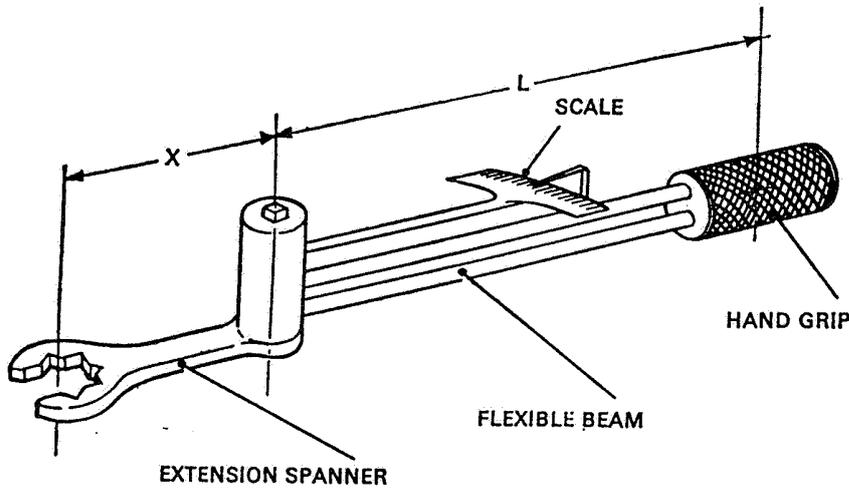
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Figure 1 TYPICAL BEAM-TYPE TORQUE WRENCH

4.4 Extensions

4.4.1 Figure 1 shows a typical beam type torque wrench which has an extension spanner attached. If this combination is used to torque load a fastener then the following formula should be used to calculate the wrench scale reading which corresponds to the specified torque value:—

$$\text{Scale reading} = \text{specified torque} \times \frac{L}{L + X}$$

Where L = distance between the driving tang and the centre of the handle

X = length of extension spanner between centres.

4.4.2 A simple way of calculating the scale reading required without using the formula is set out in the following example, for which the specified torque loading is 300 lb in and the lengths of the wrench and spanner are 10 and 5 inches respectively.

(a) Force required on wrench handle to produce a torque of 300 lb in is 300 lb in divided by the distance between nut and wrench handle,

which is, $\dfrac{300 \text{ lb in}}{10 \text{ in} + 5 \text{ in}} = 20 \text{ lb}$

(b) Scale reading when force on handle is 20 lb is, 20 lb × 10 in = 200 lb in

Force must therefore be applied to the wrench handle until a reading of 200 lb in is shown on the wrench scale, and this will represent a 300 lb in torque load applied to the nut. With the 'break' type wrench, the adjustment must be preset at 200 lb in.

NOTE: For the purpose of conversion, 1 lb in = 1·15 kg cm or 0·113 Nm.

4

4.4.3   When using an extension spanner with a torque wrench, the spanner and wrench should be as nearly as possible in line. If it is necessary to diverge by more than 15° from a straight line (due, for example, to intervening structure), then the direct distance (D) between the nut and wrench handle must be substituted for 'L + X' in the formula (paragraph 4.4.1) for calculating wrench scale reading. This is shown in Figure 2, and the scale reading in this instance will be equal to specified torque $\times \dfrac{L}{D}$.
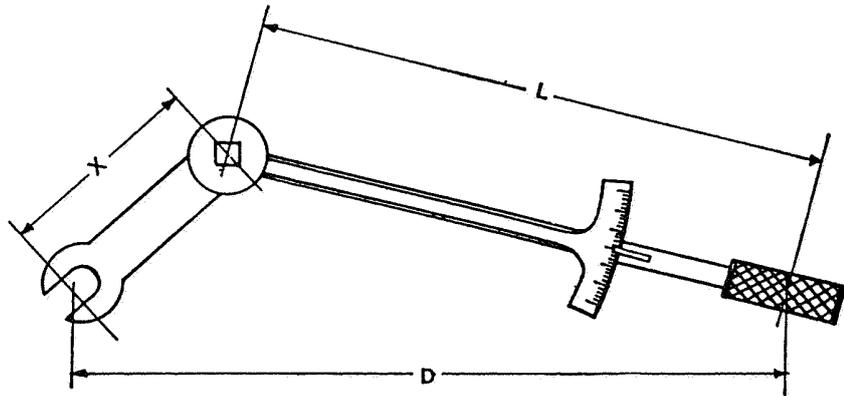

Figure 2   ALTERNATIVE METHOD OF USE

4.4.4   Whenever a torque wrench is used, it must be confirmed that the specified torque and the wrench scale are in the same units; if not, then the specified torque should be converted, by calculation, to the units shown on the wrench scale, and any measurements taken in appropriate units.

4.4.5   When applying torque the wrench handle should be lightly gripped and force applied smoothly at 90° to the axis of the wrench.

4.5   **General Considerations**

4.5.1   Values of torque within the first quarter of the wrench scale may be difficult to read accurately, and some manufacturers specify that the torque wrench selected for a particular use should have a range such that the specified torque falls within the upper range of the scale.

4.5.2   When using a ratchet type wrench with a floating drive (i.e. a driving tang which is located in a socket in the wrench and is moved axially through the socket to reverse the direction of operation of the wrench), it is important to ensure that the wrench is used the right way round. If incorrectly used, severe overstressing of the fasteners could occur before the error is noticed.

4.6   **Over Torqued Fasteners.**   Fasteners which have been tightened beyond the maximum specified torque value must be removed, rendered unserviceable and scrapped. In the case of over torqued bolt-nut or screw-nut fasteners, both bolt or screw and nut must be discarded.

NOTE: Over torqued fasteners must not be backed off and retorqued to the correct value due to possible internal damage to the material structure and the increased likelihood of fatigue failure in service.

4.7 **Retorquing.** Where it is necessary to retorque a fastener assembly, the nut must be backed off part of a turn and retightened to the specified value. Unless the installation requires the torque to be applied to the bolt or screw in the first instance, the bolt or screw must be supported and not be allowed to turn during a retorquing operation.

5   CHECKING OF TORQUE WRENCHES

5.1 Beam-type torque wrenches should be checked before use to ensure that the scale reading is zero.

5.2 All torque wrenches should be checked for accuracy preferably before use or at intervals normally not exceeding six months. However, for those torque wrenches subject to greater use, checks for accuracy should be carried out at more frequent intervals. If a spring balance is attached to the centre of the wrench handle, and force applied tangentially to the arc of movement, the wrench scale reading should correspond to the spring balance reading multiplied by the wrench length. Checks should be made at several values within the wrench scale range.

BASIC

PROTECTIVE TREATMENTS

ANODIC OXIDATION

1   INTRODUCTION This Leaflet gives general guidance on the processes used for the anodic oxidation of aluminium and aluminium alloys. It should be read in conjunction with Defence Specification DEF-151 entitled "Anodising of Aluminium and Aluminium Alloys".

    1.1   Aluminium-based materials obtain some corrosion resistance from the natural formation of a thin oxide film on the surface of the metal which occurs when the metal is exposed to air, and this prevents further oxidation of the metal.

    1.2   The electrolytic process known as "anodic oxidation" or "anodising" produces a much thicker oxide film or coating which is more resistant to corrosion and abrasion but does not necessarily give complete protection. The corrosion resistance obtained by anodising depends on several factors such as the specification of the base metal, the type of anodising process used, and the efficiency of the sealing procedure.

    1.3   An anodic oxidation process may be specified for any of the following purposes:—
      (i)   To provide a temporary protection against corrosion.
      (ii)   To provide a suitable surface for the application of a more permanent protective scheme.
      (iii)   To provide a suitable surface for bonding with plastics materials.
      (iv)   To improve resistance to wear.
      (v)   As an aid to inspection, (see paragraph 2.3).

2   GENERAL Unless otherwise specified by the approved Design Organisation, all anodising processes and related inspections and tests must comply with the latest issue of Defence Specification DEF-151. For information only, descriptions of typical processes are given in the following paragraphs but detailed information must be obtained from the Specification.

NOTE: There are various proprietary treatments approved under the terms of DTD 900 which are suitable for general anodising.

    2.1   There are three types of anodic coating in general use which are designated according to their anodising process: the sulphuric acid process, the chromic acid process and the hard anodising process.

    2.2   **Sulphuric Acid Process** The sulphuric acid process is widely used and is generally preferred for its decorative and protective qualities. It gives a wide range of coat thicknesses and is transparent in the thinner ranges. It is, however, not suitable for use on parts containing riveted, lap or folded joints. Unless otherwise specified the coating thickness should be between 0.0003 and 0.0005 inch and it should be sealed in a chromate solution, except in some circumstances where sealing by immersion in boiling water is specified on the drawing or order.

2.3   **Chromic Acid Process**   This process can be used for the protection of some riveted assemblies and thin aluminium sheet (normally sheet below 0.01 in thick).   It is usually preferred for the treatment of castings of suitable composition and as a surface for bonding to plastics materials.   It gives a relatively thin coating (e.g. 0.0001 in) but minimises loss of fatigue strength due to anodising.   The process will show surface defects such as cracks which are revealed through the residual electrolyte in the crack drying out to form a brownish-yellow stain.   Chromic acid is less corrosive to aluminium than sulphuric acid and is therefore used in cases where the electrolyte can become trapped such as may occur with riveted assemblies, lap or folded joints and small blind holes.

NOTE: If castings of high silicon alloy are anodised in chromic acid there is a tendency for the amperage to rise rapidly with a risk of burning and therefore extra cooling is needed.   The sulphuric acid process is better in this case but a prompt rinse is necessary to neutralize the acid.

2.4   **Hard Anodising Process**   The thicker and harder anodic coating (0.001 to 0.003 in) produced by this process provides excellent corrosion protection and good abrasion resistance, it also has good insulation properties.   The process may reduce the fatigue strength of the metal, as proved in rotating beam type tests, by about a half but the fatigue strength can be partly restored by sealing the coating in an aqueous dichromate solution at the cost of some loss in abrasion resistance.

NOTE: The requirements of the Factories Act and the Chromium Plating Regulations should be given careful consideration before installing or operating an anodising plant.   Because of the danger to health from inhaling fumes from an anodic oxidation plant suitable fume extractors are usually necessary.   Protective clothing including rubber gloves, aprons and boots are also required.

3   PREPARATION FOR ANODISING

3.1   To obtain a satisfactory anodic coating the surface of the metal must be absolutely clean and free from blemishes, (anodising tends to emphasise rather than conceal blemishes).   The trichlorethylene process (Leaflet BL/6-8) is a widely used method of cleaning; as an alternative, a mixture of equal parts of white spirit and solvent naphtha can be used, but this must be dried off immediately after cleaning.   Particular attention must be paid to removing all traces of flux from welded parts.

NOTE: When trichlorethylene is used for cleaning it is important to ensure that all traces of the fluid are removed before the anodising procedure.   Special care should be given to lapped joints or blind holes where trichlorethylene could remain trapped.

3.2   When parts have been buffed or heavily rolled, a certain amount of grease may become embedded in the surface and be difficult to remove.   In such instances, degreasing followed by the use of a mildly alkaline cleaner is necessary.   Mild alkali cleaning is also permissible as an alternative to, or as an additional operation after, the other degreasing methods.

3.2.1   A suitable solution for this purpose will be found in Process Specification DTD 901 entitled "Cleaning and Preparation of Metal Surfaces" which should be referred to when preparing parts for anodising.   Also applicable is DTD 915 entitled "Process for Cleaning Aluminium and Aluminium Alloy Plating".   Caustic soda must not be used.

3.2.2   The time of immersion of aluminium alloy in alkali cleaner should be strictly limited and should be followed promptly by immersion in a weak chromic acid to neutralise the alkali, followed by a further wash in running water.   Great care should be taken when handling cleaned material to ensure that it does not become contaminated in any way.   It is recommended that gloves be worn when handling parts, since perspiration may cause staining under the anodising.

NOTE: When preparing close tolerance parts for hard anodising, it is important that machining allowances are made for dimensional growth.

3.3   When parts which have been in use are to be re-treated, the original anodic coating should be removed. Re-anodising without previous stripping is undesirable due to the difficulty of ensuring proper electrical contact because of the insulating properties of the coating. Parts previously treated by the sulphuric acid process should never be re-anodised without previous stripping, as pitting may occur on the surface and a soft coating may result.

NOTE: In some instances parts freshly anodised by the sulphuric acid process, if found to be inadequately coated, can be returned to the bath and the process continued.

3.4   Anodic coating may be removed by one of several chemical solutions. The following solutions may be used:—

    (i)   Sulphuric acid (s.g. 1.84) .. .. 15% v/v
        Chromic acid .. .. 5% w/v
        Water .. .. Remainder
        Used at about 50°C (123°F).
    (ii)   Phosphoric acid (s.g. 1.75) .. .. 3.5% v/v
        Chromic acid .. .. 2.0% w/v
        Water .. .. Remainder
        Used gently boiling.
    (iii) After the coating has been dissolved, the parts should be thoroughly washed in water.

4   ANODISING PROCESS

4.1   **Suspension and Racking**   The articles form the anode and should be suspended in the anodising baths so that all parts to be treated are exposed to the solution. Hooks, wires, racks or other suspension devices should be made of aluminium or titanium. Good electrical contact is necessary and spring or screw contacts are recommended which should be cleaned before use. The area of contact should be as small as possible but sufficient to allow the current to pass without overheating the metal. Large articles may require connecting at several points and in some cases they are bolted to special racks. The articles must not come in contact with the tank, the stirring device, heating or cooling pipes, cathode plates or other suspended parts. This is particularly important when the solution is agitated.

4.1.1   Hooks, wires and other suspension devices should be checked for temperature rise. Heating up at any point of the electrical circuit indicates either poor contact or a suspension device too small in cross section.

NOTE: The aluminium alloy used for the suspension devices must be at least comparable in purity with the parts to be anodised, if not there is a danger of galvanic action.

4.1.2   Rivets and similar small articles may be clamped in a perforated aluminium or titanium canister (which may be plastics coated on the outside), and a means of adequate circulation of the electrolyte inside the canister should be provided. This can be done by pumping the solution into the canister through a flexible tube connected to the circulating pump. Parts with flat surfaces, such as washers, should be separated by aluminium wire so attached and formed to act as spacers.

NOTE: For longer life and more efficient coating, hooks, racks and other suspension devices are often made of titanium. The choice of this more costly material will depend on the type of production anticipated.

4.1.3   Special care is necessary when suspending hollow articles in the bath, since the trapping of air or the evolution of gas bubbles will prevent the formation of the anodic film. Internal pitting will also occur unless good circulation of the electrolyte

is maintained. It is often necessary to provide an internal cathode for anodising hollow articles, and the size of the cathode should be approximately 10% of the internal area. Care should be taken to prevent the cathode touching the sides of the article and where necessary this must be done by fixing a suitable insulating material, such as wood or fibre, to the cathode. Special care is necessary when containers such as oil, fuel or water tanks are withdrawn from the bath otherwise the structure may be strained by the weight of electrolyte in the container.

4.2 **Temperature Control** Close temperature control is important because the current density alters considerably with temperature variations and this affects the properties of the coating. Automatic temperature control (e.g. by thermostat) to within $\pm 1°C$ (1.8°F) should be used for consistent results. The electric current passing through the electrolyte generates a considerable amount of heat and efficient means of agitation and means of cooling the electrolyte are necessary. Cooling coils fitted at the sides of the tank just below the surface of the liquid, or water jackets in which cold water is circulated, are the normal ways of cooling the electrolyte.

4.2.1 In some instances refrigeration of the electrolyte is necessary, (a) when the load in amperes exceeds the bath volumes in gallons, (b) for hard anodising, and (c) where the ambient temperature is high.

4.2.2 When the heating of baths is necessary, immersion heaters, graphite heat exchangers or steam coils may be used.

4.2.3 The electrolyte can be agitated by an external pump which circulates the electrolyte through a rubber hose. Air injection is also satisfactory when anodising articles of simple form. An air pressure of 10 lb/in² in pipes about nine inches apart with holes of about 0.05 inch diameter at 3 to 6 inch centres can be used. To avoid oil contamination the air pressure should be supplied by a water lubricated rotary pump.

4.3 **Solution** It is recommended that for more effective anodising and economy of electrolyte the solution should be continuously and effectively filtered. This can easily be done when using an external agitation pump. The quality of water used in anodising and sealing is important. The use of other than distilled or deionised water can produce coatings of lower corrosion resistance, cause drying stains and shorten the bath life.

NOTE: Deionised water is water from which almost all impurities have been removed, it is processed by passing tap water through ion-exchange resins to remove mineral constituents.

4.4 **Sulphuric Acid Anodising**

4.4.1 The tank or bath used for this process should be lined with either lead or rubber but a ceramic bath is also suitable. When lead lining is used this will form the cathode, but with ceramic or rubber linings cathode plates made of lead or aluminium are necessary. The insulated anode bars or rails for suspending the articles are made of copper and should be kept bright and all connections should be electrically efficient and free from corrosion. Direct current from a rectifier or generator is generally used and the supply should be sufficient to meet the requirements of paragraph 4.4.5.

4.4.2 The electrolyte used should be within the range of 5 to 22% by volume of sulphuric acid in water, (most operators use 10 to 15% by volume solutions). Contamination by chlorides or other foreign matter should be avoided. The chloride content of the electrolyte should not exceed 0.20 g of sodium chloride per litre. When the solution is being made up, the bath should be half filled with cold water and the requisite quantity of sulphuric acid poured very slowly into the water, stirring vigorously all

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the time. Considerable heat will be generated, and the solution should be allowed to cool before adding further cold water to produce the required density figure.

4.4.3 The temperature and voltage at which the bath is operated is dependent on the free sulphuric acid content of the electrolyte. When the bath is in use, aluminium dissolves in the acid, increasing the metal content and this decreases the acid strength.

4.4.4 The temperature at which the bath should be operated should be fixed in relation to the free sulphuric acid content, and should not exceed that indicated on the graph (Figure 1).
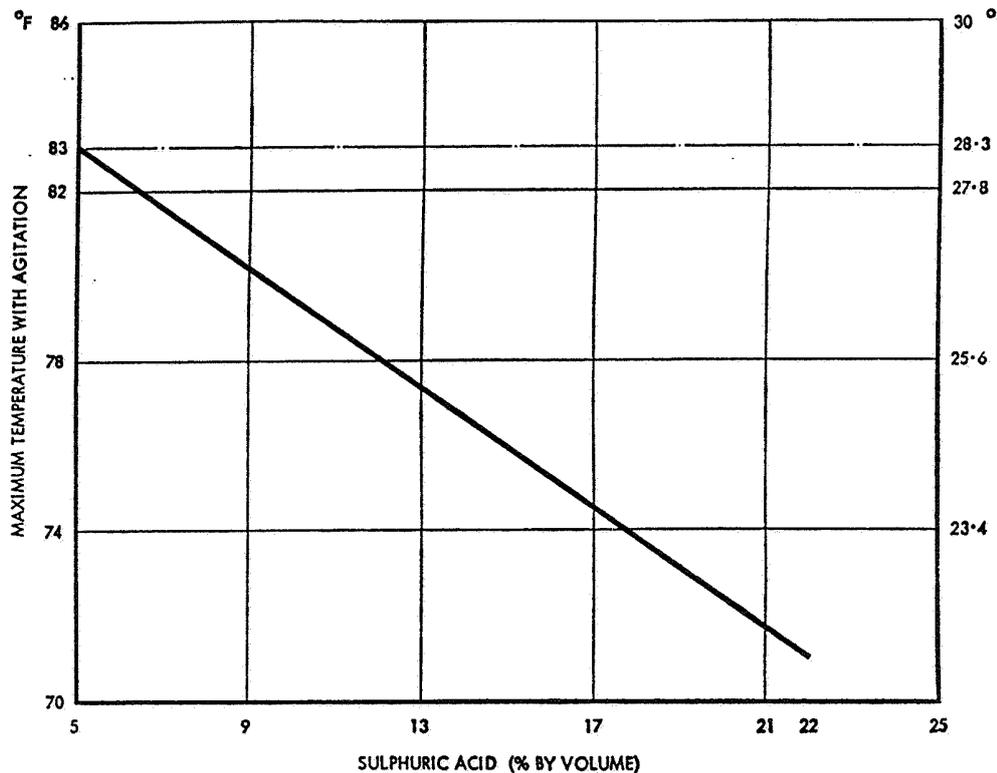
Figure 1

4.4.5 The voltage required to operate the bath at the selected temperature should be determined by suspending in the electrolyte a test sheet or sheets of aluminium of 99% purity, having a surface area requiring at least 10% of the normal electrical load of the bath. The current density should then be regulated to a steady 12 to 15 amperes per square foot, calculated on the total sheet area, and the voltage noted. The operating voltage of the bath should be determined during the test and usually results in a figure of 15 to 18 volts. In this process a steady voltage is maintained throughout the treatment period.

4.4.6 The intervals at which the tests are carried out should be related to the quantity of the work which passes through the bath and changes in the concentration of the electrolyte that occur due mainly to drag-out losses and bath additions. The test samples can be used repeatedly, provided the film is stripped before each test and the surface has not become unduly roughened.

4.4.7 It is permissible with this process to remove or immerse parts for treatment if desired, as the potential is maintained at a constant figure. It should be noted that the current density may depend on the total surface area of the bath load.

4.4.8 After anodising, the parts should be washed in cold running water and transferred directly to the sealing or dye bath.

NOTE: Modern plants catering for large scale production have automatic or semi-automatic transfer machines to convey work from one treatment bath to another. To minimise deterioration of solutions it is essential that the "dwell" time between each treatment is adequate to allow for proper draining and reduce the carry over of solution from one bath to the next. Work pieces such as channels or tubes should be supported so as to drain naturally or should be rotated to pour out trapped electrolyte or water.

4.4.9 The parts can be sealed by immersing for 5 to 10 minutes in a solution composed of 70 to 100 grammes of potassium or sodium dichromate, and 18 grammes of sodium carbonate, added to one litre of water. The temperature of the solution should be maintained at 94 to 98°C (201 to 208°F) during the process, and the parts should be dried immediately upon removal from the solution. The parts should be sealed as soon as possible after anodising as, due to porosity, the new film is highly absorbent, and serious corrosion may result if the parts are exposed to humid atmosphere for long periods. In addition, contamination of the parts may occur if in contact with certain oils or greases. The pH value of the solution should be maintained between 6·0 and 7·0 as measured with a glass electrode, or 6·3 to 7·3 if measured with indicators.

4.4.10 An alternative sealing solution is a composition of 45 to 55 grammes of potassium or sodium dichromate added to one litre of water. The sealing time is the same as that for the anodic treatment, and the temperature of the solution should be maintained at 94 to 98°C (201 to 208°F). The pH value of the solution should be maintained at 5·6 to 6·6 if measured with a glass electrode, or 5·9 to 6·9 if measured with indicators.

4.5 Chromic Acid Anodising

4.5.1 The electrolyte for this process may consist of a solution of 30 to 100 grammes of chromic acid per litre. The chromic acid should be of 99·5% purity and chloride in the electrolyte should not exceed the equivalent of 0·02 g per litre.

4.5.2 The tank used to contain the electrolyte should be of steel and be provided with anode bars or rails, usually manufactured in copper and insulated from the tank, from which the articles to be treated are suspended. The tank or separate plates of mild steel or stainless steel form the cathode. When plates are used for this purpose, it will be necessary to provide cathode bars, and the plates should be firmly attached to these to prevent movement when the electrolyte is agitated.

4.5.3 The working temperature of the bath should be maintained at 40 ± 2°C (104 ±4°F), for the treatment of wrought aluminium alloy parts, but in the case of aluminium alloy castings, particularly those having a high copper content, it is recommended that the temperature should be lowered to between 25 and 30°C

(77 to 86°F) in order to prevent pitting on the surface of the parts. Under full load conditions heating can be dispensed with after two or three loads, as sufficient heat will have been generated by the passage of the electric current through the electrolyte to maintain the temperature at the required level.

4.5.4 Metals other than aluminium-base alloys should not be introduced into the bath, since copper or copper-rich alloys, steel, zinc-base die castings or magnesium, for example, do not build up an oxide film and are severely corroded. This results in excessive absorption of current by the foreign metal, preventing or retarding the anodic oxidation of the aluminium and contaminating the solution. Care should also be taken to prevent contamination of the bath by the copper-rich drippings, which would occur if the anode bars were attacked by the solution or its fumes.

4.5.5 Current can be supplied by a dynamo or a rectifier and transformer. Voltage should be controlled within the range of 0 to 50 volts D.C. in steps of not more than 5 volts. The amperage should be sufficient to deal with the largest bath load. A voltmeter should be provided to measure the potential difference across the bath, and an ammeter to measure the current flow.

(i) With the operational temperature of the electrolyte between 38 to 42°C, current should be supplied so that the voltage across the bath is increased in steps of not more than 5 volts from 0 to 40 volts in the first 10 minutes, maintained at 40 volts for 20 minutes, gradually raised to 50 volts in the next 5 minutes and maintained at 50 volts for 5 minutes. These times should be regarded as minima.

(ii) At the commencement of the process the current density may be as high as 10 amperes per square foot but this will drop during processing to about 3 to 4 amperes per square foot of treated surface.

NOTE: The maximum voltage can be taken to 60 volts with advantage on work being prepared for redux bonding.

4.5.6 When castings are being treated at the temperature recommended in paragraph 4.5.3, the voltage should be increased in steps of not more than 5 volts from 0 to 40 volts during the first 10 minutes, then be maintained at 40 volts for 30 minutes. As castings generally take a much heavier current than wrought materials, care is necessary not to treat too much material at the one time in order to avoid overloading the electrical supply or causing excessive temperature rise of the electrolyte.

4.5.7 On completion of the process, the anodised parts should be sealed by swilling thoroughly in cold running water, then rinsed in boiling water and allowed to dry in air. This is an essential part of the normal anodising protection process as it serves to seal the pores of the coating.

NOTE: When chromic acid anodising is to be carried out on a surface which is to be painted it is preferable not to seal it. Paint keys better to an unsealed surface, especially if carried out promptly after anodising. If chromic acid anodising is carried out before redux bonding, it is important to omit any sealing and to dry the work promptly after the cold wash by drying at a temperature of not more than 40°C. (In this case the surface to be redux bonded must not be touched by hand. Operators should wear clean linen gloves.) The hot water wash must also be avoided when chromic acid anodising is used as a flaw detection procedure (see paragraph 6.2).

4.6 Hard Anodising

4.6.1 The electrolyte used and the processing procedures are basically similar to the ordinary sulphuric acid process. Low concentrations of sulphuric acid (e.g. 10 per cent by volume) are recommended and should be used with low electrolyte operating temperatures (e.g. between —5 to +5°C (23 to 41°F). Low temperature on the

surface of the work is important and this is normally achieved by a vigorous flow of cooled electrolyte flowing over all the surfaces to be treated. This low temperature is achieved by pumping the electrolyte through cooling coils immersed in refrigerated anti-freeze solution before passing it back to the bath.

4.6.2 The process can be operated with direct current or a combination of direct and alternating currents. The current density in a typical sulphuric acid electrolyte may vary from about 25 to 400 amperes per square foot depending on the process employed and the alloy being treated. Likewise the final voltage may vary from about 40 to 120 volts, depending largely on the thickness of coating required and the alloy being treated. The work should be suitably jigged and the electrical connections made very firmly to withstand the considerable agitation of the electrolyte necessary with this process.

4.6.3 Care and attention to detail is essential for satisfactory hard anodising and the requirements of the Specification DEF-151 together with any approved Design instructions must be closely followed.

4.6.4 The conditions of hard anodising must be selected to suit the material being treated and the thickness of coating required. Sample parts of the material should be anodised for trial purposes and, when found satisfactory, the method of treatment (i.e. electrolyte, temperature, agitation, current, voltage, time, suspension and sealing treatment) should be recorded in detail and the batch hard anodised under the same conditions as the sample. Particular attention should be given to maintaining good agitation and the temperature of the electrolyte should be maintained within 2°C (3·5°F) of the nominal value.

NOTE: When determining the optimum conditions for hard anodising a particular work the composition of the alloy is important. It is therefore essential to segregate work of different casts or batches and for the operator to be informed of any change in alloy so that he can adjust his technique accordingly.

4.6.5 Hard anodising may impair the surface finish, and this should be considered in relation to the surface required on the finished part. In order to produce good coatings and to reduce possible damage to the coating, edges of parts should be radiused to a minimum of 0·06 inch.

4.6.6 The sealing of hard anodic coatings is optional. Some softening of the coating is caused by sealing but sealing may also partially restore the loss of fatigue strength resulting from hard anodising.

4.6.7 Hard anodising is often applied to limited areas of aluminium alloy items, the remaining surfaces of which have to be protected by some other means, usually ordinary chromic acid anodising.

(i) It is usual to carry out the ordinary chromic acid anodising before hard anodising and the areas to be hard anodised stopped off with a suitable lacquer. When this has been completed and the work washed, the stopping off lacquer is removed and the area to be hard anodised thoroughly cleaned (usually by mechanical means) to ensure that all traces of lacquer have been removed. The original anodised area is then stopped off and the hard anodising carried out on the cleaned area.

(ii) Stopping off must be in accordance with the requirements of the approved process or drawing instructions. It is much easier to end a masked area at an external angle or shoulder than in an internal angle. Where an anodised area

is required to achieve a satisfactory fit then the stopping off must be particularly carefully done as hard anodising produces a distinct growth.

4.6.8   In some instances parts are hard anodised all over, after which the coating is machined off in the areas where close tolerances are required and where protection is applied by another method.

5   INSPECTION

5.1   Experience is essential in estimating the quality of an anodic coating.   In general an anodic coating appears warmer to the touch than the bare metal and some resistance is felt when passing the fingers over an anodised surface.   (It should be noted that a thin unsealed coat will offer more resistance than a good sealed coat.)   As contamination of the surface can easily occur from the natural oils exuded by the skin it is essential that such checks are made on representative test samples only.

5.2   **Gauge Check**   Anodic oxidation will cause slight increase in the volume of the part treated.   With the sulphuric acid process, however, as the metal is soluble in the electrolyte, prolonged or incorrect treatment may cause a serious loss of base metal and, therefore, thin sheet treated by this process should be checked for gauge occasionally.

5.3   **Dye Test**   This test should be made immediately after washing and drying but before any sealing process.   The anodic coating should be such that when dyed with methyl violet dye, vigorous rubbing with a damp cloth shall not produce any appreciable loss of colour.   The dye should be applied either by using violet endorsing ink on a rubber pad or by a copying pencil rubbed over the moistened anodised surface.   Dye tests should not be used where appearance is important.   The marks can never be removed and tend to appear through any subsequent paint coat.

5.4   **Sealing Test**   To test whether anodic coatings have been sealed or made non-absorptive, a drop of violet dye solution made by dissolving 1 gramme of anthraquinone violet R in 50 ml of water, should be applied at room temperature to the coated surface of the item, which must not have been contaminated by handling.   The solution should be allowed to stand for five minutes and should then be washed off with running water and the test area rubbed with soap and water.   If the surface is properly sealed, no colour will remain.

5.5   **Electrical Tests**   The electrical test may be used to ascertain the quality of a sealed coat but is not reliable on rough surfaces such as those found on the unmachined portions of castings.

5.5.1   The test can be made with a 60 volt dry battery connected to a spring clip and a metal ball of not less than ¼ inch diameter.   A voltmeter should be connected into the circuit.

5.5.2   The spring clip should be attached to the component, ensuring that the points of the jaws penetrate the film.   The ball should then be passed over the surface of the component and, if the coating is satisfactory, the voltmeter will read 60 volts.   At raised points, sharp edges or corners, the coat will be thinner, and consequently the resistance will be less, resulting in a drop in voltage.   Pressure should not be exerted on the ball during the test otherwise the anodic coating may be damaged.

5.5.3   The main use for this test is to determine whether or not a part has been anodised.

5.6 **Visual Inspection** Various factors affect the colour of an anodic coat but a distinct, even colour is a good indication of a satisfactory coat. The coat produced by the sulphuric acid method is more transparent than that produced by the chromic acid process, and is consequently more difficult to assess.

5.6.1 The chromic acid coat is translucent to opaque, and should be light grey in colour on pure aluminium. On alloys having a high silicon content, however, it will appear as dark gray or purple.

5.6.2 The sulphuric acid process, although producing an almost transparent coat, will again appear darker on alloys having a high silicon content.

5.6.3 Some variation of colour may appear between different batches of the same material. Coatings vary in colour according to the composition of the material and between different forms of the same material. Absence of coloration does not necessarily indicate a poor coating, but dense coloration may be regarded as a favourable sign.

5.6.4 Hard anodising should have a continuous coating free from visible defects and there should be no signs of powdering. An assessment of the hardness of the film can be made by rubbing the surface two or three times with emery paper or cloth to B.S. 871, Grade 00, using medium finger pressure. The paper or cloth should not abrade the surface but should skid over the surface and should show not more than a trace of whitening on the surface.

5.7 **Thickness of Coating** The average coating weight can be determined by weighing a dry test piece before and after stripping the anodic coating in a phosphoric/chromic acid mixture such as given in paragraph 3.4 (ii). The stripping sequence is continued until the weight remains constant. The test piece should form part of, and be treated with, the batch of work which it represents.

5.7.1 The test piece should have a total surface area of not less than 5 square inches and should be of such shape that the surface area of coating can be easily determined. On removal from the stripping bath the test piece should be washed in hot distilled water and dried before re-weighing.

5.7.2 An average thickness can be calculated from the formula:—

$$T = \frac{W}{44 \times A}$$

where T = average thickness of coating in inches.
       W = weight of coating in grammes.
       A = surface area of coating in square inches.

The formula is based on an assumed density of 2.7 g/cm^3 for anodic coating sealed in aqueous solution.

6   CRACK DETECTION The use of chromic acid anodising as an inspection aid makes it easier to detect such defects as coarse grain or segregation. It also shows up surface cracks, laps, or subcutaneous faults which break through to the surface and could remain undetected.

NOTE: As a suitable method of flaw detection for Class 1 castings, forgings and extrusions, the process has been largely superseded by fluorescent flaw detection. It is known that in some instances the anodic coating can 'bridge' small cracks.

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6.1   During the anodising process, which should be effected in the minimum permissible period, chromic acid will be deposited in any cavity which may exist in the material. Upon removal from the bath, the acid will be carried to the surface by the absorbent anodic film in the vicinity of the defect, causing a yellow or brown stain to appear.

6.2   When the parts are removed from the bath they should be washed by a brief swill in cold water to remove the chromic acid from the outer surface. The parts should be allowed to become thoroughly dry, and should be left for at least 24 hours before commencing the examination.

NOTE: Prolonged washing or the use of hot water may remove the chromic acid from the crevices and render the test abortive.

6.3   It is preferable to carry out the examination either in daylight or under a mercury vapour lamp, as the stains may be difficult to recognise in a yellow light. Electrolyte which has been in use for some time is darker than newly made solution, and used electrolyte will therefore give a more positive indication of a defect.

6.4   Contamination caused by perspiration will tend to appear as a yellow stain after chromic acid anodising.

7   MAINTENANCE OF THE ELECTROLYTE

7.1   **Chromic Acid Process**   When the bath is in use, a gradual reduction of the chromic acid occurs, together with the formation of trivalent chromium compounds in which the chromium is no longer effective. The bath may be regenerated with chromic acid, provided the total chromium content does not exceed 10% by weight.

7.1.1   Additions to the chromic acid content should also be made when the titration value falls below 3. Analysis of the electrolyte for total chromium content, titration value, and chloride content should be carried out as detailed in the latest issue of Specification DEF-151.

7.2   **Sulphuric Acid Process**

7.2.1   The concentration of a new solution should be within the range of 5 to 22% by volume of sulphuric acid in water, and losses should be made good by the addition of water or sulphuric acid as necessary.

7.2.2   When the bath is in use aluminium dissolves in the acid, thus the metal content increases and the acid strength decreases; this should be rectified by the addition of sulphuric acid. Analysis of the electrolyte for free sulphuric acid content, aluminium content and chloride content should be made as detailed in the latest issue of Specification DEF-151.
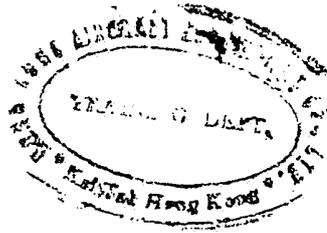
BASIC

PROTECTIVE TREATMENTS

CADMIUM PLATING

1   INTRODUCTION   This Leaflet gives guidance on the processes used for the cadmium plating of carbon and low-alloy steel parts for protection against corrosion, and on the requirements for the cadmium plating of copper-base materials and corrosion-resisting steels for the reduction of contact corrosion of less noble metallic materials. The requirements for cadmium plating are contained in Specification DEF STAN 03-19.

1.1   Parts made of steel of specified minimum tensile strength exceeding 1400 N/mm² or equivalent hardness (see paragraph 1.6) are subject to the special limitations and requirements of Specification DEF STAN 03-4, further guidance on which is given in paragraphs 4.5 and 5.3. Cadmium plating must not be used on parts liable to be subject to temperatures in excess of 235°C (455°F).

NOTE: Throughout Specification DEF STAN 03-19 the unit of force called the Newton (N) has been used and is therefore also used in this Leaflet. 1 N is the force which, when acting on a body of mass 1 kg, gives an acceleration of 1 m/sec².

1.2   Preparation for plating and stress-relieving heat treatment, when required, should be carried out in accordance with DEF STAN 03-2.

1.3   The cadmium-plating process deposits a protective coating of cadmium on the surfaces of the parts by electro-chemical means; it is used mainly for the protection of ferrous metals and provides protection against nearly all forms of surface corrosion, except that the cadmium itself is liable to attack from the vapours emitted from some organic varnishes and plastics insulating materials. The resistance of cadmium to these vapours can be increased if the plating is subjected to the chromate passivation process prescribed in Specification DEF 130.

1.4   The treatments applied to steel parts before and after cadmium plating depend partly on:–

(a)   the tensile strength (or hardness) of the steel,

(b)   the presence of surface-hardened areas,

(c)   the need or otherwise for stress-relieving heat treatment, and

(d)   whether the steel is of carbon, low-alloy or corrosion-resisting type.

1.5   In view of 1.4 above, it is essential that the plater be given the necessary information by the Design Organisation specifying the process to enable him to select the appropriate pre-treatment and, where applicable, the post-plating treatment for the removal of embrittlement, or that he be given precise instructions regarding the treatments to be applied for these operations.

1.6 If no minimum tensile strength is specified for the steel, the treatments must be based on the minimum specified hardness number (Vickers hardness number – HV). Hardness values of 300 HV and 425 HV may be regarded as equivalent to tensile strengths of 1000 N/mm² and 1400 N/mm² respectively. Steels which have been wholly or partly surface hardened must be considered as being in the category appropriate to the hardness of the surface layer.

1.7 General guidance on the protection of aircraft parts against corrosion, and on the selection of suitable protective treatments, is given in Leaflets **BL/4-1, BL/4-2** and **BL/4-3**. Leaflet **BL/4-3** also describes methods of assessing the effectiveness of cadmium plating and should be read in conjunction with this Leaflet. A list of associated Standards and Specifications is given in paragraph 11.

2   PLATING PLANT   The cleanliness of the plating equipment and of the plating room is of the utmost importance if consistently good plating is to be obtained. Sludge should be removed each time the plant is cleaned and the electrolyte should be filtered periodically.

2.1 **Plating Baths.**   The electrolyte should be contained in a steel or plastics-lined tank; the use of a lead-lined tank is prohibited. The tank should be provided with insulated copper or brass rails from which the parts to be plated can be suspended and which should be clean and free from verdigris. The parts being treated serve as the cathode, and plates, balls or oval extruded sections of solid cadmium serve as anodes.

NOTE: The anodes must conform to the requirements of British Standard 2868 and must be certified free of mercury.

2.1.1 To prevent the cadmium content of the electrolyte becoming too high, a proportion of insoluble anodes, such as iron or mild steel plates or balls, may be used.

2.1.2 To obviate the necessity of 'wiring up' very small items such as nuts, bolts and washers for suspension in a tank-type bath, a rotating barrel-type bath may be used.

2.2 **Electrical Control.**   Direct current is required for the operation of the bath. This is usually supplied by a rectifier and is controlled according to the current density required, both voltage and current density varying with the composition of the electrolyte.

2.2.1 The electrical control should be capable of operation within reasonably fine limits and accurate voltmeters and ammeters should be provided.

2.2.2 Porous plating of poor quality will result if the voltage and current density are of too high a value during the plating operation. The time taken to obtain a plating of acceptable thickness varies between 15 and 40 minutes, depending on the efficiency of the plant. However, when high-speed bright plating solutions are used, current densities of approximately 300 A/m² (30 A/ft²), at a pressure of 1½ to 2½ V are often specified, and a deposit of 0·00762 mm (0·0003 in) thickness can be obtained in 8 to 10 minutes.

2.3 **Heating the Electrolyte.**   The electrolyte can be heated to the prescribed operating temperature by means of gas, electricity or steam.

NOTE: The operating temperature of a proprietary electrolyte should be as recommended by the supplier.

3   PREPARATION OF PARTS FOR PLATING   The surfaces of the parts to be plated must be quite clean otherwise the process will not be successful. In addition, for certain materials, stress-relieving heat treatment is essential before plating. Suitable cleaning and stress-relieving heat-treatment processes are prescribed in Specification DEF STAN 03-2.

3.1   Where copper-base materials are concerned, it is recommended that the cleaning process prescribed in DEF STAN 03-2 should be followed by nickel plating to a thickness of between 0·00127 mm (0·00005 in) to 0·00254 mm (0·0001 in).

3.2   Steel parts which are to be chromium plated locally and then heated in the range of 440°C to 480°C, as prescribed in DEF STAN 03-14, must be given these treatments before cadmium plating is commenced.

3.3   Where steels having a specified minimum tensile strength exceeding 1400 N/mm^2 are concerned, the special requirements regarding surface preparation prescribed in Specification DEF STAN 03-4 must be taken into account.

4   THE PLATING PROCESS   Cadmium plating is usually effected with a cyanide electrolyte, but when freedom from hydrogen embrittlement is a primary consideration, the use of a modified cyanide or fluoborate electrolyte may be advantageous. Addition agents, such as those used to improve the properties or appearance of the coating, may also accentuate hydrogen 'pick-up' during plating.

NOTE: The throwing power of fluoborate electrolyte is less than that of cyanide electrolyte.

4.1   Any suitable electrolyte may be used provided that:–

(a)   the plating satisfies the quality and thickness requirements prescribed in DEF STAN 03-19,

(b)   the materials are certified mercury-free by the suppliers, and

(c)   when a proprietary electrolyte is used the proprietary salts, i.e. brighteners, are employed for the maintenance of this, then the composition of the electrolyte for standard chemicals as given in paragraph 4.2 must be controlled.

4.2   Guidance on the composition of suitable cyanide electrolytes for bath and barrel plating is given in the following paragraphs. The units used are grammes per litre (g/litre) and ounces per gallon (oz/gal).

4.2.1   **Composition for Baths.**   A suitable electrolyte is as follows:–

Cadmium ..   ..   14–17 g/litre (2·25 to 2·75 oz/gal)

Total cyanide (as NaCN) ..   ..   56–63 g/litre (9 to 10 oz/gal)

Sodium hydroxide   ..   ..   ..   11–14 g/litre (1·75 to 2·25 oz/gal)

Addition agents may be included if desired.

(a)   The bath should be operated at a temperature of between 15°C and 35°C at a current density of approximately 50 to 100 A/m^2 (5 to 10 A/ft^2).

(b)   An electrolyte having approximately the composition of that given above may be prepared, using cadmium cyanide or cadmium oxide to provide the metal content, as follows:–

Cadmium cyanide	..	..	25 g/litre (4·0 oz/gal)
Sodium cyanide	..	..	43 g/litre (6·9 oz/gal)
Sodium hydroxide	..	..	9 g/litre (1·5 oz/gal)

or

| Cadmium oxide | .. | .. | 19 g/litre (3·1 oz/gal) |
| Sodium cyanide | .. | .. | 58 g/litre (9·3 oz/gal) |

4.2.2 **Composition for Barrels.** A suitable electrolyte is as follows:-

Cadmium ..	..	..	..	..	23–27 g/litre (3·75 to 4·25 oz/gal)
Total cyanide (as NaCN)	..	..	94–100 g/litre (15 to 16 oz/gal)
Sodium hydroxide	..	..	..	17–20 g/litre (2·75 to 3·25 oz/gal)

Addition agents may be included if desired.

(a) The bath should be operated at a temperature of between 15°C and 35°C at a current density of approximately 50 A/m² (5 A/ft²).

(b) An electrolyte having approximately the composition of that given above may be prepared, using cadmium cyanide or cadmium oxide to provide the metal content, as follows:-

Cadmium cyanide	..	..	38 g/litre (6·0 oz/gal)
Sodium cyanide	..	..	75 g/litre (12·0 oz/gal)
Sodium hydroxide	..	..	19 g/litre (3·0 oz/gal)

or

| Cadmium oxide | .. | .. | 29 g/litre (4·7 oz/gal) |
| Sodium cyanide | .. | .. | 97 g/litre (15·5 oz/gal) |

4.2.3 **High-Speed Bright-Plating Electrolyte.** A high-speed bright-plating electrolyte suitable for use with both baths and barrels is as follows:-

Cadmium ..	..	..	..	..	19–25 g/litre (3·0 to 4·0 oz/gal)
Total cyanide (as NaCN)	..	..	94–137 g/litre (15·0 to 22·0 oz/gal)
Sodium hydroxide	..	..	..	19–38 g/litre (3·0 to 6·0 oz/gal)

It is essential that a suitable addition should be used.

(a) The bath should be operated at a temperature of between 15°C and 35°C at a current density of approximately 300 A/m² (30 A/ft²).

(b) An electrolyte having approximately the composition of that given above may be prepared, using cadmium cyanide or cadmium oxide to provide the metal content, as follows:-

Cadmium cyanide	..	..	32 g/litre (5·1 oz/gal)
Sodium cyanide	..	..	106 g/litre (17·0 oz/gal)
Sodium hydroxide	..	..	31 g/litre (5·0 oz/gal)

or

Cadmium oxide	..	..	25 g/litre (4·0 oz/gal)
Sodium cyanide	..	..	125 g/litre (20·0 oz/gal)
Sodium hydroxide	..	..	16 g/litre (2·5 oz/gal)

4.3 **Suspension of Parts.** Large components or parts should be suspended from the cathode rails by means of clips or wire having several contact points of small area rather than a few points of large area. The clips or wire should be removed from time to time so that unplated patches on the parts are avoided.

NOTE: Laminated or assembled parts must not be cadmium plated due to the risk of corrosion resulting from entrapped electrolyte.

4.3.1 Small parts which cannot be suspended individually should be placed in wire baskets, the baskets being suspended in the usual way. However, they should be shaken up from time to time to ensure that an even plating is obtained. Where very small parts are concerned, the barelling process described in paragraph 2.1.2 is more suitable.

4.3.2 Parts having very deep recesses, such as tubular parts, will not receive a satisfactory internal plating unless internal anodes are used. Such anodes should have a minimum surface area of 10% of the internal area of the part under treatment, and should be positioned centrally.

4.3.3 Close coil springs (heat-treated before plating) should be slightly extended during the process of plating to ensure satisfactory deposition between the coils.

4.4 **Masking.** Where necessary components may be masked to avoid plating various sections but the practice of plating all over and then removing the plating not required by final machining operation is considered more satisfactory. However, if machining is not possible, steel parts from which the masking has been removed should be suitably protected, immediately after the plating and subsequent washing, to prevent corrosion.

4.5 **Very High Tensile Steels.** Parts manufactured of materials having a specified minimum tensile strength exceeding 1400 N/mm^2 are subject to the specific requirements of DEF STAN 03-4. The parts must be cleaned and prepared, as prescribed in DEF STAN 03-4 by one or more of the methods described and numbered in DEF STAN 03-2, after which the general requirements of DEF STAN 03-19 should be applied, including chromate rinsing and chromate passivation.

NOTE: Unplated areas must not be allowed to come into contact with the passivation solution, i.e. stopping-off compound should be left on.

4.5.1 An alkaline cyanide bath is generally used. There is evidence to show that acid baths based on fluorborate or perchlorate cause less embrittlement but, unfortunately, the latter baths have relatively poor throwing power.

4.5.2 There is evidence that embrittlement is less in baths of high cadmium concentration, baths of low cyanide concentration, and baths operated at high current density. Brightening agents must not be added to the bath.

5   TREATMENT AFTER PLATING Immediately after plating the parts should be washed in clean running water until all traces of the electrolyte are removed and, unless they are to be immediately passivated without drying, should then be dipped in a 5% (48 g/litre (8 oz/gal)) aqueous solution of chromic acid free from other acids, maintained at a temperature of not less than 60°C (140°F) for 15 to 30 seconds. The parts should then be washed in clean running water, finally in warm water, and dried.

5.1 Washing should normally be followed by chromate passivation conforming with Specification DEF 130, and may only be omitted when the parts are to be etch-primed or at the specific request of the Approved Design Organisation.

NOTE: In some districts it may be found desirable to use de-mineralised water in washing or chromate dip operations in order to avoid staining.

5.2 Parts not required to be heated for removal of embrittlement (see paragraph 5.3) must be passivated immediately after plating and washing without intermediate drying. Parts made of high tensile steel must be treated for removal of embrittlement before chromate passivation.

5.3 Removal of Embrittlement

5.3.1 All plated steel parts of specified minimum tensile strength of 1000 N/mm^2 or greater (or of equivalent hardness) must be heated as described below as soon as practicable but not more than 16 hours after plating. This treatment must also be applied to parts of this tensile strength after any stripping, except that the minimum time of heating of stripped parts may be reduced to not less than half of that specified for plated parts. Parts of minimum specified tensile strength exceeding 1400 N/mm^2 must not be replated without the consent of the Approved Design Organisation responsible for the design.

5.3.2 Plated parts, other than those with carburised areas, made of steel of specified minimum tensile strength of 1000 N/mm^2 or greater up to and including 1400 N/mm^2 must be heated at a temperature between 190°C (374°F) and 230°C (446°F) for not less than 8 hours. Parts of minimum specified tensile strength exceeding 1400 N/mm^2 must be heated in accordance with the requirements of DEF STAN 03-4.

5.3.3 Plated steel parts having carburised areas which would suffer an unacceptable reduction in hardness by treatment as outlined in paragraph 5.3.2 must be heated at not less than 130°C (266°F) for not less than 8 hours.

6   INSPECTION

6.1 **Visual.** Before chromate passivation or chromate dipping, the plating should be smooth and silvery-white in colour; it should also be continuous and free from burns or blisters, or any tendency to flake off. The colour should be uniform in appearance on any one part.

NOTE: The appearance of the plating may be affected by the chromate passivation treatment or by the chromate dip (as appropriate), therefore visual inspection should be made before the application of either of these treatments.

6.2 Selection of Test Samples

6.2.1 **Bath-plated Parts.** A sample (minimum of two parts) of production parts should be selected from each bath load and should be checked for freedom from porosity (if applicable) (paragraph 6.3), adhesion (paragraph 6.4) and thickness (paragraph 6.5), the tests being made in that order. Where a continuous form of bath plating is in operation, a representative sample should be taken at intervals of not more than one hour.

6.2.2 Barrel-plated Parts

(a) A sample normally consisting of ten parts or more, from each group of parts of the same size and shape from each barrel load, should be selected and checked for freedom from porosity (where applicable), adhesion and thickness. The number of parts selected must be such that significant weighing errors are avoided.

(b) For groups of not more than 100 parts of the same size and shape plated together, two or more samples should normally be selected and should be checked for freedom from porosity, adhesion and thickness. The number of parts selected must be such that significant weighing errors are avoided.

6.2.3 Parts Plated in Small Numbers.

In exceptional circumstances, e.g. the bath plating of single large parts or the barrel plating of small numbers of parts, DEF STAN 03-19 permits, under the conditions prescribed in that specification, a modification of the sampling procedure described in paragraph 6.2.2 (a) or (b). In suitable instances coupon samples may be used, due consideration being given to their shape, size and material and, if applicable, their position in the bath. The treatment of the coupon samples must be suitably representative of that applied to the parts being plated.

6.3 Freedom from Porosity.

Freedom from porosity should be determined as soon as convenient after the plating process is completed. The test is applicable to all cadmium-plated steel parts plated all over, except screws and bolts of major thread diameter not greater than 3 mm (0·126 in) and parts made from corrosion-resisting steel. Internal threads, screw-driver slots and similar shielded areas can also be excepted from the test at the discretion of the Chief Inspector. Large or complete parts plated to the normal requirements of thickness (see Table 1) may be excepted if so specified by the Designer.

6.3.1 The samples should be carefully cleaned in a suitable solvent vapour and should then be immersed in a solution of 1% (v/v) of hydrochloric acid (d = 1·16) at room temperature for 5 minutes, after which active evolution of hydrogen, as distinct from infrequent bubbling, should lead to rejection.

6.3.2 The test is non-destructive to the plating and after testing, the samples which pass the test should be thoroughly washed in hot water and dried.

NOTE: The test is not suitable for non-ferrous or corrosion-resisting steel parts.

6.4 Adhesion.

When the shape and size of the part permits, a small area of the plated surface should be rubbed rapidly and firmly with a suitable tool for about 15 seconds and visually inspected, when there should be no indication of the deposit becoming blistered or otherwise detached from the base metal. The pressure applied must be sufficient to burnish the plating at each stroke but not to cut the deposit. Suitable tools are a 6 mm (0·25 in) diameter steel rod with a smooth hemispherical end or a copper disc used edgewise and broadside.

6.5 Thickness Tests.

The amount of cadmium deposited on the parts varies at different points, e.g. areas which are recessed or shielded, or those which are furthest from the anodes, plate less rapidly than those areas which are more favourably situated; conversely the plating tends to build up on the extremities of the parts. However, the thickness of the plating must be reasonably uniform and, when tested by the procedures described in paragraphs 6.5.2 and 6.5.3, must not be less than the requirements

prescribed in DEF STAN 03-19 (see Table 1). For parts plated by the bath process, the difference between the plating thickness of the parts (mean local thickness or average thickness as appropriate) must not exceed 50% of the thickness specified in Table 1.

NOTE: Wherever practicable, the local thickness test (paragraph 6.5.2) should be used.

6.5.1 Where the tolerance requirements of mating parts or where interchangeability considerations apply, e.g. screw-threads, a maximum limit on the thickness of the plating may be prescribed by the drawing. (For reference to threaded parts, see Leaflets **BL/3-1** and **BL/3-2**.)

6.5.2 **Local Thickness.** The local thickness of the coating should be determined by a method agreed by the Approved Design Organisation, and should have an accuracy of 10% or better of the thickness being measured. Where possible, four measurements should be made on each selected sample, and where practical these measurements should be made at places which are widely separated and which can be expected to be comparatively thinly coated. Normally the measurement points should be capable of being touched by a sphere of 20 mm (0·8 in) diameter and should not be less than 6 mm (0·25 in) from any edge. On some items the coating may be required to have an adequate thickness in recesses and other areas which would be excluded from the test by this limitation; in such cases the drawing should specify the special requirements.

6.5.3 **Average Thickness.** The average thickness of the cadmium coating and, where applicable, the nickel undercoat, should be determined as follows:–

(a) The plated sample should be cleaned in a suitable solvent vapour, weighed and then totally immersed in a solution prepared by dissolving 30 g of ammonium nitrate in 100 ml of water. The solution should be stirred occasionally until the plating is dissolved (10 minutes usually being sufficient). The sample should then be removed from the solution, washed, dried and re-weighed.

$$\text{Cadmium thickness } (\mu\text{m}) = \frac{\text{loss of mass (g) x 116 x } 10^3}{\text{Area of coating (mm}^2)}$$

(b) Alternatively the sample may be cleaned and weighed as in (a) then totally immersed in a solution containing 2·5 g of antimony trichloride and 600 ml of hydrochloric acid (d = 1·16) per litre. The solution should be stirred occasionally until the plating is dissolved (2 minutes usually being sufficient). Immediately effervescence has ceased the sample should be removed from the solution, washed, dried and re-weighed. The coating thickness is determined from the formula shown in (a).

(c) To determine the thickness of a nickel undercoat on copper-base materials, after the cadmium coating has been removed ((a) or (b)), the sample should be immersed in a solution of 70% (v/v) sulphuric acid (d = 1·84) with a little glycerine added. The sample should be treated anodically at 6 to 12 volts and immediately solution of the nickel is complete it should be removed, washed rapidly, dried and re-weighed.

$$\text{Nickel thickness } (\mu\text{m}) = \frac{\text{loss of mass (g) x 113 x } 10^3}{\text{Area of coating (mm}^2)}$$

TABLE 1
THICKNESS REQUIREMENTS (DEF STAN 03-19)

Application	Minimum Local Thickness μm	Minimum Average Thickness (see Note 1) μm
1 Normal requirements:		
Steels (non-corrosion resisting)	10	14
Copper-base materials and corrosion resisting steels	8	12
2 Threaded items not exceeding 20 mm dia. (see Notes 2 and 3), screws, bolts and nuts of nominal major thread diameter:		
Up to 3 mm	–	4
Over 3 mm up to 5 mm	–	5
Over 5 mm up to 13 mm	–	6·5
Over 13 mm up to 20 mm	–	7·5
3 Washers	–	5
4 Rivets, taper pins, and split cotters	–	8

NOTES: (1) For barrel-plated items average thickness is normally based on the whole sample, but if used for vat-plated items it is normally based on individual items.

(2) Thickness requirements for copper-base materials are inclusive of nickel undercoating (see clause 7.3 of DEF STAN 03-19).

(3) The coating thickness requirements for threaded items are dictated by dimensional tolerance limits. Such thicknesses will not necessarily provide adequate protection against corrosion.

6.6 **Freedom from Mercury.** Tests for mercury in the deposit shall be made periodically at the discretion of the Approved Design Organisation. Suitable tests for mercury contamination are given in DEF STAN 03-19.

7 **PERIODIC SOLUTION TESTS** The electrolyte should be checked periodically in accordance with the supplier's instructions to ensure continued efficiency; suitable standards for the bath described in 4.2.1, for example, are:–

(a) Cadmium (as metal) 12–19 g/litre (2–3 oz/gal)

(b) Free sodium cyanide 15–19 g/litre (2·5–3·0 oz/gal)

(c) Caustic soda 5–9 g/litre (0·75–1·25 oz/gal)

7.1 The metal content will maintain itself provided there is adequate anode surface and a normal amount of free cyanide present. However, should the solution become depleted of metal but is found to contain ample free cyanide, or if the free cyanide content is found to be excessive, cadmium carbonate should be used. One part by weight of this

will introduce 0·6 part of cadmium into the electrolyte and will neutralise one part of free sodium cyanide. The cadmium carbonate should not be added directly to the bath but should be dissolved in some of the plating solution which has been heated to a temperature of about 60°C (140°F) in a suitable vessel. Excessive free cyanide content will result in poor throwing power and considerable gassing at the cathode.

8   RE-PLATING STEEL PARTS   When steel parts are to be re-plated, the original cadmium should be removed and, prior to re-plating, the parts should be inspected for absence of corrosion and damage and for dimensional accuracy. Where appropriate, the parts should be examined for cracks by the electro-magnetic method (Leaflet **BL/8-5**) or some other suitable method. The parts should be re-plated in accordance with the recommendations given in the previous paragraphs of this Leaflet.

9   STORAGE - All plated parts should be stored in suitable containers and protected from excessive changes in temperature and humidity until required for use. Where the period of storage is likely to be lengthy, the parts should be further protected by means of a thin coating of suitable grease or oil, such as de-watering oil. Cadmium plated parts should never be stored in close proximity to phenolic plastics in poorly ventilated places, since the vapours emitted by such materials tend to cause corrosion of the plating (see paragraph 1.3).

10   FAULTS IN CADMIUM PLATING   The following paragraphs give some common faults in cadmium plating, together with the possible methods of rectification.

10.1 **Imperfect Adhesion and Blisters.**   Such faults may be due to lack of free cyanide in the ectrolyte, this being indicated by black slime on the anodes and little, if any, gassing at the cathode. The faults can usually be remedied by the addition of sodium cyanide as indicated in paragraph 7. Other reasons for these results include the presence of grease, oxide or stains on the metal before plating, occlusion of hydrogen by the base metal due to cleaning hardened steel cathodically and presence of acid on the base metal immediately prior to plating.

10.2 **Rough, Dark, Granular Deposit.**   A coating of this nature results from the use of excessive current, causing a 'burnt' deposit; the tendency may be aggravated by lack of free cyanide. In such instances, any deficiency in free cyanide content should be made good (paragraph 7), the voltage should be reduced and the parts coated at a lower density. It may also be necessary to reduce the anode surface by removing a number of plates or balls, but if the effect is usually found only on small parts, these should be suspended between larger parts.

10.3 **Rough Upper Surfaces.**   When the deposit is of good colour and appearance but the surfaces which have been uppermost during treatment are rough, this is due to suspended matter in the electrolyte. In such instances the solution should be filtered or, after removing the sediment from the tank and allowing the solution to settle, clear solution should be syphoned into a spare tank.

10.4 **Thin, Meagre Deposit.** This fault, coupled with slow deposition, indicates that the solution is deficient in metal. The metal content should be checked and made good (see paragraph 7.1).

10.5 **Non-Deposition.** Non-deposition may be due to reversed electrical polarity, faulty contacts, or passivity of the parts being plated. In the first instance the electrical conditions should be checked, but where passivity is suspected, the passive surface of the parts can be removed by scratch-brushing or polishing, depending on the importance of the surface or part.

11   ASSOCIATED STANDARDS AND SPECIFICATIONS

BS 2868	Cadmium Anodes and Cadmium Oxide for Electroplating.
DEF 130	Chromate passivation of Cadmium and Zinc Surfaces.
DEF STAN 03-2	Cleaning and Preparation of Metal Surfaces.
DEF STAN 03-4	The Pre-treatment and Protection of Steel Parts of Specified Maximum Tensile Strength Exceeding 1450 N/mm².
DEF STAN 03-14	Electro-deposition of Chromium for Engineering Purposes.
DEF STAN 03-19	Electro-deposition of Cadmium.

BASIC

PROTECTIVE TREATMENTS

CHROMATE TREATMENT OF MAGNESIUM ALLOYS

1   INTRODUCTION   This Leaflet gives general guidance on the initial protection of magnesium-rich alloys by chromate treatment.   The purpose of the treatment is to provide a temporary protective and an initial treatment prior to surface sealing, painting, stove enamelling and other filming processes.   The Leaflet should be read in conjunction with Leaflet BL/7-5 entitled "Protection of Magnesium Alloys" and the latest issue of Specification DTD 911.   Chemical formulae for the chemicals used in these treatments will be found in Specification DTD 911.

1.1   Chromating produces a film on the surface integral with the basis metal (as distinct from a deposited coating) and, in addition to conferring a useful measure of protection from corrosion, it provides a key for subsequent applications of surface sealing resin or paint.

1.2   In order that the materials will show the greatest resistance to corrosion after chromating, it is important that the materials themselves should be reasonably free from impurities and that their surfaces should not be contaminated by fluxes or other impurities which may be introduced during workshop processes such as rolling, forging, bending, welding, forming, etc.   It has been shown that when colloidal graphite is used as a lubricant during drawing operations, graphite residues reduce the corrosion resistance of magnesium alloy sheet.   A suitable method for removing graphite consists of (a) immersion of the material in nitro-benzene and (b) a dip in 10 per cent aqueous nitric acid and then chromate treatment.

1.3   The latest issue of Specification DTD 911 provides for the use of three types of chromating processes, i.e. the Hot Half-Hour Chromate Bath (Bath iii), the Acid Chromate Bath (Bath iv) and the Chrome Manganese Bath (Bath v).   The purposes of these various processes are described in subsequent paragraphs of this leaflet.

1.4   Guidance on the Anodic Oxidation of Aluminium Alloys is given in Leaflet BL/7-1, on Cadmium Plating in Leaflet BL/7-2, on Phosphating of Steels in Leaflet BL/7-4 and on Painting in Leaflet BL/16-20.

2   PREPARATION FOR TREATMENT—CLEANING   The method of surface preparation depends to a large extent on the nature of the part and the degree of surface finish accorded to it.   Irrespective of the cleaning process used, however, all parts must be transferred to the chromating bath immediately after cleaning.

NOTE: Emery should never be used for dressing operations unless its use is followed by Fluoride Anodising (see paragraph 2.1.1).

2.1   Castings in the "As Cast" Condition.   Such castings, which are normally chromate treated for protection during storage and machining, should be treated by one of the following processes.

2.1.1   Electrolytic Cleaning by Fluoride Anodising.   This process is described in Leaflet BL/7-5 and is recommended for maximum corrosion resistance.   The process for the removal of the fluoride film is also given as this is necessary before chromating by means of Bath (iii) paragraph 3.1 and Bath (v) paragraph 3.3.   Removal of the fluoride film is not necessary prior to chromating by means of Bath (iv) paragraph 3.2.

2.1.2 **Acid Pickling.** When this process is used, the parts should be immersed in a 5 to 10 per cent (by volume) solution of nitric acid, or in a 5 per cent (by volume) solution of sulphuric acid, for short periods until uniformly clean.

2.1.3 **Abrasive Blasting.** When an abrasive blasting process is used, this should preferably be followed by machining or scurfing all over or by Fluoride Anodising. The use of abrasive blasting is not permitted on high purity magnesium alloys unless they are subsequently machined all over to a depth of 0·04 in.

2.2 **Castings in the "Finished Machined" Condition.** After machining and degreasing in an organic solvent such as trichloroethylene (Leaflet BL/6-8) the parts, according to the dimensional tolerances applicable, should be cleaned preferably by Fluoride Anodising or by one of the following processes.

2.2.1 **Parts not Machined to Very Fine Tolerances.** The parts should be immersed in a 5 to 10 per cent (by volume) solution of nitric acid, or in a 5 per cent (by volume) solution of sulphuric acid, for short periods until uniformly clean. Alternatively, any of the methods described below may be used.

NOTE: When cleaning wrought magnesium-zirconium alloys by this method, any smut produced in the acid bath should be removed by dipping the parts in a solution of 10 per cent w/v chromic anhydride plus 1 per cent v/v nitric acid (sp. gr. 1.42) for 30 seconds, followed by thorough washing in water.

2.2.2 **Parts Machined to Fine Tolerances.** The standard treatment for such parts is immersion for 15 minutes in a boiling 2 to 5 per cent solution of caustic soda or of a suitable alkaline metal cleaning solution.

NOTE: For parts that have been treated as outlined in paragraphs 2.2.1 and 2.2.2 a hydrofluoric acid immersion treatment as described in paragraph 2.2.3 is beneficial.

2.2.3 **Parts Previously Chromate Treated.** Such parts can usually be cleaned by the treatment described in paragraph 2.2.2, but where a thick chromate film is present, this treatment may not be entirely satisfactory when judged by the appearance of the film after re-chromating. In such instances the parts should be immersed for 5 to 15 minutes in a boiling 5 per cent caustic soda solution, washed, and then immersed for 2 to 15 minutes in a 10 to 15 per cent boiling chromic acid solution to remove the film. This should be followed by immersion of the parts in a boiling 5 per cent caustic soda solution for 10 minutes, or in a cold 15 to 20 per cent hydrofluoric acid solution for 5 minutes. Where hydrofluoric acid is used, this should be contained in a lead, plastic, guttapercha or rubber-lined receptacle, and can be prepared by diluting one volume of technical grade "50/60" HF with 2·5 volumes of water. Fluoride Anodising is also effective in softening and removing old chromate films.

NOTE: (i) If the sulphate content of the chromic acid solution used to remove the film exceeds 0·03g SO_4 per 100 cms³ the solution will attack the metal appreciably. The chromic acid should be contained in a mild steel vessel.

(ii) Chloride ions present in chromic acid will also attack the metal. Small additions of barium chromate and silver chromate will precipitate sulphate and chlorides respectively and so minimise any attack.

2.3 **Sheets, Extrusions and Forgings.** Any one or more of the processes described in the preceding paragraphs are suitable. The use of abrasive blasting processes is prohibited (unless otherwise agreed, see Note), unless the parts are subsequently machined or scurfed all over to a depth of 0·04 in. or more. If desired, chemical precleaning may be preceded by scouring with pumice powder applied with a moist rag.

NOTE: The prohibition of abrasive blasting processes on wrought forms of magnesium is waived in certain instances, e.g. production of forgings.

2.4   When abrasive blasting is employed, clean alumina grit should be used and its cleanliness controlled.   No accumulations of iron, carborundum, rust, graphite or dirt residue should be allowed to collect in the blasting plant.

2.5   Vapour blasting can sometimes be employed with advantage since it has the abrasive blasting effect with less tendency to contaminate the surface of the material.   Since this process removes only very little metal, it can be applied to semi-finished work.

2.5.1   Although contamination is not so severe as with abrasive blasting, Fluoride Anodising after vapour blasting is still recommended.

3   THE CHROMATE TREATMENT PROCESSES   When applying any of the following processes, care must be taken not to inhale the fumes given off by the baths and acids or other chemicals must not be allowed to come into contact with the skin.   It is essential that the chromate treatments outlined below comply with the latest issue of Process Specification DTD 911.

NOTE: The chromate films produced by the Chrome Manganese (Bath v) process and the Hot Half-Hour (Bath iii) process are superior to that produced by the Acid Chromate (Bath iv).   Consequently they are recommended for use wherever possible.

3.1   Hot Half-Hour Chromate Bath (Bath iii).   This process is suitable for all types of magnesium alloys, but fairly close control is necessary when treating alloys of the magnesium-manganese and magnesium-zirconium classes.   The process is particularly suitable where a high degree of protection is required but where significant dimensional changes cannot be tolerated.

3.1.1   The treatment is applied by immersion of the parts in a boiling solution of the following composition:—

Potassium dichromate   1·5 per cent w/v (15 lb/100 gal)
Ammonium dichromate   1·5 per cent w/v (15 lb/100 gal)
Ammonium sulphate   3·0 per cent w/v (30 lb/100 gal)

NOTE: The potassium dichromate may be replaced by the same weight of sodium dichromate.

3.1.2   Ammonia solution having a specific gravity of 0·880 should be added to the solution to establish a pH value (Leaflet BL/10-1) suitable for the alloy to be treated (see Table 1).   The solution should be contained in a tank of pure aluminium or mild steel equipped with heating coils and a fume extractor.   Providing all the salts are in solution, the method of mixing is unimportant, but care should be taken to ensure that the solution is well stirred and that there is no layer of undissolved crystals in the bottom of the tank.

TABLE 1		
Alloy	pH Range	Percentage of Ammonia Necessary to Bring pH of Bath to Start of Range (by volume)
Magnesium-zirconium alloys	5·90 to 6·00	0·27
Magnesium-aluminium alloys	5·90 to 6·05	0·27
Magnesium-manganese alloys:—		
DTD 118	6·05 to 6·13	0·37
DTD 140, DTD 142	6·13 to 6·18	0·43

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3.1.3 The pH measurement of the bath may be controlled by any convenient method, but care must be taken to ensure that the measuring instrument used gives true pH values or that readings given by it can be converted into true values, since it is these which are quoted above. A list of apparent pH values and the corresponding true pH values covering the pH range applicable is given in Table 2. Further information on the determination of pH values is given in Leaflet BL/10-1.

NOTE: The discrepancy between observed and true pH values is only found when using colorimetric instruments in which bromocresol-purple is used.

TABLE 2	
Apparent pH Value	True pH Value
5·1	4·8
5·3	5·0
5·5	5·2
5·7	5·4
5·9	5·6
6·1	5·8
6·4	6·0
6·6	6·2

3.1.4 **Operation of the Bath.** The parts should be immersed for 30 minutes in the boiling solution and after removal from the bath should be washed immediately in warm water, the temperature of which should not exceed 50°C.

(i) Losses by evaporation should be made up from time to time by the addition of water.

(ii) The pH value of the solution should be checked daily and, if low (but see note below), additions of ammonia should be made as necessary. If the pH value is too high, this can be corrected by additions of chromic acid or sulphuric acid. The quantities of chemicals to be added to correct the pH value are given in Table 3.

NOTE: As the bath ages (due to accumulation of magnesium salts) it will be necessary to lower the pH value to produce a satisfactory film; nevertheless, the pH value should be as high as possible consistent with a good film appearance.

TABLE 3		
Additive	Quantity	Effect on pH Value
Ammonia (sp. gr. 0·880)	8 fl. oz. per 100 gal of chromate bath (0·05 per cent v/v)	Raised by approximately 0·1
Chromic Acid	10 oz. per 100 gal of chromate bath (0·063 per cent w/v)	Reduced by approximately 0·1
Sulphuric Acid (sp. gr. 1·84)	5 oz. (2.7 fl. oz.) per 100 gal of chromate bath (0·17 per cent v/v)	Reduced by approximately 0·1

NOTE: The ammonia should be diluted with at least its own volume of water and the sulphuric acid with at least twice its own volume of water before being added to the hot solution. The acid must always be added to the water and not vice versa.

(iii) The chloride content of the bath must not exceed 0·5 per cent calculated as sodium chloride.

3.1.5 **Inspection of Film.** On completion of treatment, the surfaces treated should be covered with an adherent, unbroken film of uniform colour, free from bloom. The actual colour of the film will vary, according to the alloy treated, from straw to jet black, as shown in Table 4. The adhesion of the film can be tested by rubbing with white paper, after which the film must show no signs of damage and only the faintest stain must show on the paper.

NOTE: Parts which have been welded may exhibit variations of film colours in the welded areas.

TABLE 4	
Material	*Film*
Magnesium-manganese alloys:— DTD 118, DTD 140, DTD 142	Uniform straw to light brown without blemishes.
Magnesium-aluminium alloys	Brown-black through jet black to grey-black with increasing content of aluminium in the alloy from 4 per cent upwards.
Magnesium-zirconium alloy (with or without rare earth elements, zinc or thorium)	Brown to black on wrought or machined surfaces.

NOTE: On Magnesium-manganese alloys, chocolate coloured films, which result from an excessively acid bath, are brittle and non-adherent, whilst patchy and uneven films are sometimes caused by surface impurities. The quality of chromate treatment on castings should be judged by the appearance on machined surfaces.

3.2 **Acid Chromate Bath (Bath iv).** This process is particularly suitable for the treatment of magnesium-manganese alloys or generally for the treatment of unmachined parts subject to temporary storage. It is not recommended for the treatment of parts machined to fine tolerances, since approximately 0·0005 in. of metal will be removed from each treated surface during the process.

NOTE: Parts previously treated in an acid chromate bath may be re-treated directly in the same bath.

3.2.1 The treatment is applied by immersing the parts in a solution of the following composition:—

Sodium or potassium dichromate   15 per cent w/v (150 lb/100 gal)
Nitric acid (sp. gr. 1·42)   20 to 25 per cent v/v (20 to 25 gal/100 gal)

3.2.2 The solution should be contained in a tank lined with earthenware, slate, pure aluminium or stainless steel; because of the acidity of the solution mild steel should not be used. The tank should be fitted with an efficient fume extractor.

3.2.3 The solution should be prepared by adding the nitric acid to the water and then stirring in the dichromate, making sure that it is completely dissolved.

3.2.4 The parts should be immersed for about 20 seconds with the solution at a temperature of 5°C. to 25°C., but longer soaking periods may be necessary if the solution is partly spent. On removal from the solution the parts should be drained for about 10 seconds and then washed thoroughly in clean warm water, the temperature of which should not exceed 50°C. When large structures are treated, longer immersion times may be required, i.e. from 15 seconds upwards, but in such cases the nitric acid content of the bath may be reduced to lessen the activity of the bath.

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3.2.5 The specific gravity of the bath should be checked at regular intervals with a hydrometer. It should be approximately 1·20 for a freshly prepared solution but will rise with use. When the specific gravity reaches 1·22, the solution may be revived by adding 5 per cent to 8 per cent by volume of nitric acid. This may be done two or three times, but when the specific gravity reaches 1·24 the solution should be rejected.

3.2.6 **Inspection of Film.** The film should be adherent and free from bloom, and should be tested with white paper as described in paragraph 3.1.5. On magnesium-aluminium alloys the colour of the film varies with the condition of heat treatment; in the "as cast" and solution-treated conditions the film tends to be brassy yellow in colour but in the annealed and fully heat-treated conditions the film tends to be light grey in colour. On other alloys the film should be of a clear brassy yellow colour.

3.3 **Chrome-Manganese Bath (Bath v).** This process is suitable for the protection of all types of magnesium alloys where a high degree of protection is required with negligible dimensional change.

3.3.1 The treatment is applied by immersing the parts in a solution of the following composition:—
Sodium dichromate 10 per cent w/v (100 lb/100 gal)
Manganese sulphate 5 per cent w/v (50 lb/100 gal)
Magnesium sulphate 5 per cent w/v (50 lb/100 gal)
The addition of a small amount of a suitable detergent (in amounts not exceeding 1 per cent) is beneficial, but should not be used if the bath is to be boiled, as frothing will result.

3.3.2 The solution may be contained in tanks of glass, pure aluminium or steel, and provision should be made for suspending parts so that they do not touch the sides or bottom of the tanks, especially if these are metal.

3.3.3 After mixing the concentrated solution of the salts, water should be added to dilute to the correct strength. Care should be taken to ensure that the solution is well stirred and that there is no layer of undissolved crystals at the bottom of the tank. The bath can be operated at any temperature up to boiling point, but the time of treatment will have to be varied according to the temperature selected. Table 5 gives a guide on suitable times.

TABLE 5	
Temperature	Time of Treatment
20°C. to 30°C.	1½ hours
50°C. to 60°C.	30 minutes
70°C. to 80°C.	15 minutes
Boiling	3 to 10 minutes

3.3.4 The pH value of the solution is not critical and will range from about 4 when freshly made to about 6 when almost spent. An exhausted solution may be rejuvenated by the addition of 5 per cent of manganese sulphate or, alternatively, sulphuric acid or a mixture of equal weights of sulphuric acid and chromic acid may be added until the pH value is reduced to not less than 4.

3.3.5 **Inspection of Film.** The film on machined or extruded surfaces should be adherent and free from loose powdery deposit and should be tested with white paper as described in paragraph 3.1.5. The film should be of a dark brown to black colour, light golden films not being acceptable except on magnesium-manganese sheet complying with DTD 118.

4   FAULTS IN CHROMATE FILMS

4.1   **Faults Produced by the Bath (iii) Process**

    4.1.1   **Loose, Powdery Coatings, Without Lustre.**   This fault results from an excessively acid bath, so that it is advisable to work the bath on a pH value on the high side rather than on the low side.   The method of correcting this condition is given in paragraph 3.1.4.

    4.1.2   **Thin Coatings.**   This fault usually results from an excessively alkaline bath, caused by the gradual dissolution of magnesium, and indicated by a rise in pH above the specified value.   The method of correcting this condition is described in paragraph 3.1.4.

    4.1.3   **Chocolate Colour Films on Magnesium-Manganese Alloys.**   Such films, which are brittle and non-adherent, result from the use of an excessively acid bath.   The method of correcting this condition is given in paragraph 3.1.4.

    4.1.4   **Patchy and Uneven Film.**   This condition is often caused by surface impurities in the material being treated, or by inadequate cleaning or handling before chromating.   Surface segregation effects may also lead to patchiness of films on cast surfaces.   The quality of films may best be assessed on machined areas.

        (i)   When impurities are suspected the manufacturer of the material should be notified.

        (ii)   Chill castings, and, especially pressure die-castings, in magnesium alloys of high aluminium content, tend to give a patchy finish due to the presence of aluminium-rich areas on the surface of the material.   A similar effect is also found in sand castings on an area where the metal chill has been inserted in the mould.   On this class of material, it may be necessary to increase immersion times or, alternatively, to remove the surface skin of the casting prior to immersion.

4.2   **Faults Produced by the Bath (iv) Process.**

    4.2.1   **Loose, Powdery Coatings.**   This fault is due to the nitric acid content of the bath being too low or to a spent bath.   The bath should be controlled as described in paragraph 3.2.5.

    4.2.2   The chrome-nitric bath should be discarded when the parts, after washing, show yellow staining, since these stains will lead to poorly adherent coatings.

4.3   **Faults Produced by the Bath (v) Process.**

    4.3.1   **Loose and Powdery Coatings.**   Wrought magnesium-zirconium alloys will show this fault if the smut produced in the acid bath described in paragraph 2.2.1 is not removed before treatment in the Chrome-Manganese Bath.

5   REPAIR OF CHROMATE FILMS

5.1   **Chromic Anhydride.**   Chromated parts requiring local repair can be cleaned by swabbing with a solution of 2 oz chromic anhydride in 1 pint of water, with 8 drops of concentrated sulphuric acid added to acidify the solution.

5.2   **Selenious Acid.**   The solution for selenious acid treatment consists of 10 per cent by weight of selenious acid in water and the treatment consists of brushing or wiping the solution over all surfaces exposed by damage to the original chromate film.   A soft rag can be used for the application, which should be continued until the metal assumes a permanent brown or brownish-black colour.

5.3   After the treatment the surface should be thoroughly washed with water and wiped dry.

NOTE: The solution should not be allowed to come into contact with the skin.

6   FURTHER TREATMENT Unless otherwise specified, parts which have been chromated should receive further protection against corrosion as soon as possible. For temporary protection during transit and storage, parts should be treated as described in paragraph 3 of Leaflet BL/7-5. Where surface sealing or paint is ultimately to be used, it is recommended that the process is applied as soon as possible after chromating. Unless surface sealing techniques are employed, painting should commence with a priming coat containing barium or zinc chromate. Priming paints containing lead or iron compounds should not be used.

NOTE: Lanolin as a temporary protective is not recommended for use on chromated surfaces which have to be painted subsequently. Lanolin bearing protectives cannot be completely removed from chromated surfaces by degreasing processes.

BL/7-4

Issue 2

June, 1985

BASIC

PROTECTIVE TREATMENTS

PHOSPHATING OF STEELS

1   INTRODUCTION   This Leaflet gives general guidance on the coating of steel parts with the hot immersion phosphate process as applied to impart corrosion resistance; it is not concerned with the phosphate coatings which are sometimes applied as an aid to manufacturing processes (e.g. deep drawing) or with the coatings which are applied for heat resistance purposes or for passivation treatment.

1.1   The purpose of the phosphate coating is to increase the resistance of the steel to corrosion. This is achieved by converting the surface of the metal to an inorganic phosphate coating, thereby providing the metal with a physical barrier against corrosion. The degree of protection is dependent upon the uniformity of the coating, coverage and crystal size. Immediately on production of the inorganic coating, which provides a key or base, a subsequent organic coating is added, e.g. certain paints, varnishes, lacquers, oil and greases. The phosphate coating is produced by immersing the steel in a solution containing one or more metal phosphates (e.g. iron, magnesium, zinc) and phosphoric acid, with or without additives, for a specified period and temperature, according to the process used. Phosphate coatings are classified by class numbers, in accordance with Specification DEF STAN 03-11.

1.2   When the processing solution is of the plain metal phosphate/phosphoric acid type, it is termed 'unaccelerated', and is generally characterised by the large crystal size of the coating. When additives (e.g. water-soluble oxidising agents such as nitrate, nitrite, and chlorate) are used, these have the effect of reducing the crystal size and speeding up the process, hence it is termed the 'accelerated' process.

NOTE: Additives other than oxidising agents, e.g. a mixture of zinc, nickel, cobalt and magnesium, are sometimes used as accelerators and grain-size reducers.

1.3   For detailed guidance, this Leaflet should be read in conjunction with DEF STAN 03-11 and BS 3189, both entitled 'Phosphate Treatment of Iron and Steel'.

2   PHOSPHATING PLANTS   The cleanliness of the equipment used for phosphating is of the utmost importance if consistently good coatings are to be obtained.

2.1   There are a number of proprietary processes which comply with the requirements of Specification DEF STAN 03-11, and new baths must be made up as prescribed by the supplier.

2.2 The total 'pointage' (see Note) of the solution must be determined at least once daily when the bath is in operation; if this value falls below that specified by the supplier, the bath should be brought up to strength before further work is commenced.

NOTE: Pointage is the measure of total acidity of a phosphating solution. The pointage of a phosphating bath is the number of ml of N/10 sodium hydroxide solution (NaOH) (4.0 g/l) required to neutralise 10 ml of the phosphating solution to the phenolphthalein end-point.

2.3 It may be desirable to determine periodically the 'free acid' contents of the bath, this being defined as the number of ml of N/10 sodium hydroxide solution (NaOH) required to neutralise 10 ml of phosphating solution (to pH 4) using the methyl orange end-point or an equivalent indicator system.

2.4 The free acid content of the bath is usually expressed as a percentage of the total pointage, i.e.,

$$\text{Percent Free Acid} = \frac{\text{Volume of (NaOH) for neutralisation (methyl orange)}}{\text{Volume of (NaOH) for neutralisation (phenolphthalein)}} \times 100$$

2.5 For new baths the percentage of free acid should be within the recommended range; if the free acid is found to be in excess of this figure, the supplier's instructions regarding 'working-in' the bath should be followed.

NOTE: The percentage of free acid varies with the type of process and although normally within the range of 10 to 14%, this figure may be exceeded with non-accelerated processes.

2.6 The solution should be contained in a suitably constructed tank, heated by electricity, gas or steam; to minimise heat losses it is recommended that the tank should be lagged and provided with a lid. Mild steel is generally used for tank construction where unaccelerated processes are concerned and such tanks are sometimes rubber lined. Stainless steels and acid resistant materials, such as polythene, PVC, etc., are also sometimes used, stainless steel tanks being particularly suitable for containing accelerated processes. Bottom heating of baths is not desirable since this results in a continuous disturbance of sludge. It is recommended that, where possible, a sludge trap should be fitted.

2.7 To reduce evaporation and heat losses, the free surface of the solution may be covered by a 'seal', such as a large number of small plastics spheres, rods or tubes which float on the surface, or suitable oil-based compounds which incorporate a detergent to prevent the formation of an oil film on the parts being processed as they pass through the seal.

NOTE: When an oil base seal is used, care is needed to give a thorough washing the parts after processing to ensure complete removal of the seal compound.

2.8 Materials such as copper or brass (but see paragraph 4.1) must not be introduced into the accelerated solution baths, since such materials adversely affect the quality of the coating.

3   PREPARATION FOR TREATMENT   Immediately prior to coating, all foreign matter, such as rust, scale, grease, oil and paint, must be removed from the surfaces to be treated

NOTE: A slight amount of grease or oil is not so important but in certain cases a period of immersion in a cleaning

3.1 Parts should be cleaned in accordance with the requirements prescribed in the latest issue of Specification DEF STAN 03-2, entitled 'Cleaning and Preparation of Metal Surfaces', or in accordance with any special instructions prepared by the manufacturer of the parts. Where necessary, the parts must be thoroughly rinsed in hot or cold water after cleaning to remove all traces of the cleaning residue, since the introduction of this into the solution may affect the quality of the coating and that of the solution.

3.2 Special attention to the removal of foreign matter should be given to any parts which have folds, laps or seams.

3.3 Parts made of steel having specified tensile strength of 1000 N/mm^2 or more must be given a suitable stress-relieving heat treatment before phosphating if the parts contain residual stresses which may cause cracks or loss of ductility to develop during processing. Unless a treatment is specified on the drawing, a suitable treatment consists of heating the parts to 130°C to 200°C (270°F to 390°F), or up to the tempering temperature, for not less than one hour. Steels which have been carburised, flame or induction hardened or carbonitrided should not be heated over 150°C (300°F).

4   THE PHOSPHATING PROCESS   Since there are a number of proprietary processes which conform to the requirements of Specification DEF STAN 03-11, little general guidance can be given on the actual processes, and the supplier's instructions should be followed in all instances. However, the temperature of the bath is usually maintained at 50°C to 98°C (122°F to 208°F) and the correctness of the temperature should be checked before the immersion of the parts. The process should continue for the period stipulated by the supplier or, in solutions which 'gas', until the cessation of gassing.

NOTE: It may be necessary to pre-heat large parts to avoid a drastic reduction of bath temperature on immersion.

4.1 Composite parts made up of ferrous and non-ferrous parts must normally have the ferrous parts phosphated before assembly, but exceptions are permitted where the non-ferrous metals are zinc-base or copper-base materials, providing that in the case of copper-base materials, they do not constitute more than 10% of the total surface, and providing that, in any case, joints are unlikely to be penetrated by the phosphating solution.

4.2 Where necessary, parts should be suitably jigged before immersion in the phosphating solution. Springs or other components subject to flexing, that are manufactured of steel having a tensile strength greater than 1000 N/mm^2 must be free of applied stress during the phosphating treatment and until the subsequent baking treatment (paragraph 5.2) is complete. The phosphating process used for such items must be an accelerated, copper-free type, working at a pointage of not more than 30 points.

NOTE: The normal strength for these processes is 20 to 30 points.

4.3 Care must be taken at all times for preventing the formation of air locks (see paragraph 7.2).

5   TREATMENT AFTER PHOSPHATING

5.1 **Washing.**   Immediately after phosphating, the parts must be washed thoroughly in hot or cold water to remove any residue of the treatment and any adhering oil seal (paragraph 2.7) if this has been used.

5.1.1 After processing by an unaccelerated process, the parts must be rinsed in hot or cold water or in a hot diluted chromic solution of the type specified in paragraph 6(d)(3) of DEF STAN 03-11.

5.1.2 After processing by an accelerated process, the parts must be thoroughly rinsed, first in running cold water, and then in hot water maintained at a minimum temperature of 75°C (167°F) and finally rinsed in a chromic solution of the type described in paragraph 6(d)(3) of DEF STAN 03-11. Special care is necessary when rinsing parts having folds, seams or crevices to ensure complete removal of the solution residue.

5.1.3 After the parts have been washed, they should be thoroughly dried either in an oven or in a current of warm air.

5.1.4 The contamination of the hot water rinse, where used, must be determined at least once daily. The sample should be taken after the bath has been agitated and should be allowed to cool before titrating. The acidity of the water rinse is defined as the number of ml of N/10 sodium hydroxide solution (NaOH) required to neutralise a 50 ml sample of water to the phenolphthalein end-point, and must not exceed 0·75 ml.

5.2 **De-Embrittlement Treatment.** Immediately after washing and drying, and before application of the sealing process (paragraph 5.3) parts made of steels having a minimum specified tensile strength in the range of 1000–1400 N/mm² must be baked at 130°C to 220°C (270°F to 390°F) for not less than one hour to relieve embrittlement.

5.2.1 Parts made of steels having a minimum specified tensile strength in the range of 1400–1850 N/mm² must be baked at 150°C to 200°C (300°F to 390°F) for not less than four hours or not less than one hour when the section thickness does not exceed 6 mm (0·25 in).

5.2.2 Parts made of steels having a minimum specified tensile strength in excess of 1850 N/mm² must be baked at 170°C to 210°C (338°F to 410°F) for not less than six hours.

5.2.3 For certain springs, e.g. where tempering may be affected, and parts having soldered joints, the baking temperature may be required to be restricted to not more than 130°C (270°F).

5.3 **Sealing.** Phosphate coatings are porous and absorbent and offer little resistance to corrosion unless sealed. The sealing process must be applied immediately after rinsing and drying and, if applicable, de-embrittling treatment.

NOTE: This process must not be confused with the 'seal' used for reduction of loss of solution by evaporation, etc., as described in paragraph 2.7.

5.3.1 The type of sealing applied must be in accordance with drawing requirements, and may consist of an organic coating such as oil, grease, paint, varnish or lacquer. The method of application must be such as will provide a satisfactory coating.

5.3.2 Where the sealing process cannot be applied immediately, the phosphated parts should be stored in conditions that preclude contamination or condensation of moisture on the parts, but in any case parts so stored should be 'force-dried' before sealing.

6   INSPECTION

6.1   **Visual Inspection.**   A zinc or magnesium phosphate coating must be continuous and adhere well to the surface; it should be of uniform crystalline texture suitable for the intended use. Its colour should be from grey to black, and it should be free from loose smut, white powder blotchiness, excessive coarseness and poor adhesion. An iron phosphate coating, unlike the previously mentioned coatings, has no apparent crystalline structure, and its colour will vary from blue to brown.

6.2   The coating weight of the various types of processes, the method of determining this weight and the methods of testing the coating for freedom from corrosive residues and resistance to salt spray are prescribed in Specification DEF STAN 03-11.

7   .. FAULTS IN PHOSPHATE COATINGS   In the following paragraphs are given some possible faults in phosphate coatings, together with possible causes.

7.1   **Coarse or Sparkling Surface.**   Such faults may be due to inadequate or unsuitable cleaning, inadequate washing before processing or incorrect bath composition. Such surfaces will not provide an efficient key for the subsequent finish and should be stripped in a suitably inhibited mineral acid and re-coated correctly. The use of acid pickling or alkaline degreasing before phosphate processes should be avoided as coarse coatings will always result from such treatments; solvent vapour degreasing and mechanical cleaning such as grit blasting are to be preferred.

7.2   **Untreated Patches.**   This fault is generally the result of an airlock forming when the part is immersed in the bath, but can also result from insufficient cleaning.

7.3   **Flaky and Uneven Deposit.**   These faults normally occur as a result of excessive sludge in the bath or insufficient cleaning.

7.4   **Minor Variations of Colour or Surface Texture.**   These variations are usually due to previous surface treatments, heat treatments or degrees of cold work, but are normally acceptable providing they meet all other requirements of Specification DEF STAN 03-11.

BASIC

PROTECTIVE TREATMENTS

PROTECTION OF MAGNESIUM ALLOYS

1   INTRODUCTION

1.1   This Leaflet gives general information on the protection of magnesium-rich alloy parts and components. Experience has proved that failures caused by corrosion are mainly due either to inadequate or damaged protective treatments.

1.2   Like many other metallic materials, magnesium-rich alloys have an intrinsically low resistance to corrosion and require special protective treatments. These normally start with cleaning, followed by chromating, sealing and painting, but other treatments may be specified.

1.3   This Leaflet should be read in conjunction with Leaflet **BL/7-3** which deals with the chromating processes for magnesium alloys and is complementary to this Leaflet.

NOTE: All the protective processes used on magnesium alloy parts should comply with the latest issue of Process Specification DTD 911 entitled 'Protection of Magnesium Rich Alloys against Corrosion'.

1.4   Failure of corrosion protection on magnesium alloys is often due to insufficient attention to detail during production or inspection, and especially to lack of control of fitting or assembly techniques and subsequent failure to re-protect or repair the damage so caused.

1.5   It is essential that all machined or accidentally exposed areas are adequately protected as soon as possible. This applies equally to removable parts and permanent structural parts.

2   CORROSION

2.1   Corrosion is largely an electro-chemical phenomenon and is liable to occur whenever a difference in electrical potential exists between adjacent parts of different material. Corrosion is assisted by the presence of an electrically conducting solution/liquid between parts where the protective treatment has been damaged or is inadequate.

2.2   In general the corrosive substances to be avoided are aqueous solutions of salts and acids which may be derived from saline atmospheric conditions (e.g. coastal regions) or industrial atmospheric pollution which contains acids. Most of the impurities in the atmosphere which produce rust on iron and steel will also attack magnesium alloys. Other corrosive agents are rain, runway spray, fog, condensed moisture, spillages, some cleaning fluids, etc.

3   PROTECTION   The principle of protection adopted depends on completely isolating magnesium alloy parts from any aqueous solution with a coating of organic media at least 0·1 mm (0·04 in) thick. All surfaces should be covered after chromating (Leaflet **BL/7-3**) with at least 0·025 mm (0·001 in) of high quality stoving resin (surface sealing, paragraph 5), followed by a coat of pigmented paint approximately 0·075 mm (0·003 in) thick (paragraph 6).

4   STORAGE   With certain exceptions, such as welding rods, all wrought and cast magnesium alloys should leave the material manufacturers in the 'chromated' condition (see Leaflet **BL/7-3**), that is, the bare metal has been given a chemical treatment which results in the formation of a chromate-bearing surface film. Such a film provides some chemical protection against corrosion and is considered adequate where storage conditions are good, e.g. dry, warm and clean.

4.1   The chromating treatment of magnesium alloys is regarded as a foundation treatment only. The other protective processes required may not be applied until forming and machining operations are completed.

4.2   Dampness in stores should be rigorously avoided and when magnesium alloys are kept in unheated or intermittently-heated stores they should be coated with a temporary protective applied liberally over the chromated surface. One of the following temporary protective media is generally specified for storage purposes:–

  (a)   A compound of 30% lanolin in white spirit, containing optionally a green dye (Specification DEF 2331A).

  (b)   A mixture of kerosene and light mineral oil with additions of corrosion inhibitor and wetting agent (Specification CS 2060 C).

  (c)   A 15% lanolised mineral oil (Specification DEF STAN 80-34/1).

4.3   For overseas transit or storage in coastal regions the recommended minimum protection is a liberal coating of lanolin compound to Specification DEF 2331A.

NOTE: For information on Storage Conditions reference should be made to Leaflet **BL/1-7**.

5   SURFACE SEALING   Surface sealing is a non-pigmented high temperature baked epoxy resin waterproofing treatment. It has features in common with painting and stove enamelling and is normally employed as a foundation for painting.

5.1   The surface sealing process (described in paragraph 5.3.1) consists of baking or pre-stoving the component to ensure complete removal of surface moisture, then dipping in the sealing resin whilst still hot. This prevents picking up moisture through cooling and ensures that the resin penetrates any surface porosity or minute surface flaws.

5.2 Subsequent painting may be either a stove enamelling or an air-drying process since both types of paint adhere well to surface sealing resin. In either case a zinc chromate primer should be used as a first coat. The function of the chromate in a primer is to give a reserve of chromate capable of being leached away slowly in damp conditions, thereby protecting areas of magnesium which have been bared by scratches or other minor local damage.

NOTE: The surface-sealing resin is too waterproof to permit leaching of chromate from below the resin, but chromate primers applied over sealed surfaces will perform this function if and when minor damage occurs to the protective treatment.

5.3 Before surface-sealing operations the components should be cleaned, preferably by fluoride anodising (described in paragraph 7), and chromated. The surface sealing should be carried out without delay after chromating and should comply with the latest issue of Process Specification DTD 5562, 'Clear Baking Resin for Surface Sealing Magnesium'.

5.3.1 **Process for Surface Sealing.** The following sub-paragraphs give a brief description of a typical process which is fully detailed in Process Specification DTD 935:–

(a) The component should be heated to 200°C for 30 minutes or for a sufficient length of time to ensure that this temperature has been attained uniformly throughout the component.

(b) The component should be allowed to cool to 60°C then immediately dipped in the resin and agitated as necessary to avoid air traps and to ensure that every part comes into contact with the resin.

(c) The component should then be withdrawn slowly, being turned as necessary to allow drainage of resin. It should then be allowed to drain for between 15 and 30 minutes in a dust-free atmosphere. Any drips or tears should be removed with a brush or palette knife.

(d) The component should be stoved at 200°C for 15 minutes.

(e) After stoving, any remaining tears or drips should be removed with a sharp knife or glass paper, taking care not to damage the chromate film.

(f) Operations (a) to (e) should be carried out twice more so that a total of three coats is applied, turning the component each time to keep the coating uniform.

(g) The final coat should be stoved at 200°C for 45 minutes.

NOTE: Just before hardening, the resin passes through a labile (unstable) state. It is for this reason that the part is turned to a different attitude at each baking operation to assist uniform coating.

5.3.2 A compound which for some reason cannot be dipped may be coated by spraying. A full wet coat should be applied followed by heating and cooling as described in paragraph 5.3.1. The process should be repeated so that at least three coats are applied. Spraying should only be used when dipping is not practical.

5.3.3 Parts may be left overnight in the chromate-only condition, but for periods in excess of this they should be immersed in a storage protective (see paragraph 4.2) and thoroughly degreased before surface sealing.

6   PAINTING   As with most paint schemes, thorough cleanliness of the surface is essential, and after surface sealing the part should be degreased if necessary. The success of the subsequent painting scheme is largely governed by the thoroughness of the degreasing operation. A primary coat containing not less than 15% of a chromate pigment is necessary and lead or iron compounds should be avoided. The purpose of the protective scheme is to keep corrosive conditions away from the metal and the total thickness of the completed coating should not be less than 0·1 mm (0·004 in).

6.1   The organic materials should preferably comply with either Material Specification DTD 5555A 'Exterior Glossy Finishing Schemes (Cold curing epoxide type) Schemes I, II and III', or DTD 5580 'Exterior Glossy Finishing Scheme (Cold curing polyurethane type) Schemes I and II'. The priming coat may be applied by spraying, dipping or brushing and a second or even third thin coat may be given with advantage. The undercoat or filler (where applicable) may also be applied by any conventional method. The finishing coat will have been chosen for its colour and texture. There are no special conditions of application other than those which are usual with a good painting technique.

6.2   The general principles outlined in the preceding paragraph apply equally to the use of stoving enamels, but care should be taken to ensure that the materials are suitable for the stoving temperatures used.

NOTES: (1) For further information on the application of paint, reference should be made to Leaflet BL/6-20, Paint Finishing of Metal Aircraft.

(2) Stoving will improve the durability of the DTD 5555A scheme but will render it very difficult to remove should this ever become necessary.

6.3   **Local Treatment of Exposed Metal.**   The treatments described are intended for use over small areas. If large areas are damaged, immersion treatment will be necessary.

6.3.1   Parts on which the protective treatment has been damaged should preferably be returned for re-chromating, sealing and painting. Where this is impossible and where there is no danger of entrapment of treatment chemicals, the exposed metal should be treated locally as follows:–

(a)   **Acid Chromate Method.**   In this method a solution similar to the acid chromate bath solution (Bath (iv), as described in paragraph 3.2 of Leaflet BL/7-3) should be lightly applied to the bare metal using a brush or wool swab until a golden colour develops on the metal surface. The surface should then be thoroughly washed and dried by dabbing or warm air jet. This method is suitable for use prior to the application of any primer for magnesium alloys.

(b)   **Selenious Acid Method.**   In this method a solution containing 10% w/v selenious acid is applied by brushing or by swabbing with cotton wool until a dark brown stain develops. The surface should then be washed and dabbed or blown dry. This method is not suitable for use prior to the application of an etch primer.

NOTE: Neither the acid chromate solution nor the selenious acid solution should be allowed to come into contact with the skin.

6.3.2   Where there is a possibility of entrapment of treatment chemicals, the bare metal should be treated as follows:–

(a)   **Mating Surfaces.**   These should be given no chemical treatment but should be wet assembled and over-painted after assembly with not less than one coat of primer and two coats of finish.

(b) **Non-Mating Surfaces.** After cleaning with a nylon pad or glass paper, and removing the resultant debris, the surface should be treated with two coats of chromate primer followed by the normal paint scheme for the part.

NOTE: A coat of etch primer applied before the usual chromate primer will improve the adhesion of the paint scheme on un-chromated magnesium surfaces.

6.3.3 The treatments given in paragraphs 6.3.1 and 6.3.2 omit the surface sealing process and therefore give a less effective protection. Where this procedure cannot be avoided every effort should be made to give efficient paint protection by careful application of the paint scheme. Areas to be treated should first be degreased.

6.4 **Paint Repairs in the Field.** The paint schemes used on magnesium alloys are extremely difficult to remove when aged and stripping techniques may often be harmful to the surrounding structure. Unless corrosion has occurred below the surface sealing and paint scheme, it is preferable merely to degrease, lightly scuff and apply further coats of primer and finish.

7 FLUORIDE ANODISING CLEANING PROCESS This process is intended to supersede abrasive blasting as a method of cleaning magnesium alloy castings. It is also a method of substantially restoring the corrosion resistance lost as a result of abrasive blasting, and can be applied to magnesium alloys in all forms. The process renders unnecessary many of the pickling and degreasing processes used for chemical and electrochemical protective treatments.

7.1 It is not necessary to use any form of cleaning prior to anodising, but loose sand on castings should be removed by tapping or brushing and any layer of grease or paint (e.g. where the component is being reconditioned) should be removed either by vapour degreasing and/or immersion in a suitable alkaline metal cleaning solution. Pre-cleaning will also increase the useful life of the anodising bath.

7.1.1 **Anodising Bath.** The bath should be lined with a hard rubber or suitable plastic material which does not conduct electricity, and the electrolyte should consist of a 15 to 25% solution of ammonium bifluoride in water. The content of fluoride may be determined by any suitable analytical method. The solution should be kept up to strength by the addition of ammonium bifluoride, but should be discarded if it has become contaminated with foreign metals, acid radicals other than fluoride, or organic matter.

7.1.2 The parts should be fixed in pairs in good electrical contact on electrode bars across the bath, and suspended at least 230 mm (9 in) below the level of the solution. The parts should be arranged so that approximately equal surface areas are present at each electrode. The fixing clamps below the surface of the solution must be of magnesium rich alloy.

7.1.3 The high voltages used are dangerous and access to the bath must be prevented while the current is switched on. Spray from the bath is poisonous and adequate ventilation is necessary.

7.1.4 **Operation.** Alternating current should be applied and the voltage increased progressively until 90–120 volts is reached. Current flow will be heavy at first, but diminishes rapidly as impurities are removed and a coating of unbroken magnesium fluoride forms in their place. The treatment should be continued for 10 to 15 minutes or until the current falls to below 54 A/m² (5 A/ft²) of the smaller electrode. The current should be switched off and the parts removed, washed in hot water and quickly dried.

7.1.5 The temperature of the bath should not exceed 30°C, and it is an advantage to stir the bath well between batches of items with a wooden pole to ensure that the upper layers of liquid are not depleted of fluoride or become warmer than the bulk of the bath. No foreign metal, organic matter, salts or acid radicals should be introduced into the bath.

7.2 **Appearance.** The parts should have a uniform clean white or pearly grey appearance and should be free from foundry sand.

7.2.1 **Defects.** A very thin semi-transparent film indicates treatment at too low a voltage, but on wrought surfaces in good condition or on machined surfaces such a film is acceptable. Dark areas in hollows may indicate entrapment of gas during treatment. An etched appearance indicates a bath too low in ammonium bifluoride, too hot, or possibly operated at too high a voltage. A thick dense film may indicate the presence of acid radicals other than fluorides. Pitting of the surface may be caused by chloride in the bath.

7.3 **Subsequent Treatment.** The presence of a fluoride film on anodised magnesium alloys does not prevent treatment by the acid chromate bath, (Bath (iv) Leaflet **BL/7-3**, paragraph 3.2) though somewhat longer times may be required to achieve the desired results. The fluoride layer is slowly displaced and a chromate film substituted. For chromating by the hot half-hour bath, (Bath (iii) or the chrome-manganese bath, Bath (v), Leaflet **BL/7-3**, paragraphs 3.1 and 3.3), the fluoride film should be removed (paragraph 7.4).

NOTE: The chromate films produced by the chrome maganese and hot half-hour baths are superior to that produced by the acid chromate bath. Consequently they are recommended for use wherever possible.

7.4 **Removal of Fluoride Film.** The film can be removed by immersion for 15 minutes in a boiling (10 to 15% w/v) solution of chromic acid, followed by immersion for 10 minutes in a boiling (5% w/v) solution of caustic soda or for 5 minutes in a cold (15 to 20% w/v) solution of hydrofluoric acid.

7.5 **Dimensional Change.** The anodising process outlined above does not lead to an appreciable decrease in the dimensions of a component, but material may be lost during film removal and chromating (especially the acid chromate bath) processes.

8 ASSEMBLY OF PARTS   It is particularly important that the instructions for wet assembly with the appropriate jointing compound are carefully followed.

8.1 **Wet Assembly.** Wet assembly is the assembly of parts using a resinous jointing compound in the liquid state between faying surfaces. Rivets and bolts are also assembled in this manner.

8.1.1   A large variety of jointing compounds and sealing compounds are available but it is important that the compound specified for a particular joint or fitting technique is used. The compounds are usually selected from the DTD 900 series of approved proprietary materials and are listed in that document under the titles 'Jointing Materials' and 'Sealing Materials'.

8.1.2   Jointing compounds for magnesium alloy parts usually contain a percentage of chromate as an inhibitor. They vary in consistency from thin liquids to fairly stiff pastes, and their purpose is to separate metal faying surfaces with an electrically-inert medium and to fill gaps which would otherwise present a potential corrosion hazard in service. The compounds retain a solid but flexible consistency when dry while being thin enough to spread evenly when first applied. Many of the compounds are unaffected by fuels and oils and may be painted over.

8.2   **Galvanic Action – Assembly Techniques.**   In general, liberal use of wet assembly media (paragraph 8.1) followed by painting, will effectively prevent galvanic attack at the junction of different metals.

8.2.1   A plastic insulating gasket is recommended where joints are made and broken repeatedly and wet assembly is also necessary. Special nuts incorporating plastic washers are often used. Nuts, bolts, washers and special fasteners of metallic materials other than aluminium, as well as mating surfaces of components, must be cadmium or zinc plated and wet assembled. In the case of studs, thread inserts, etc., the surface sealing resin itself may be used and the whole appropriately stoved (paragraph 5.3.1).

8.2.2   Where earthing points are involved, the whole area of the junction should be completely sealed by covering with a sealing compound or several layers of paint.

8.2.3   **Rivets.**   Aluminium alloy rivets to specification L58 should be used (e.g. BS SP70, 79, 84, 160 and 161). Where stronger rivets (e.g. Monel, steel, etc.) are needed cadmium plating of the rivet is essential. In all cases wet assembly is necessary.

NOTE: See Leaflet **BL/6-26** for identification of rivets.

9   **MAINTENANCE OF PROTECTIVE COATING** It is essential that parts and components are kept thoroughly clean. Careful attention should be given to the condition of the organic protective coating. In severe environments the use of a de-watering oil on the surface of parts and components will materially reduce the corrosion hazard.

9.1   **Local Damage.**   Any local damage to the surface coating should be touched-up with air drying paint (primers and top coats) as soon as possible after the damage has occurred.

9.2   **Superficial Corrosion**

9.2.1   Where the corrosion is of a superficial nature and occurs in a few isolated spots only, the protective paint should be scraped away and the corrosion removed by brushing with a stiff non-metallic brush (e.g. nylon), glass paper or by light blasting with non-metallic grit.

9.2.2   After smoothing down the surrounding areas of paint with glass paper, the debris should be removed and local damage should be made good by applying two coats of chromate primer followed by the normal paint scheme.

9.2.3 Where there is no danger of entrapment of treatment chemicals, the area should be cleaned by swabbing with a solution of 10% by weight chromic acid and 0·1% by volume sulphuric acid (D = 1·84) followed by rinsing with several changes of water. The treatment should be continued until all corrosion is removed then finally treated by the normal protective paint scheme for the part concerned. (See also paragraph 6.3.2(b) Note.)

9.3 Corrosion Rectification – Workshop Procedure

9.3.1 Wherever possible components should be dis-assembled, and parts made from materials other than magnesium alloy should be removed.

9.3.2 If necessary the components should be cleaned of surface sealing resin by either blasting with clean non-metallic grit, machining or scuffing, or by application of an approved chemical solvent or by a combination of both. Uncorroded areas on parts made to close tolerances should be masked during these operations.

9.3.3 Each part should be inspected and checked for cracks using a suitable non-destructive examination procedure. (Leaflets **BL/8-2, 8-3, 8-4, 8-5,** or **8-7** as appropriate.)

NOTE: The presence of a surface sealing resin may interfere with the dye-penetrant method of non-destructive examination.

9.3.4 Provided the part can be dis-assembled and stripped of surface sealing resin it may be re-sealed and finished in the normal way.

9.3.5 If the part cannot be stripped of surface-sealing resin and there is corrosion of a superficial nature, paint and surface sealing should be removed from around the corroded area using either a non-metallic brush or blasting with non-metallic grit.

(a) Provided the part can be washed completely free from chemicals, the corroded area should be cleaned using a solution containing 10% by weight chromic acid and 0·1% by volume sulphuric acid (D = 1·84) and rinsed with clean water. The process should be repeated until all corrosion is cleaned off, then the part should be rinsed in several changes of clean water until free from chemicals.

(b) The cleaned area should be treated with acid chromate solution as given in paragraph 6.3.1(a), then repainted with two coats of chromate primer followed by the normal paint scheme.

9.3.6 If the part cannot be washed clean with chemical cleaners it should be cleaned by mechanical methods (see paragraph 9.3.2), then debris should be removed and it should be painted with either etch or epoxy primer followed by a complete paint scheme.
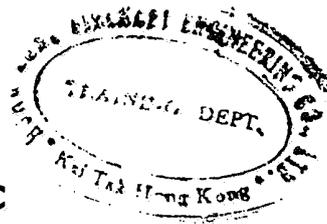
(a) The final assembly should be carried out with the same care as that applied to a new component and should include the same wet assembly procedure, priming and painting.

(b) Care should be taken to avoid contaminating the surface of magnesium. Any abrasive papers or tools used must be free from all loose metal impurities and rust.

BASIC

NON-DESTRUCTIVE EXAMINATION

OIL AND CHALK PROCESSES

1   INTRODUCTION   This leaflet gives guidance on the detection of surface defects, such as cracks and porosity, by processes involving the use of oil and chalk. The principle upon which the process is based is the absorption by chalk of fluids. A penetrant oil is applied to the surface of the parts to be checked and, after removing the surplus oil, a layer of chalk is applied. Oil entrapped in defects is absorbed by the chalk, the resulting stains indicating their position.

1.1   There are two basic methods of applying the process, i.e. the "Hot Fluid Process" and the "Cold Fluid Process". Of these, the process employing hot oil is the more efficient and should be used wherever possible, but both methods suffer serious limitations, as indicated in paragraph 2. However, some proprietary processes, e.g. the "Bristol Modified Method of Oil and Chalk Test", which is an adaptation of the hot fluid process, are not subject to such deficiencies. The Bristol Modified Method is considered in more detail in paragraph 5.

1.2   Guidance on the use of penetrant dye and fluorescent ink processes, which have largely superseded the conventional oil and chalk processes, is given in Leaflet BL/8-2. Information on the use of ultrasonic equipment for the detection of flaws is given in Leaflet BL/8-3, and on the radiological examination of aircraft structures in BL/8-4. Guidance on magnetic methods of flaw detection is given in Leaflet BL/8-5.

2   LIMITATIONS OF THE PROCESSES   The oil and chalk processes were devised for the detection of surface defects in non-ferrous and some non-metallic materials, but the deficiencies described in the following paragraphs should be considered before deciding upon the suitability of either of the processes for the work in hand. The processes are nor considered suitable for the detection of minute flaws or tightly shut cracks.

2.1   The processes are quite effective for such applications as the detection of large cracks in rough castings, but in general, the degree of contrast obtained by oil exudation is very poor and, unless the pre-cleaning and final drying processes are efficiently done, spurious indications of defects may be given.

2.2   Defect indications, at best, will appear only as dark grey stains on a light grey background, and are not sufficiently defined to make the detection of small cracks practicable, particularly when examining parts having dark surfaces, e.g. chromated magnesium alloy parts.

2.3   When the hot oil process is used for parts which are dimensionally large or are of intricate shape, it is often not possible to remove the surplus oil quickly enough to be able to apply the chalk before the parts become cool, thus the object of heating is defeated (see paragraph 3.4). On the other hand, if the drying is not done efficiently,

masking of defects may occur due to the spontaneous staining of the chalk in damp areas.

3   HOT FLUID PROCESS   To obtain satisfactory results it is essential that the parts should be thoroughly cleaned before immersion. If the parts have previously been immersed in an acid pickle bath, paint stripper, or some other strong solution, all traces of such solutions must be removed by adequate washing to avoid contamination of the test oil.

3.1   The parts to be examined should be immersed or (if a specified area only is to be examined) partly immersed, in a solution consisting of approximately 28 per cent (by volume) of lard oil in paraffin. The solution should be maintained at a temperature of approximately 80°C., and the period of immersion must be sufficient to allow the parts to attain this temperature. If preferred, solutions consisting of three parts paraffin and one part lubricating oil, or 50 per cent paraffin and 50 per cent spindle oil, may be used.

3.2   After immersion the parts should be dried quickly and thoroughly with a non-fluffy rag ; excellent final cleaning can be achieved by the use of unglazed tissue paper.

3.3   The parts should then be placed in the chalk cabinet and a fine layer of dry powdered French chalk should be applied, preferably by a method that will distribute the chalk in a gentle cloud. A paint spray gun with a conical funnel fitted in front of the jet, operated at a pressure of about 10 lb. sq. in., will be found suitable for this purpose. The gun should be provided with an efficient water trap. Surplus chalk should be removed by lightly tapping the parts on a block of wood.

NOTE : The chalk cabinet should form an enclosed area in which the parts to be examined can be placed. It should have a transparent front and should be fitted with an exhaust fan to remove surplus chalk. The parts can be coated more rapidly if a turntable is used.

3.4   The parts should be inspected for defects when quite cool and it will be found that if any cracks are present, the fluid will have been forced from them as the metal contracted on cooling, causing the chalk to become stained. A gentle air stream from a source pressurised at not more than 10 lb. sq. in., if directed on to the surfaces of the parts, may assist in the revelation of defects by removing the adjacent unstained chalk. It is essential that the examination should be made with the aid of a strong light.

4   COLD FLUID PROCESS   As stated in paragraph 1.1, the efficiency of this process is not equal to that of the hot fluid process, and it should be used only where the application of the latter process would not be practicable, e.g. when examining parts of assembled structures or parts too large for immersion.

4.1   The parts should be thoroughly cleaned and then coated with a solution of lard oil and paraffin, or lubricating oil and paraffin, in the proportions recommended in paragraph 3. After the surfaces to be examined have been thoroughly coated, all traces of the solution should be removed with a non-fluffy rag, followed by final wiping with unglazed tissue paper. The surface should then be coated with French chalk (paragraph 3.3).

4.2   Any oil entrapped in defects will be drawn out by the absorbent chalk, the resulting stains indicating the position of the defects. It is essential that the examination should be made with the aid of a strong light.

5 THE BRISTOL MODIFIED METHOD   In this process, finished parts or rough castings are immersed in hot oil, are removed and have the surfaces degreased, and are then sprayed or dusted with dry French chalk.

5.1 The parts to be examined should be immersed or (if a specified area only is to be examined) partly immersed, in a solution consisting of 50 per cent paraffin and 50 per cent spindle oil. The solution must be maintained at a temperature of 70°C., and the period of immersion should be sufficient to allow the parts to attain this temperature, one hour usually being sufficient.

5.2 After immersion, the parts should be allowed to stand until all surplus oil has drained off, after which they should be transferred to a degreasing tank containing a solution consisting of the following :

Teepol   5 per cent ⎫
Cresylic Acid 5 per cent ⎬ by volume
Water   90 per cent ⎭

The solution should be maintained at a temperature of between 70°C. to 80°C. When the cleansing action deteriorates, additions of Teepol and cresylic acid should be made to restore the above proportions.

NOTE : The cresylic acid should comply with the requirements of British Standard 524, Grades A or B.

5.3 The parts should be immersed in the degreasing solution for 3 to 5 minutes and should be agitated throughout this period.

5.4 After degreasing, the parts should be transferred to a tank containing clean hot water, and should be thoroughly swilled for a period of from 3 to 5 minutes, after which they should be allowed to drain.

5.5 When dry, the parts should be coated with a layer of dry French chalk, the equipment described in paragraph 3.3 being suitable for this purpose, except that an air pressure of 60 to 80 lb. sq. in. is recommended, after which surplus chalk should be removed by the application of a jet of air at about 25 to 30 lb. sq. in. pressure.

5.6 The parts should now be examined for defects, and cracks will be indicated by a thin white line of chalk.

BASIC

NON-DESTRUCTIVE EXAMINATION

PENETRANT DYE PROCESSES

I **INTRODUCTION** This leaflet gives guidance on the penetrant dye processes used for the detection of defects which break the surface of the part, such as cracks, cold shuts, folds, laps and porosity.

1.1 Penetrant dye processes are used mainly for the detection of flaws in non-ferrous and non-magnetic ferrous alloys but may also be used for ferrous parts where magnetic flaw detection techniques are not specified or are not possible. However, in some instances both penetrant dye and magnetic flaw detection techniques may be specified for a particular part (see paragraph 1.5.4). Penetrant dyes may also be used on some non-metallic materials but their use with perspex-type materials is not recommended, since crazing may result.

1.2 Although the processes are usually marketed under brand names, those used on aircraft parts for which a penetrant process of flaw detection is a mandatory requirement must comply with the requirements of Process Specification DTD 929. It must be ensured that any storage limiting period prescribed by the manufacturer of the process is not exceeded.

1.3 The processes available can be divided into two main groups. One group involves the use of penetrants containing an emulsifying agent (termed water-emulsifiable or water-washable processes) whilst in the other group a dye solvent has to be applied separately after the penetration time (paragraph 4) has elapsed if the surplus dye is to be removed by a water-wash operation. The processes may be further sub-divided insomuch that with some processes the use of a dry developer is recommended whilst with others a wet developer is used. The manufacturers' recommendations and instructions for each individual process must be followed carefully to ensure satisfactory results.

NOTE : An emulsifier is a blending of wetting agents and detergents which enables excess dye to be removed with water and, in the case of wide flaws, assists in preventing the dye seeping out too quickly.

1.4 Basically all the processes consist of applying a red penetrant dye to the surface of the part to be tested, removing after a predetermined time the dye which remains on the surface and then applying a developer, the purpose of which is to draw to the surface any dye that has entered into defects, the resultant stains indicating the positions of the defects.

1.5 The selection of the most suitable type of penetrant process (e.g. penetrant dye or fluorescent penetrant (Leaflet BL/8-7) ; with or without post-emulsification) for any given application must largely be governed by experience, since when used correctly a high degree of efficiency can be obtained with any of the processes. Guidance on some of the factors which should be given consideration is provided in the following paragraphs.

1.5.1 Within a given type of process, the post-emulsification method is generally considered to be the most sensitive and is usually selected for finished machined parts

and for the detection of "tight" defects. However, its use on rougher surfaces (e.g. castings) may be less effective than would be the use of a penetrant containing an emulsifier, since it may pick up the surface texture of the material, thus rendering the detection of actual defects more difficult.

1.5.2 Where large heavy parts are concerned, and particularly where mechanical handling is involved, the use of penetrant dyes may be more practicable than that of fluorescent penetrants, since the necessity of darkening a relatively large area before the examination can be made does not arise.

1.5.3 When making "in situ" checks on aircraft, the use of penetrant dyes may be more suitable where there is sufficient light but in darker areas a fluorescent process may provide better definition of defects.

NOTE : Battery-operated ultra-violet light sources are now available.

1.5.4 With steel castings, for example, porosity may be detected more easily by a penetrant process than by a magnetic flaw detection technique (Leaflet BL/8-5) and for this reason the application of both processes is sometimes specified. If the magnetic flaw detection test precedes the penetrant test, great care will be necessary with the intervening degreasing process to ensure that all traces of the magnetic testing medium are removed, otherwise the subsequent penetrant test may be un-successful.

1.6   Some of the materials associated with penetrant testing have low flash points and the appropriate fire precautions should be taken.

1.7   Guidance on fluorescent penetrant processes, which previously formed part of this leaflet, will be given in Leaflet BL/8-7, at present in preparation.

2   **SURFACE PREPARATION**   The major reason for the failure of penetrant processes to provide indications of defects is incorrect or inadequate surface cleaning. For example, embedded extraneous matter can seal off cracks, etc., whilst contaminants remaining on the surface can trap the dye and give rise to false indications or, more detrimentally, obscure genuine defects. Thus the surface to be tested must be free from oil, grease, paint, rust, scale, welding flux, carbon deposits, etc., and the method of cleaning should be selected with the intention of removing extraneous matter from within the defects as well as from the surface to permit maximum dye penetration.

2.1   On unmachined steel stampings and forgings it may be necessary to remove rust or scale by sandblasting and to prepare aluminium alloy forgings by light sandblasting. However, the use of such processes must be given careful consideration, since they may result in the filling or "peening-over" of defects. Generally, unless specified otherwise, aluminium alloy forgings should be prepared by a suitable pickling process (e.g. by one of the methods prescribed in Process Specification DTD 901).

2.2   Magnesium alloy castings should be tested after chromating in order to reduce the risk of corrosion, but the requirements of Process Specification DTD 911, with regard to surface protection, must be taken into account and a suitable sequence devised.

2.3   Where contamination is mainly of an organic nature, degreasing by the trichloro-ethylene process (unless there are instructions to the contrary) is usually suitable. However, not all types of trichloroethylene are suitable for use with titanium alloys and

further guidance on this and other aspects of trichloroethylene cleaning is given in Leaflet **BL/6-8**. The cleaning of titanium alloys by methanol should be avoided.

2.4   Where parts have to be tested "in situ", the use of volatile solvents (e.g. carbon tetrachloride) as cleaning agents should be given consideration. Where paint is present, this should be removed from the surface to be tested prior to cleaning. Subsequent to the test, the surface should be reprotected in the prescribed manner.

NOTE : Suitable fire precautions must be taken when flammable materials are used.

2.5   Sufficient time should be allowed after cleaning for drying out, otherwise the efficiency of the penetrant dye may be affected. The time interval allowed for the evaporation of solvents can only be determined by the prevailing conditions of temperature and humidity and the type of solvent used.

3   APPLICATION OF THE DYE   The penetrant dye can be applied to the surface by dipping, spraying or brushing, the method used depending largely on the size, shape and quantity of the parts to be examined. The surface must be dry before the dye is applied. Even the condensation which forms on a cold surface in humid conditions may interfere with dye penetration ; in such conditions the part should be warmed to a temperature of about 90°F. to 100°F. but temperatures in excess of 140°F. must be avoided, since these may result in the volatilization of some of the lighter constituents of the dye.

3.1   **Dipping Method.** Dipping should generally be used where large numbers of small parts are to be examined. The parts must be completely dried before immersion, since apart from affecting penetration, water or solvents will contaminate the dye.

3.1.1   During dipping care must be taken to ensure that the parts are so racked that air pockets are avoided and all surfaces to be examined are completely wetted by the dye.

3.1.2   It is not necessary for the parts to remain submerged in the tank during the penetration time (see paragraph 4) but only for a period sufficient to permit thorough wetting. "Drag-out" losses can be reduced if the dye is allowed to drain back into the tank during the penetration time.

3.2   **Flooding Method.** The flooding method should generally be used where large areas are to be examined. The dye should be applied with low-pressure spray equipment which will not permit atomisation of the fluid, any surplus dye being allowed to drain back into the tank.

3.3   **Aerosol Can Method.** Penetrant contained in Aerosol type cans is often used for "in situ" inspections. The best results are obtained when the can is held about twelve inches from the surface under test.

3.4   **Brushing Method.** The brushing method is generally used for individual items and items of complicated shape. A clean soft bristle brush should be used and retained only for this purpose.

4   PENETRATION TIME   The penetration time is the time which has to be allowed for the dye to penetrate effectively into the defects. It is dependent upon a number of factors, such as the characteristics of the process being used, the material from which the part is made, the size and nature of the defects being sought, the processes to which the

part has been subjected and the temperatures of the atmosphere, the part and the dye. Clearly the time can be decided only by experience of the particular local conditions but is usually in the range of 5 minutes to 1 hour, the smaller the defect the longer the time necessary.

4.1   Temperatures below 60°F. will retard the penetrant action of the dye, thus the penetration time should be extended proportionately. Testing in temperatures at or near freezing point should, if possible, be avoided, since in such conditions the performance of the penetrant is considerably reduced.

4.2   Where the effectiveness of the pre-cleaning process cannot be guaranteed or where parts have been sandblasted, the penetration time should be extended but it should be borne in mind that this is no guarantee that defects will, in fact, be revealed in such conditions.

5   REMOVAL OF EXCESS DYE   Any dye remaining on the surfaces of the parts after expiry of the penetration time should be removed as thoroughly as possible but without disturbing the dye which would have found its way into any defects present. Excessive cleaning, however, may result in the dilution of the dye or its complete removal from defects. The method of removal depends on whether a water-washable or post-emulsifiable dye was used and the size and condition of the surface under test.

5.1   **Water-washable Dye.**   Water-washable dye should be removed as indicated in the following paragraphs.

5.1.1   The dye should be removed from "in situ" parts with clean rags saturated in water, followed by wiping with clean rags until the surfaces are both dry and free from dye.

5.1.2   The dye should be removed from small parts with clean rags saturated in water, followed by drying as recommended in paragraph 5.3.

5.1.3   The dye should be removed from large areas or irregularly shaped parts by flushing with an aerated spray of water, followed by drying as recommended in paragraph 5.3.

5.2   **Post-emulsifiable Dye.**   Post-emulsifiable dye should be removed from small areas and "in situ" parts first by wiping with a clean rag damped with dye solvent, followed by wiping or blotting with a clean dry rag.   The bulk of the dye may be removed from large areas, irregularly-shaped parts and rough-textured surfaces by a quick water wash (allowing this to drain) followed by the application of the dye solvent and a final water wash.   The dye solvent should be applied by spraying, swabbing, dipping or brushing, except that brushing should not be used where relatively large defects are suspected. Washing should be followed by thorough drying, as outlined in paragraph 5.3.

5.3   **Surface Drying.**   Prior to applying the developer (paragraph 6) it should be ensured that the surfaces of the part under test are completely dry.   The following methods of surface drying are recommended which, although slower than the use of, for example, compressed air, are less likely to disturb entrapped dye.

5.3.1   Small areas may be wiped dry but since this may disturb the dye in the wider defects, the use of warm air is preferred.

5.3.2   Hot-air ovens and similar equipment may be used for drying, a temperature of about 130°F. being suitable ; temperatures in excess of 175°F. must be avoided.

The use of lamps for drying is not recommended unless uniform heat application can be guaranteed.

6   APPLICATION OF THE DEVELOPER   The developer usually consists of a very fine absorbent white powder which may be applied in (a) the form of a spray, the powder being suspended in a volatile carrier liquid which rapidly evaporates, leaving a white coating on the surface, (b) as a dip with the powder suspended in water or (c) as a dry powder which may be blown on to the component or into which the component may be dipped. The action of the absorbent powder is to draw out the dye from the surface defects, thus indicating their position by the resulting stain.

6.1   Where it is suspected that microscopic defects may be present, great care is necessary to ensure that the developer is applied evenly and very thinly, since a thick layer might conceal completely a defect holding only a minute quantity of dye.

6.2   Where a wet developer is concerned, the best results are obtained when the developer is applied by means of a paint-type spray gun operating at an air pressure not in excess of 15 lb. sq. in. The pressure pot of the spray gun should be equipped with a stirrer to keep the developer agitated and the absorbent particles in suspension. Before pouring the developer into the spray gun it should be well shaken to ensure a thorough distribution of the absorbent particles.

6.3   When requirements are not too exacting, small parts can be dipped into a bath of developer but the action must be performed rapidly to minimise the possibility of the dye being washed out of shallow defects. The bath should be agitated from time to time to ensure that the absorbent particles are kept in uniform suspension. The formation of pools of developer on the parts during draining must be avoided, otherwise the resultant thick coatings may mask defects.

6.4   Due to the usually uneven results obtained, the use of a brush for applying the developer is not recommended.

6.5   If the developer dries with a slightly pinkish hue, this is probably due to faulty cleaning or "carried over" penetrant in the penetrant remover (see paragraph 7.2) but provided sufficient contrast remains to enable minute defects to be detected, the condition is acceptable.

6.6   Water must not be permitted to enter the developer containers, since its presence will retard considerably the drying rate of the developer.

7   INTERPRETATION OF DEFECTS   If defects are present and all stages of the process have been applied correctly, the position of the defects will be indicated by red marks appearing on the whitened surface. The majority of defects are revealed almost immediately the developer dries but additional time (approximately equal to the penetration time (paragraph 4)) should be allowed for "tight" flaw indications to appear and for flaw patterns to reach their final shape and size. (Figure 1.)

7.1   By noting and comparing the indications that appear during the first 30 seconds of development with those which exist after about 10 minutes, a more accurate assessment of the characteristics of the defects is possible. For example, the dye exuding from a shallow crack is little more after 10 minutes than after 30 seconds but in the case of a deep narrow crack, considerably more dye is present, causing a much wider indication

to develop over a similar period of time. Thus the rate of staining is an indication of the width and depth of the defect, whilst the extent of staining is an indication of its volume.

Figure 1 INDICATIONS GIVEN BY DEFECTS

7.2   Scattered dots of dye indicate fine porosity or pitting (Figure 1(d)) whilst gross porosity may result in an entire area becoming stained. Where doubt exists as to whether the overall pinkish effect is due to inadequate washing, the process should be repeated, more care being taken particularly during the stage of cleaning off the excess dye.

7.3   Closely spaced dots in a line or curved pattern (Figure 1(c)) usually indicate tight cracks or laps but such patterns are also characteristic of very wide defects from out of which most of the dye has been washed. Wide cracks, lack of fusion in welded parts and other similar defects are indicated by continuous lines as shown in Figures 1(a) and 1(b).

7.4   Examination by means of a powerful magnifying glass is often useful when minute defects are being sought.

7.5   All defects should be suitably marked prior to removing the developer, but crayons should not be used on highly-stressed components subject to heat treatment, since this is known to induce fractures.

8   REMOVAL OF DEVELOPER   Developer can be removed by brushing or by air or water under pressure, but since the surface is then in a condition susceptible to corrosion (where this is applicable) the prescribed protective treatment should be applied with the minimum of delay. It should be noted that the adhesion of paints and resins may be seriously impaired by certain oil-base dyes if thorough cleaning is not ensured.

9   LEAK TESTING WITH PENETRANT DYES   On components or assemblies where the main purpose of the test is to locate defects which would result in a fluid leakage (e.g. cracks in pressure vessels) the methods of testing described in the previous paragraphs may not be conclusive. In such cases the inner and outer surfaces should be thoroughly cleaned and degreased, the dye being applied to one surface (usually the inside of pressure

vessels) and the developer to the other. After the pentration time (paragraph 4) has elapsed, the surface should be inspected for evidence of staining.

9.1 Where no definite penetration time has been determined then, with a wall thickness of from $\frac{1}{16}$ in. to $\frac{1}{8}$ in., the penetration time should be at least three times that which would be allowed for a standard "one-side-only" test.

9.2 More than one application of the dye is often required and as a general rule an additional application for each $\frac{1}{16}$ in. to $\frac{1}{8}$ in. wall thickness is recommended.