Part 2   Engineering Practices and Processes

Leaflet 2-1   Engineering Drawings

1   Introduction

The purpose of an engineering drawing is to record and convey the designer's requirements. The drawing must therefore, include sufficient information to enable production planning, manufacture, assembly, testing and inspection of the particular component or assembly to be carried out. So that there can be no misinterpretation of drawings, it is essential that both the person preparing the drawing and the person using the drawing should have a knowledge of the terms, symbols, abbreviations, and methods of presentation. This Leaflet gives general guidance on the various aspects of engineering drawings and should be considered in conjunction with any special methods used by the design office responsible for a particular drawing. This Leaflet is not intended as a standard for drawing offices, but should be regarded as a general guide to drawing procedures and interpretation.

NOTE: This Leaflet deals with general engineering drawing procedures, and does not include information on specialised subjects, such as electrical or electronic drawing practice, computer produced lofting, or numerically controlled tapes.

1.1   Drawing practice in the United Kingdom generally conforms to British Standard (BS) 308. The particular requirements for companies within the aerospace industry in the UK, are covered in the recommendations contained in the Society of British Aerospace Companies' (SBAC) Technical Specification (TS) 88. Design organisations amend both the BS and SBAC drawing systems to suit their own particular requirements, and generally produce their own Drawing Office Standards.

1.2   For current projects the International Organisation for Standardisation (ISO) system for dimensioning and tolerancing of drawings is used, but, at the present time, Imperial units, Metric units, terms, and tolerances, may be found on many drawings.

1.3   The abbreviations listed in Table 3 and the conventional representations of some standard features shown in Figures 10 and 15, are in accordance with BS 308 and will be found on most drawings. The terms and symbols used for tolerances in accordance with ISO recommendations, are shown in Table 5.

2   The Authority of the Drawing

Civil aircraft manufactured in the United Kingdom are manufactured from parts and components which have been manufactured to approved drawings. Design drawings and associated documents are normally produced by an organisation which has been approved by the Civil Aviation Authority, in accordance with British Civil Airworthiness Requirements (BCAR).

2.1   BCAR prescribes that all calculations on which the airworthiness of an aircraft depends, must be independently checked. Thus the design drawing itself is subject to a system of inspection, as are the parts produced to its requirements.

2.2   Drawings are used by Purchasing Departments, Production Engineers, Planners, Inspectors, and personnel engaged on the manufacture and assembly of

components. A drawing must therefore, contain all the necessary dimensions, limits of accuracy, classes of fit, material specifications and any other information likely to be required by any of the departments concerned, so that the user can carry out their respective responsibilities without reference back to the Design Department.

2.3   Any deviation from the approved drawings or associated documents during manufacture, must be approved by the CAA. During overhaul, modification, maintenance and repair, the Approved Organisation, or the appropriately licensed engineer, must ensure that all replacement parts, or repairs carried out, are in accordance with the approved drawings and associated documents.

3   Types of Drawings

There are four types of drawings recommended in BS 308; single-part (unique parts or assemblies), collective (parts or assemblies of essentially similar shape, but of different dimensions), combined (a complete assembly including all individual parts on a single drawing), and constructional (an assembly drawing with sufficient dimensional and other information to describe the component parts of a manufacture). A complete set of drawings for an aircraft and any documents or specifications referenced on the drawings, present a complete record of the information required to manufacture and assemble that aircraft. They also form part of the inspection records. The manner in which a set of aircraft drawings is arranged, enables any particular component, dimension, procedure or operation, to be traced.

3.1   A main 'general arrangement' drawing of the aircraft and 'general arrangement' drawings of the main assemblies and systems are provided. These drawings usually contain overall profile particulars only, with locations and references of the associated main assembly and installation drawings; they also provide a guide to the identification of drawing groups used by the particular design organisation.

3.2   Main assembly drawings may also contain profile particulars only, but will include the information required for the assembly of individual parts of sub-assemblies. The sequence of assembly is given where appropriate, but the information contained in single part or sub-assembly drawings, is not repeated. Parts as such are referenced, but in the case of sub-assemblies, only the sub-assembly will be referenced and not its individual parts.

3.3   Installation drawings are issued to clarify the details of external dimensions and attitudes of components, locations, adjustments, clearances, settings, connections, adaptors, and locking methods between components and assemblies.

3.4   Sub-assembly drawings are issued to convey specific information on the assembly of component parts. When the method of assembly entails welding, or a similar process, the drawing will include details of any heat treatment or anti-corrosive treatment that may be necessary. Sub-assembly drawings are sometimes issued in connection with spares provisioning and also in cases where assembly would be difficult without special tools, jigs or techniques.

3.5   Drawings of individual parts contain all the information necessary to enable the parts to be manufactured to design requirements. The material specification, dimensions and tolerances, machining details and surface finish, and any treatment required, will all be specified on the drawings.
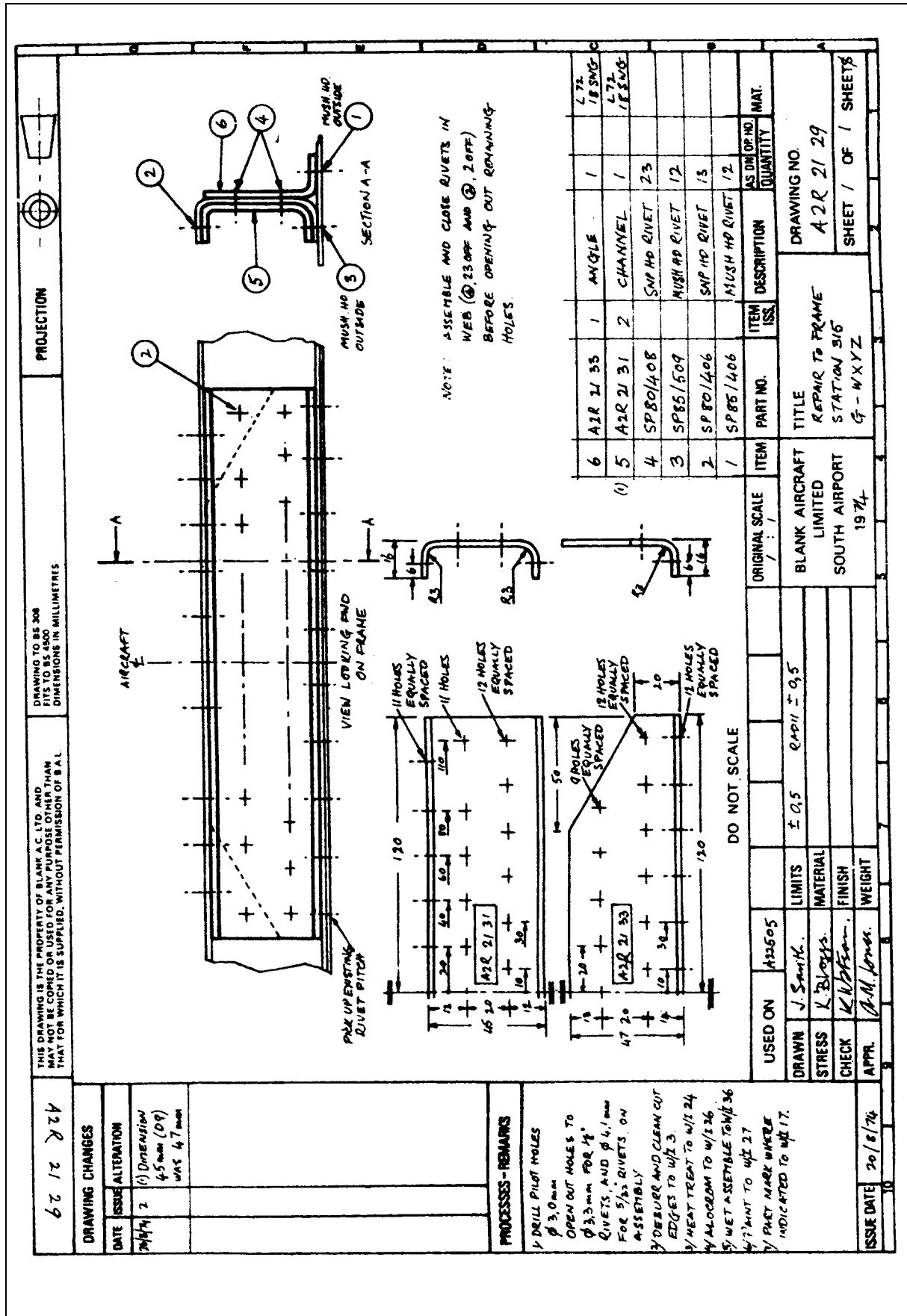
Figure 1   Typical Engineering Drawing

4   Drawing Systems

Section A of BCAR, prescribes that each drawing must bear a descriptive title, drawing number, issue number and the date of issue. It also prescribes that all alterations to drawings shall be made in accordance with a drawing amendment system which will ensure amendment to design records. If an alteration is made, a new issue number and date must be allocated to the drawing. To comply with the requirements, procedures must be introduced to progressively amend the total definition of the product in terms of its associated list of drawings at specific issues. Each particular variant of a product and its state of modification, must be identifiable in relation to the appropriate list of drawings. The following paragraphs amplify these procedures and explain the purposes of various parts of a drawing, together with the systems used and the methods of presentation. A typical drawing which illustrates many of the features with which this Leaflet is concerned, is shown in Figure 1.

4.1   The Drawing Number

No two drawings should bear identical numbers and a design office should maintain a register of all drawings issued. The drawing number has three features, the project identity (A2 in Figure 1) the group breakdown (21 in Figure 1), and an individual register number (29 in Figure 1). TS 88 describes an acceptable numbering method, but considerable discretion is allowed for particular design office requirements. In Figure 1, A2 indicates the aircraft type, R indicates a repair, 21 indicates the front fuselage, and 29 indicates the register number in this group of drawings. Except for repair drawings, the drawing number is also generally the part number of the item.

4.1.1   Handed Parts

Drawings of handed parts usually have the left hand (port), upper, inner, or forward part drawn, this item taking the odd number and the opposite hand the consecutive even number. Parts which are not handed have an odd drawing number. The drawing sheet bears the legend 'AS DRAWN' and 'OPP HAND' in the item quantity column. Where necessary the handed condition is indicated by a local scrap view or annotation.

4.1.2   Sheet Numbers

Where a complete drawing cannot be contained on a single sheet, successive sheets are used. The first sheet is identified as 'SHEET 1 of X SHEETS', as applicable and subsequent sheets by the appropriate sheet number. Where a schedule of parts applicable to all sheets is required, it appears on Sheet 1.

4.2   Drawing Changes

Any change to a design drawing, other than the correction of minor clerical errors, must be accompanied by a new issue number and date. New parts added to the drawing, or 'drawn on' parts affected by the change, take the new issue number, and parts which are not affected retain the original issue number. In all cases where interchangeability is affected, a new drawing number and part number are allocated.

4.2.1   Details of the drawing changes are recorded in the appropriate column on the drawing, or recorded separately on an 'Alteration Sheet', which is referenced on the drawing. Changes are related to the change number quoted in the change of issue columns on the drawing and the marginal grid reference is given to identify the altered features.

4.2.2   The issue 'number' may sometimes be represented by a letter. Some organisations use alphabetical issues for prototype aircraft drawings and numerical issues for

production aircraft drawings; thus all drawings of a prototype aircraft become 'Issue 1' when production commences.

4.2.3   An alteration to a single part drawing may also result in changes to associated drawings; in addition, it may be necessary to halt manufacture or assembly of the product. The drawing office system usually makes provision for the proper recording of drawing changes, by publishing, concurrently with the re-issued drawing, an instruction detailing the effects these will have on other drawings, on work-in-progress and on existing stock. As a further safeguard, some organisations publish Drawing Master Reference Lists, which give details of the current issues of all drawings which are associated with a particular component or assembly.

4.3   **Part Referencing**

Every item called up on a drawing is given an item number, which is shown in a 'balloon' on the face of the drawing, as illustrated in Figure 1. No other information is given in or adjacent to the balloon, with the exception of information necessary for manufacture or assembly, such as 'equally spaced', 'snap head inside', or the symbol 'ND', which indicates that no separate drawing exists for the part.

4.3.1   A schedule of parts is usually given in the manner shown in Figure 1, or on a separate sheet of the drawing (see paragraph 4.1.2).

4.3.2   As an alternative to the system described above, grid references may be given in the list of parts; in such instances the actual part numbers appear in the balloons. Where a part occurs a number of times on a drawing, e.g. as may be the case with rivets, bolts, etc., it may be impractical to list all grid references, in which case this column is left blank.

4.3.3   In instances where ND parts are shown as items on a drawing, the part number of such items may be that drawing number, followed by the drawing item number. Alternatively the part may be given its own part number, but will be identified as an ND part, e.g. 'A1 31 101 ND'. The information required for the manufacture of an ND part is contained in the description and material columns of the drawing, but reference may also be made to other drawings, where necessary.

4.3.4   Materials such as locking wire and shimming, which are available in rolls and sheets, will be detailed by specification number in the 'Part No' column, and the quantity will be entered as 'As Required', or 'A/R'. Standard parts to BS and SBAC Specifications will be detailed by the appropriate part numbers, but will not be drawn separately.

4.4   **Drawing Queries**

Drawing queries may arise through mistakes in draftsmanship, through ambiguity or through inability to purchase, manufacture, or assemble the items as drawn. Design Office procedures must be introduced which cater both for raising queries, and for providing satisfactory answers to those queries.

4.4.1   Drawing queries are usually raised on a Drawing Query Form, which is passed to the Design Office for action. The answer to the query may be an immediate provisional one, detailed on the query form; a temporary, fully approved answer, issued by means of a Drawing Office Instruction, and having the same authority as the drawing to which it refers; or a permanent answer provided by means of a new or re-issued drawing.

4.4.2   Drawing Query Forms and Drawing Office Instructions should be suitably identified, and should be referenced on the amended drawing. The effects on other drawings, on existing stock, and on work-in-progress, should be included in the answer to the query.

4.4.3   The number of Drawing Query Forms or Drawing Office Instructions permitted on a drawing, should be limited, and a new or re-issued drawing should be completed as soon as possible.

5   Interpretation of Drawings

The following paragraphs indicate some of the general drawing practices used on aircraft drawings. These practices are in accordance with the recommendations contained in BS 308 and TS 88, but many drawings will have been issued to previous British or foreign standards, and some degree of interpretation may be necessary. In cases of doubt the Drawing Office Handbook, or similar publication issued by the relevant Design Organisation should be consulted.

5.1   **Scale**

Drawings are normally drawn to a uniform scale and are normally shown in the 'ORIGINAL SCALE' box on the drawing in the form of a ratio, e.g. 1:2 (i.e. half size). Where details or views are drawn to a different scale, this should be clearly stated on the drawing. Aircraft drawings are often full size, i.e. 1:1, but no drawing should be measured to obtain a particular dimension which is not shown; the omission should be referred to the Design Office. On earlier drawings the scale may be represented by a fraction, e.g. ¼ which is 1:4.

5.2   **Lines**

The types and thicknesses of lines recommended in BS 308 are shown in Table 1. Drawings are often completed in pencil, however, line thickness may in practice vary considerably, especially after the drawing is reproduced.

Table 1   Types of Lines

Example	Description	Width (mm)	Application
▬▬▬▬▬	Continuous (thick)	0·7	Visible outline and edges.
─────	Continuous (thin)	0·3	Fictitious outlines and edges, dimensions and leader lines, hatching, outlines of adjacent parts and revolved sections.
∿∿∿	Continuous irregular (thin)	0.3	Limits of partial views or sections when the line is not on axis.
– – – – –	Short dashes (thin)	0·3	Hidden outlines and edges.
– – – – –	Chain (thin)	0·3	Centre lines and extreme positions moveable parts.
▬ – – – ▬	Chain (thick at ends and changes of direction, thin elsewhere).	0·7 0.3	Cutting planes.
▬ ▬ ▬ ▬	Chain (thick)	0·7	Indicates surfaces which have to meet special requirements.

5.3 **Projections**

The majority of drawings produced for aircraft purposes show the parts in third angle orthographic projection (paragraph 5.3.1), but a number of older drawings may have been produced in first angle orthographic projection (paragraph 5.3.2). Both systems show objects as they actually are, both in size (unless for convenience the drawing is scaled up or down) and shape, when viewed in the vertical and horizontal planes. The projection used for a drawing must be clearly stated, and the appropriate international projection symbol must be placed in a prominent position on the drawing. Any views not complying with the projection stipulated, e.g. a view showing the true shape of an inclined face, are generally marked with an arrow, and suitably annotated.

5.3.1 **Third Angle Projection**

The principle of third angle projection is shown in Figure 2. Each view represents the side of the object nearest to it in the adjacent view.
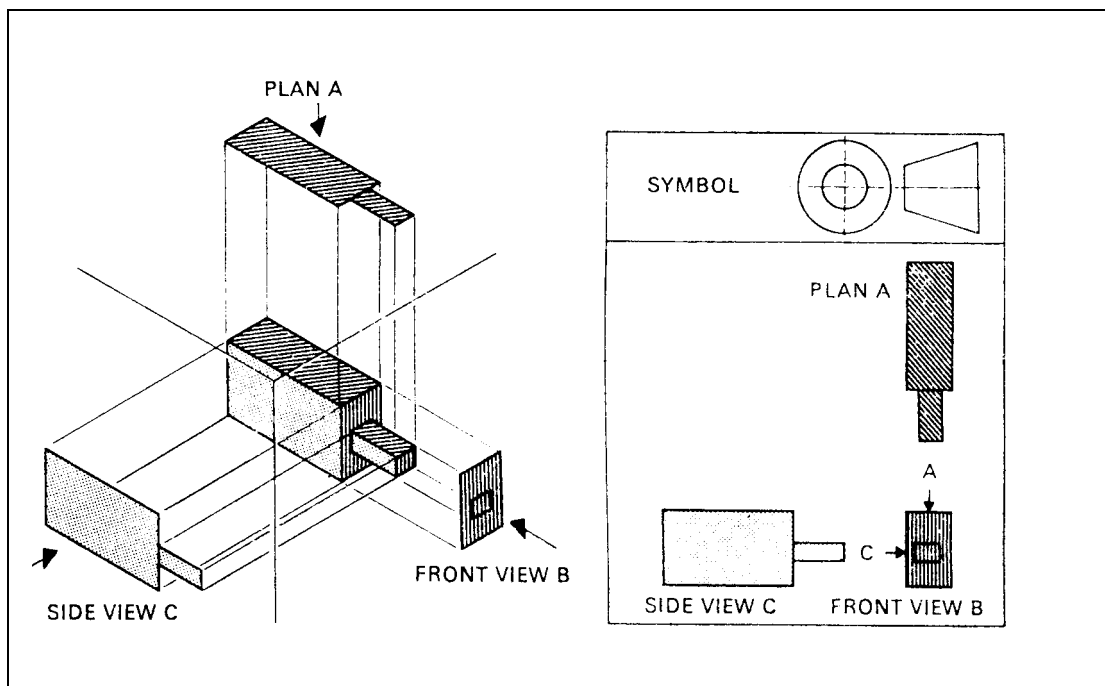

Figure 2   Third-angle Projection

5.3.2 **First Angle Projection**

The principle of first angle projection is shown in Figure 3. Each view represents the side of the object remote from it in the adjacent view.

5.3.3 **Isometric Projections**

These are pictorial views of an object, which are drawn with the three axes inclined, usually at an angle of 30°, to the plane of projection. The central drawing in Figure 2 and in Figure 3, is an isometric projection. Isometric views are sometimes used in drawings to indicate the position that the component occupies in the aircraft, or as a guide to understanding a complicated drawing.

5.4 **Views**

In general, all principal elevations are drawn looking at the left side of the aircraft, and the left hand item of handed parts is drawn. Other views are clearly annotated, e.g. 'view looking forward on frame'. The number of views shown on a drawing will

depend on the complexity of the part, although two views may often be sufficient. In some cases the three main views (Figures 2 and 3) may be insufficient to clarify all the details necessary, and a number of sectional or auxiliary views may be necessary.
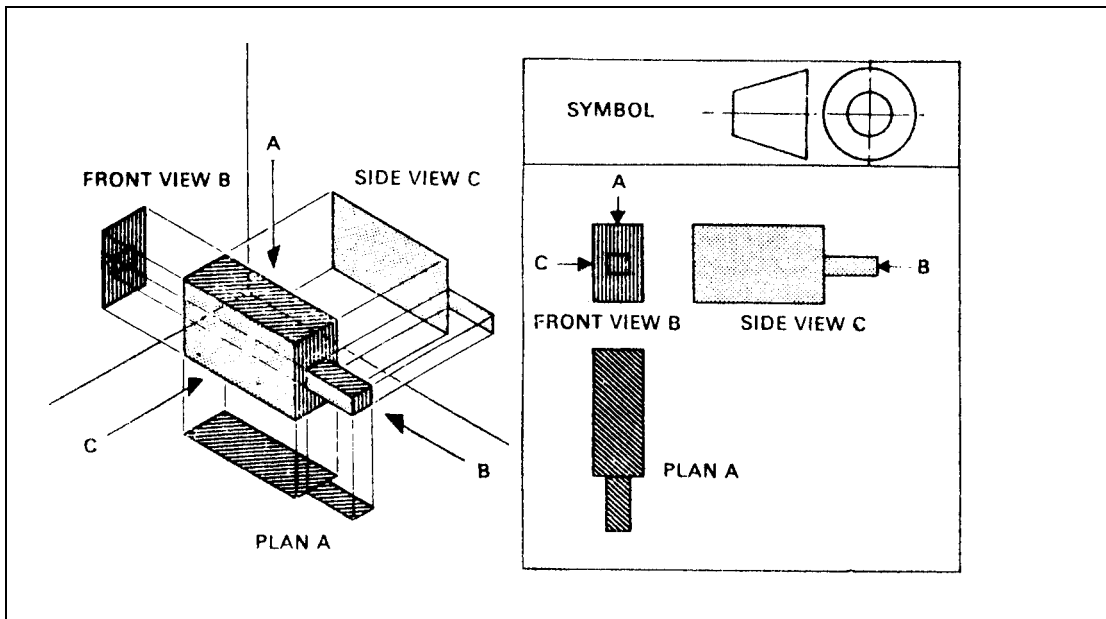

Figure 3   First-angle Projection
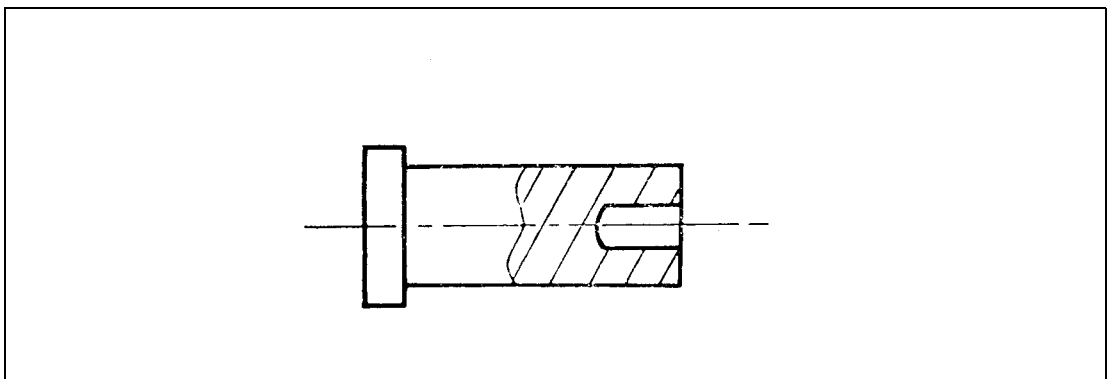
Figure 4   Part Section
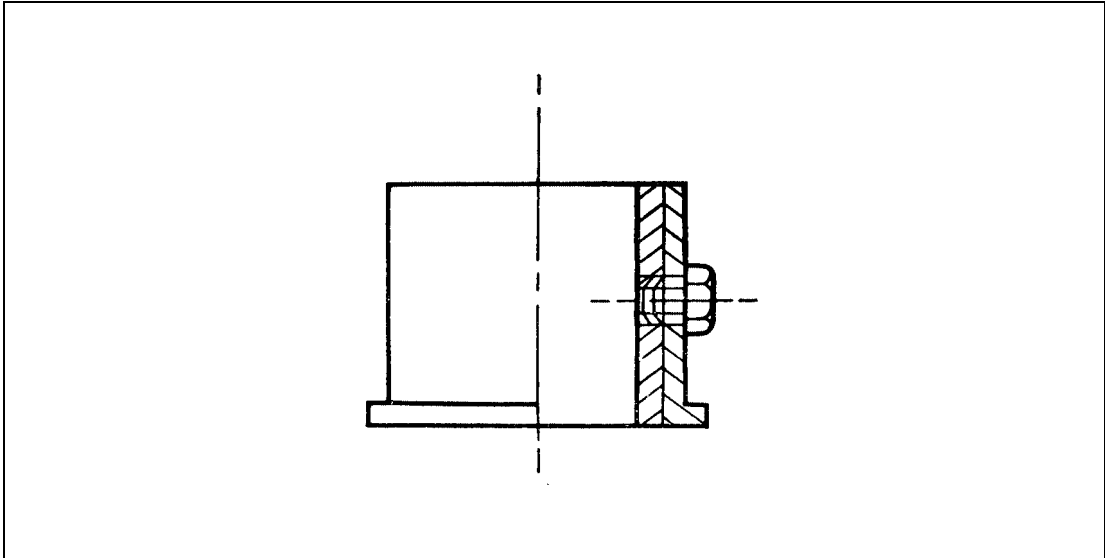
Figure 5   Half Section

5.4.1   **Sectional Views**

A sectional view may show a plan or elevation in complete section, the plane of the section being along one of the main centre lines. Where full sectioning is considered unnecessary, a part or half section may be used, and staggered sections are often used to illustrate particular features. Typical sectional views are illustrated in Figures 4, 5 and 6.

a) Hatching lines are normally used to indicate the exposed section, but these may be omitted if the drawing is clearly understandable without them. Hatching lines are usually drawn at 45° to the axis of the section, and adjacent parts are hatched in different directions.

b) Bolts, rivets, shafts, ribs, and similar features are not normally shown in longitudinal section.
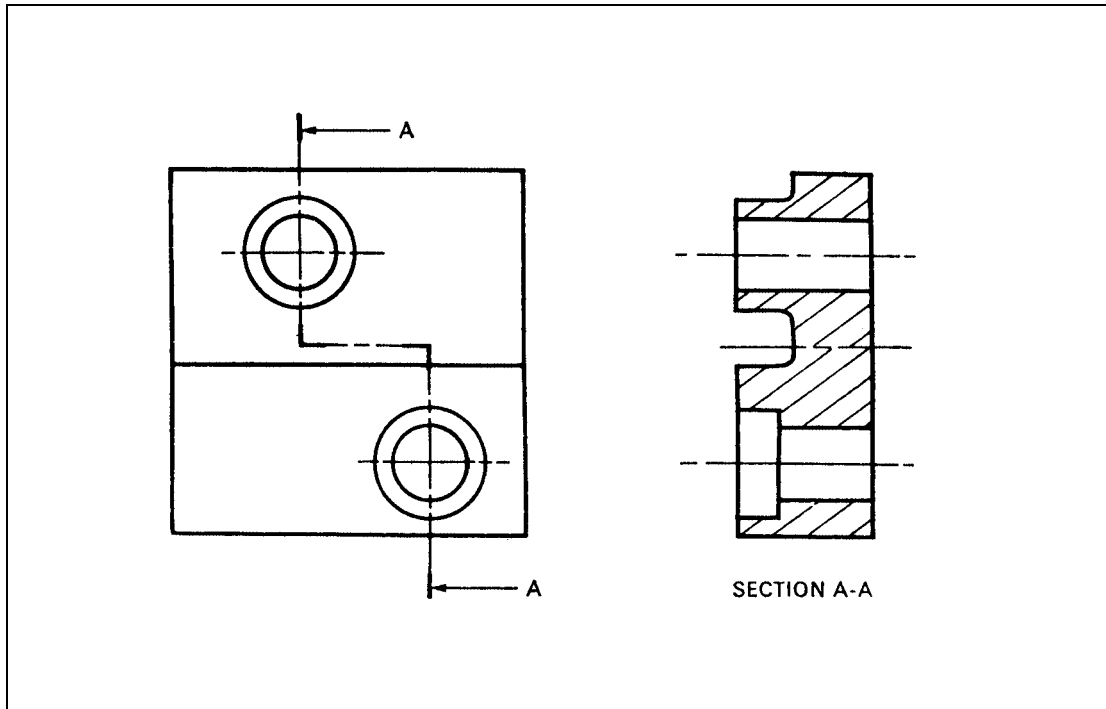
Figure 6   Staggered Section

5.4.2   **Auxiliary Views**

Neither a plan nor an elevation will show the true shape of a surface inclined to the plane of projection. The true shape of such a surface is shown by means of an auxiliary view, the auxiliary plane being imagined as being parallel to the surface being illustrated, as shown in Figure 7.
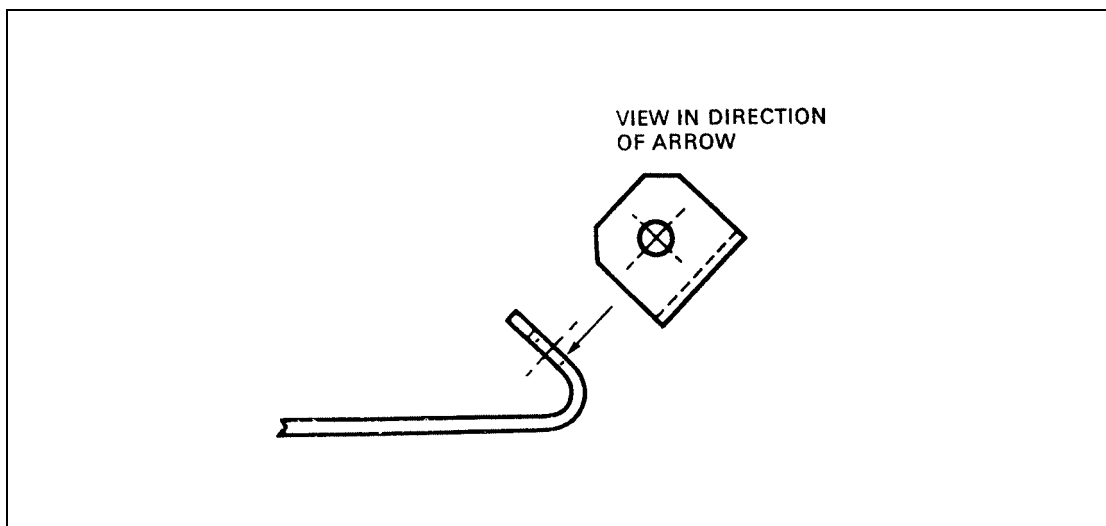
Figure 7   Auxiliary View
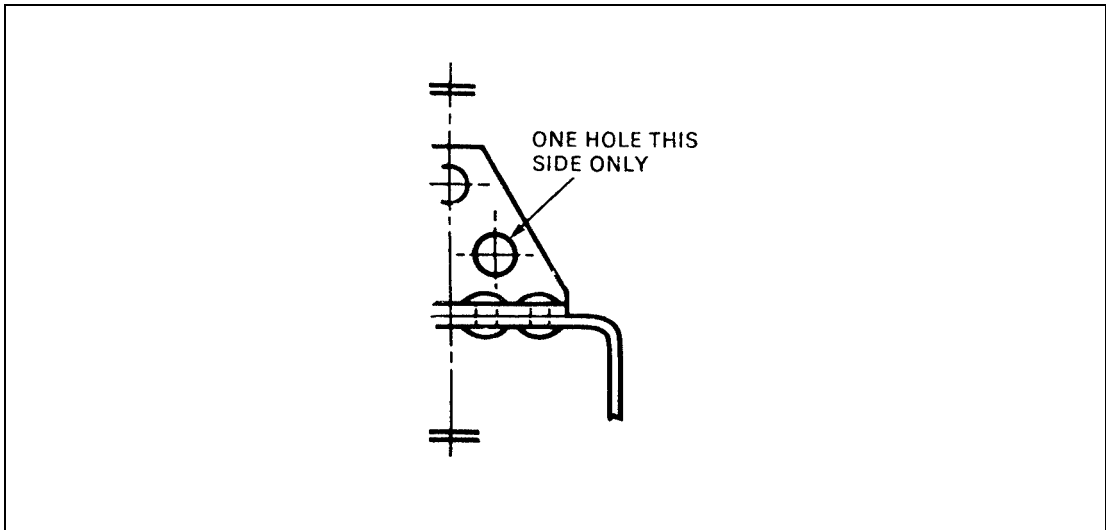
Figure 8   Symmetrical Parts

5.4.3   **Symmetrical Parts**

Parts which are symmetrical, or nearly so, may not be fully drawn. Sufficient information is normally provided by drawing one half or segment of the part; any asymmetry being identified by a note. Figure 8 shows a symmetrical part, and illustrates the method of defining the line of symmetry.

5.4.4   **Repetitive Information**

Where several features are repeated in a regular pattern, such as rivets, bolts, or slots, only the number required to establish the pattern may be shown, by marking their centrelines. Any further information will be given in a note. Figure 9 shows a typical skin joint which could be drawn in this manner.
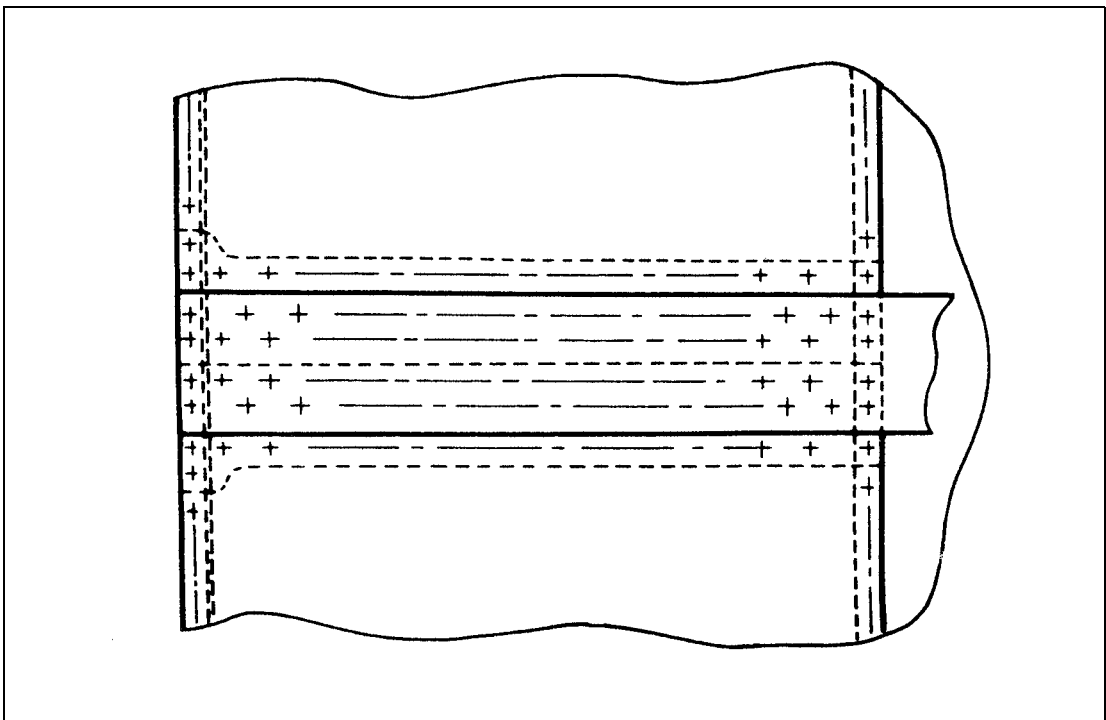
Figure 9   Repetitive Features
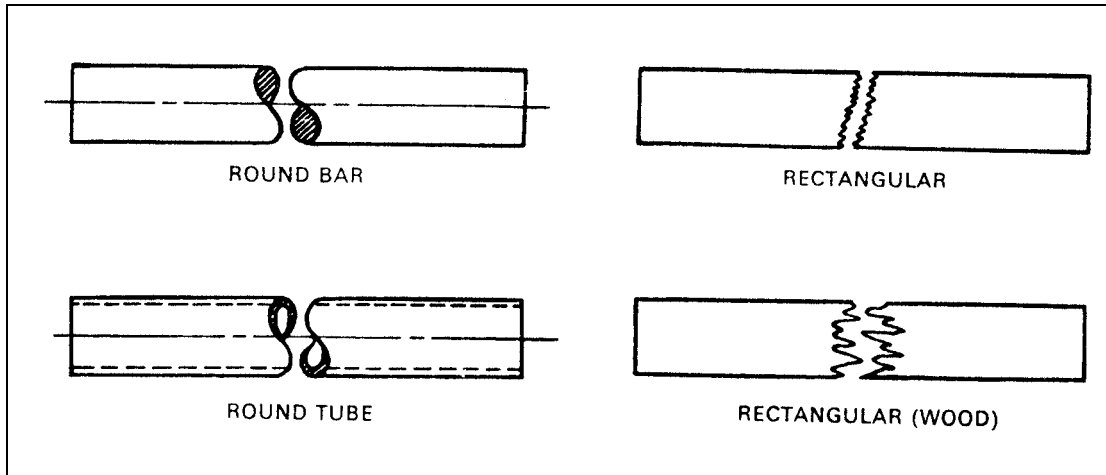
Figure 10 Break Lines

5.4.5 **Break Lines**

Break lines are used where it would be inconvenient (because of limited space) to draw long lengths of standard section. The types of break lines used for various components are shown in Figure 10.

5.5 **Dimensioning**

All dimensions necessary for the manufacture of the part or assembly are given on the drawing; it should not be necessary to deduce any dimension from other dimensions. To avoid confusion, dimensions are normally given once only. The units of measurement used are usually stated on the drawing, to avoid repetition, but any dimension to which this general statement does not apply will be suitably annotated. Dimensions are placed so that they may be read from the bottom or right hand side of the drawing.

5.5.1 When dimensions are given from a common datum, one of the methods shown in Figure 11 is normally used. Chain dimensioning, i.e. dimensioning between adjacent holes, is not often used, since it allows a build up of tolerances, which may not be acceptable. An alternative method, used with riveted joints, is to locate the end holes and add a note such as '11 rivets equally spaced'; this method is useful on curved surfaces.
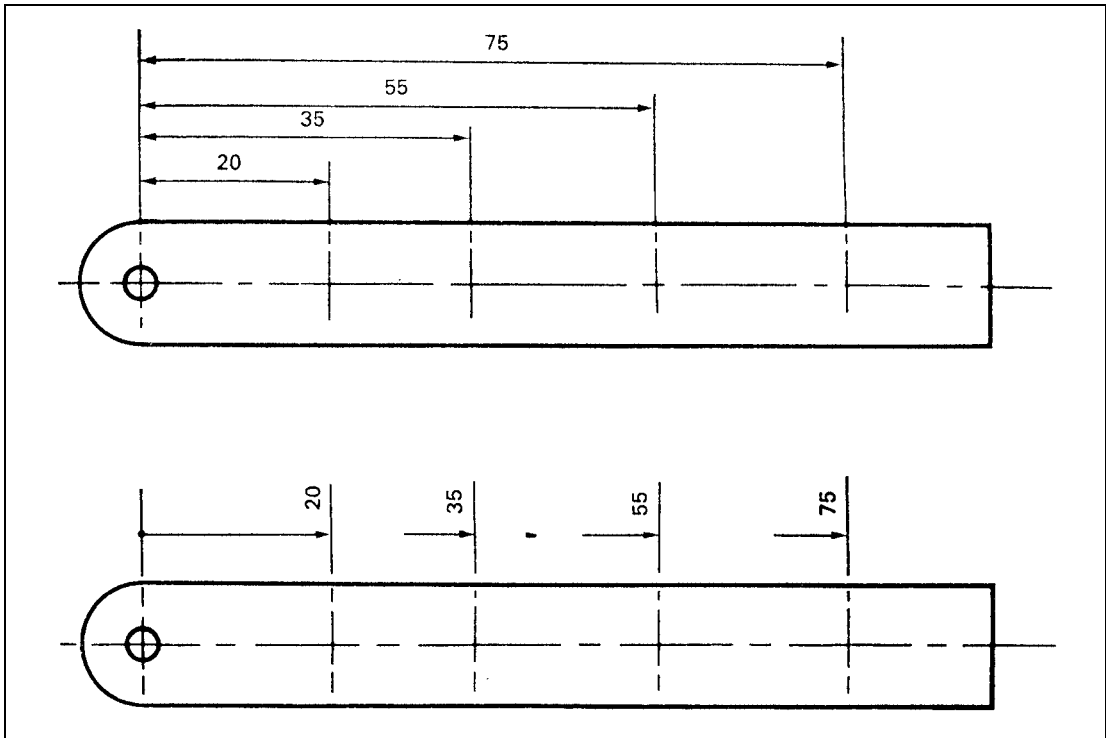
Figure 11   Dimensioning from a Common Datum

5.5.2   Machined components are usually measured by a system of functional and non-functional dimensions. The functional dimensions are those which directly affect the function of the component, e.g. the length of the plain portion of a shouldered bolt. A non-functional dimension would be the depth of the bolt head, and other dimensions chosen to suit production or inspection. Auxiliary dimensions may also be given, without tolerances, for information.
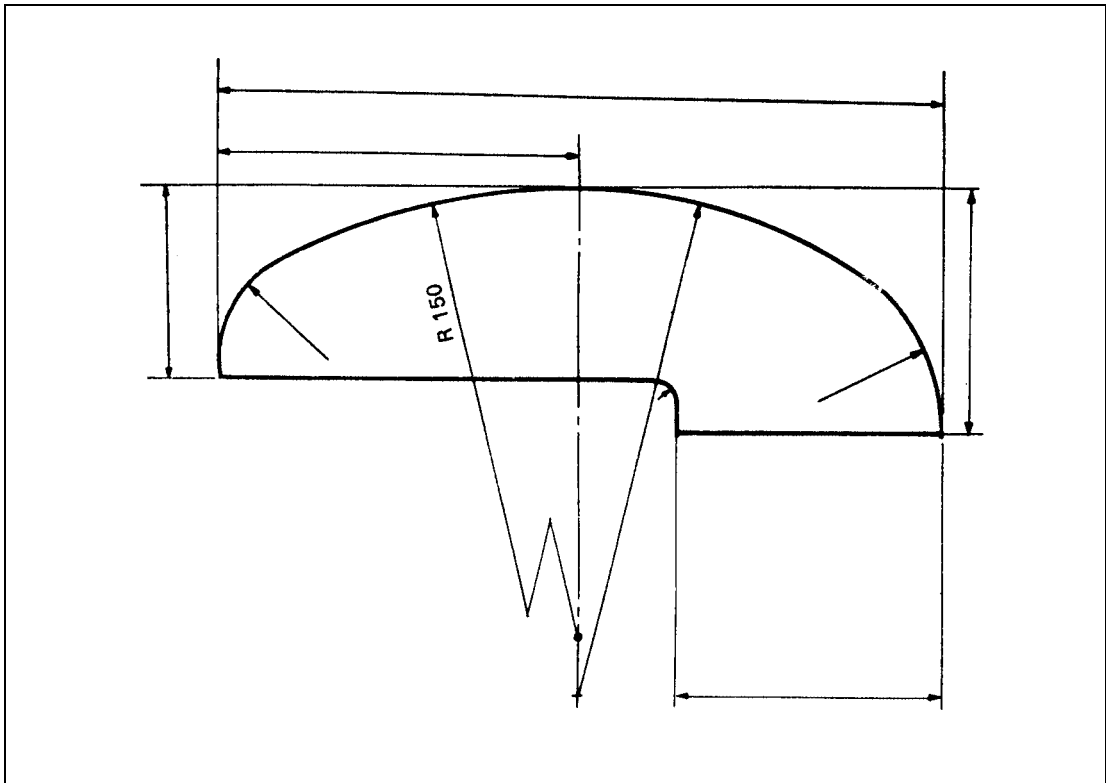
Figure 12 Dimensioning Profiles by Radii
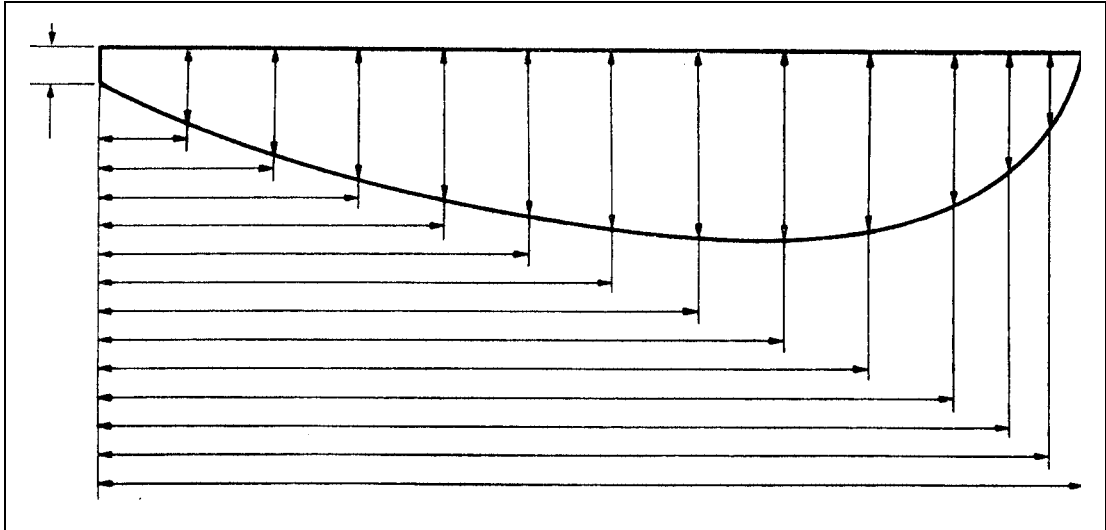
Figure 13 Dimensioning Profiles by Ordinates

5.5.3 **Dimensioning of Curved Profiles**

Items the profiles of which are curved, are where practicable, dimensioned by means of radii, as shown in Figure 12. Where a radius is very large, and the centre of the arc could not be shown on the drawing, the method shown for the R150 dimension in Figure 12 may be used; the portion of the radius which touches the arc being in line with the true centre. Where this method cannot be employed, a system of ordinates may be used, as shown in Figure 13. The radii method is usually preferred, since

accurate arcs can be produced; whereas with the ordinate system, deviations from the required curve may occur as a result of connecting the plotted points.

5.6   **Dimensional and Angular Tolerances**

A general tolerance is usually given for all dimensions on a drawing and may be found in the appropriate box on the printed layout. Where the general tolerance is inadequate or restrictive, an individual tolerance may be given to a dimension.

5.6.1   Tolerances may be expressed by quoting the upper and lower limits, or by quoting the nominal dimension and the limits of tolerance above and below that dimension. Examples of both linear and angular tolerances are shown in Figure 14. Geometric tolerances are dealt with in 5.11.
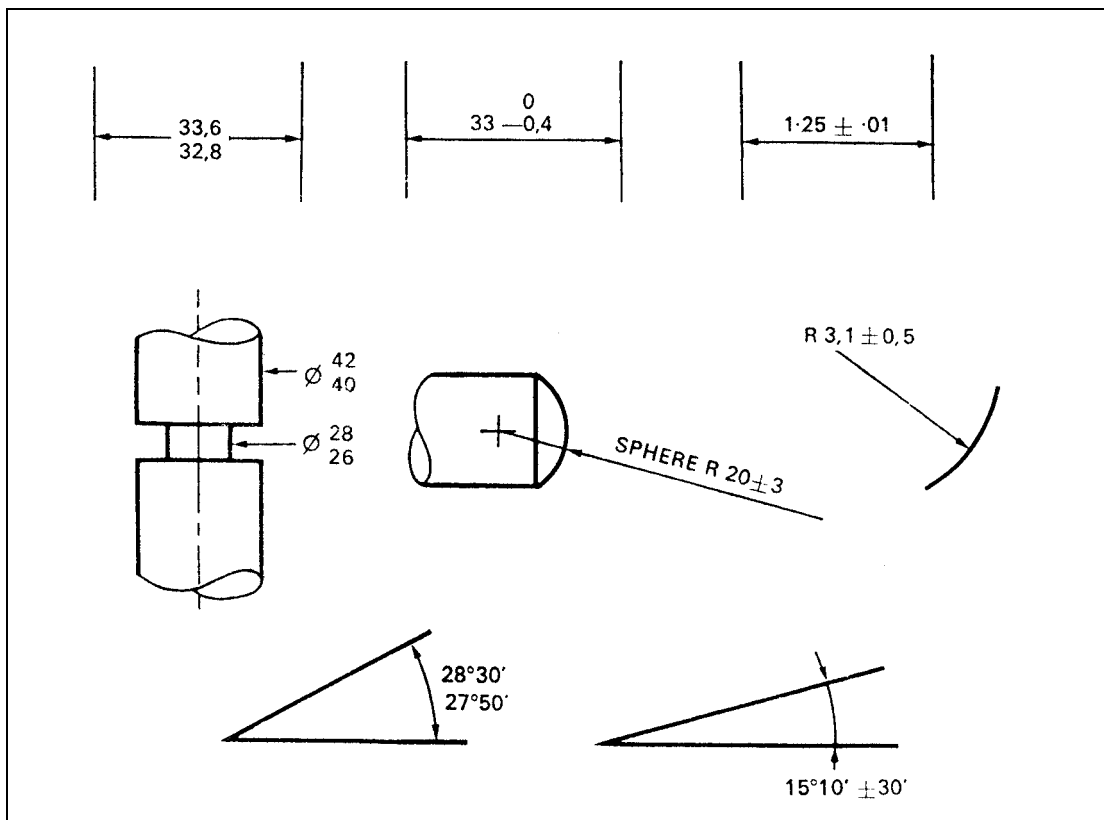
Figure 14   Dimensional Tolerances

5.7   **Machining and Surface Finish**

When a machining operation is required on a particular surface, the symbol is ▽ used, and is located normal to that surface. When the component is to be machined all over, the symbol ▽ ALL OVER is used, and, in some cases, the type of machining is indicated with a note such as ▽^{LAP}

5.7.1   The machining symbol is also used to indicate the surface finish required; the maximum roughness figure being added to the symbol thus: ▽. The surface finish quoted on a particular drawing depends on the system being used. The relationship between the various systems is included for reference in Table 2. Detailed information on the assessment of surface texture is provided in British Standard (BS) 1134 and International Organisation for Standardisation ISO/R 468 and specifications for roughness comparison specimens are contained in BS 2634.

Table 2   Surface Texture Equivalents

Nominal Values	micrometre	0·025	0·05	0·1	0·2	0·4	0·8	1·6	3·2	6·3	12·5	25	50
	microinch	1	2	4	8	16	32	63	125	250	500	1000	2000
Roughness Number		N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12

5.8   Abbreviations and Symbols

In order to save time and drawing space when compiling a drawing, a number of abbreviations and symbols are used. Table 3 lists the main abbreviations and symbols which will be found on both currently produced and older drawings.

5.9   Conventional Representations

Common features, which may appear several times on a drawing, are seldom drawn in full, since this would take up space and drawing time, unnecessarily. These features are shown by conventional representations, some examples of which are illustrated in Figure 15.
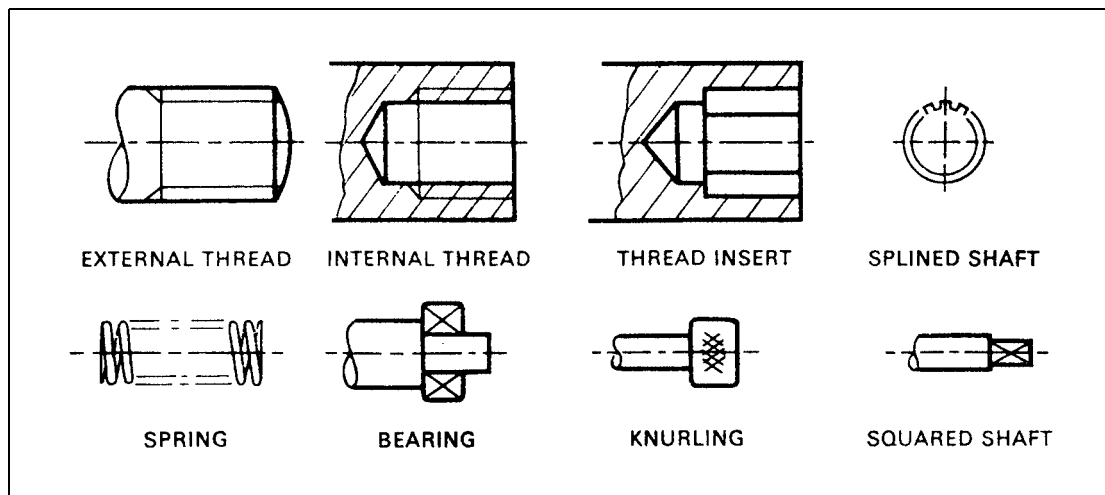
Figure 15   Conventional Representations
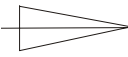
5.10   Process and Identification Markings

Drawings will often call for identification markings on parts and will indicate both the position of the markings and the method of application, e.g. rubber stamp. In addition, it is sometimes necessary to mark the component to show that a particular process has been carried out and this will also be specified on the drawing. Symbols are normally used for this purpose and some of the more common ones are shown in Table 4. Some Design Organisations may use different symbols or code letters, which should be obtained from the Drawing Office Handbook, or similar publication, produced by the organisation concerned.

5.11   Geometric Tolerances

It is sometimes necessary to place tolerances on both geometric features and dimensions, in order to adequately control the shape of a part. On older drawings this was done by annotating the feature to be toleranced, e.g. POSN TOL, and by adding notes to the drawing, in order to specify the tolerance and the method of checking. On newer drawings, the international system recommended in BS 308 is used, and this method is outlined in the following paragraphs.

Table 3   Abbreviations and Symbols

Term	Abbreviation	Term	Abbreviation
Across Flats	A/F	Pattern number	PATT NO
Assembly	ASSY	Pitch circle diameter	PCD
British Standard	BS	Pneumatic	PNEU
Centres	CRS	Pound (weight)	LB
Centre line	CL or ₵	Radius	RAD or R
Chamfered	CHAM	Reference	REF
Cheese Head	CH HD	Required	REQD
Counterbore	C'BORE	Revolutions per minute	RPM or REV/MIN
Countersunk	CSK	Right Hand	RH
Cylinder or cylindrical	CYL	Round head	RD HD
Degree (of angle)	°	Screw thread:	
Diameter - in a note	DIA	British Association	BA
- as dimension	⌀		
Figure	FIG	British Standard Fine	BSF
Full indicated movement	FIM	British Standard Pipe	BSP
Hardness - Brinel	HB	British Standard	
- Rockwell	HR (+scale letter)	Whitworth	BSW
		Unified Coarse	UNC
- Vickers	HV	Unified fine	UNF
Hexagon	HEX	Unified special	UNS
Hexagon head	HEX HD	Screwed	SCR
Hydraulic	HYD	Second (of angle)	"
Inch	IN or "	Sheet	SH
Insulated	INSUL	Sketch	SK
Internal diameter	I/D	Specification	SPEC
Left Hand	LH	Spherical diameter	SPHERE ⌀
Long	LG	Spherical radius	SPHERE R
Machine	M/C	Spotface	S'FACE
Machined	M/CH	Square	SQ
Material	MATL	Square inch	SQ IN or IN^2
Maximum	MAX	Standard	STD
Max material condition	MMC or Ⓜ	Standard wire gauge	SWG
Millimetre	MM	Taper	▷
Minimum	MIN	Threads per inch	TPI
Minute (of angle)		Undercut	U'CUT
Not to scale	NTS	Volume	VOL
Number	NO	Weight	WT
Outside diameter	O/D		

NOTE: Capital letters are normally used on a drawing, for clarity, but lower case letters may be used elsewhere as appropriate.

Table 4   Process and Treatment Symbols

Process or Treatment	Symbol
Solution treated and not requiring precipitation	(N)
Solution treated and requiring precipitation	(W)
Precipitation treatment	(P)
Solution treated and precipitated	(WP)
Annealed	(A)
Hardened and tempered	(HT)
Mechanical test	(M)
Dye penetrant check	(PFD)
Ultra-sonic test	(UFD)
Anodic flaw detected	(AFD)
Cleaned (pipes)	(AC/1)
Repaired and reconditioned	(R)
Normalised steel parts	(N)
Proof loads	(PL)
Stress relieved	(SR)
Pressure test	(PT)
X-ray flaw detection	(XR)
Salvaged	(S)
Electro-magnetic flaw detection	(MFD)
Welding	(W/S)
Etch inspection of steel	(E)

5.11.1   Information relating to a particular geometric tolerance is enclosed within a rectangular frame on the drawing, an arrow from the frame indicating the location of the feature to which the tolerance applies. If the tolerance is related to a particular datum, a leader line is drawn from the frame to the datum position, or the datum is referenced separately, and identified by a letter in the frame. Unless the datum is a dimension, it is defined by a solid equilateral triangle. Examples of the methods of indicating geometric tolerances are shown in Figure 16, and the symbols used to identify the characteristic to which the tolerance is applicable are listed in Table 5. Detail (f) in Figure 16 shows a completely dimensioned component.
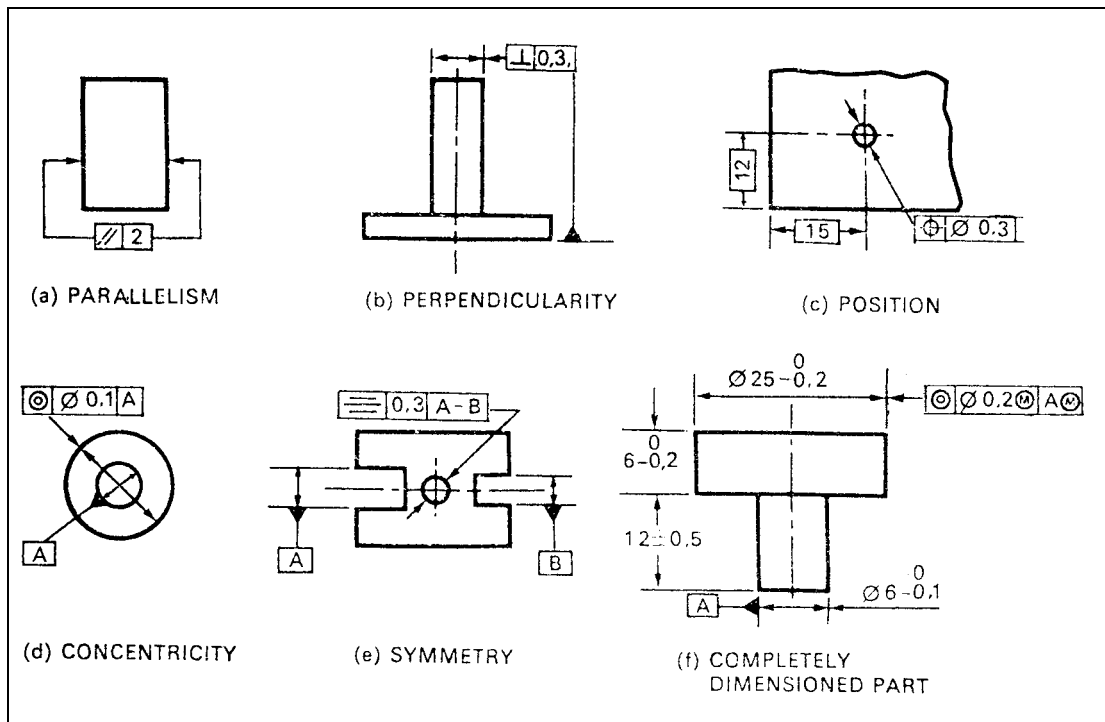
Figure 16 Geometric Tolerances

5.11.2   As a guide to the interpretation of a geometric tolerance, reference may be made to detail (e) of Figure 16. This indicates that a symmetry tolerance of 0·3 mm is required, with respect to datum features A and B. This tolerance indicates that the axis of the hole must be between two parallel planes, 0·3 mm apart, which are symmetrically disposed about the common median plane of the slots in the end of the part. The hole could also, if necessary, be marked to indicate a symmetry tolerance at 90° to the plane specified, and the tolerance for this could be different.

5.11.3   The symbol (M) in detail (f) of Figure 16, indicates that the tolerance applies only to the maximum material condition of the dimension or datum feature and may be greater at the actual finished size.

Table 5   Geometric Tolerance Symbols

Feature	Type of tolerance	Characteristic	Symbol
Single	Form	Straightness Flatness Roundness Cylindricity Profile of a Line Profile of a surface	
Related	Attitude	Parallelism Squareness Angularity	
	Location	Position Concentricity Symmetry	
	Composite	Run-out	
Maximum material condition			Ⓜ
Dimension which defines a true position			

Tolerance Frame

Datum feature

Symbol for characteristic to be toleranced

⊚ | ⌀ 21,4 | A Ⓜ

Used when tolerance applies to the MMC of the feature

Used where tolerance is circular or cylindrical

Total tolerance

Leaflet 2-2   Clean Rooms

1   Introduction

The higher reliability requirements specified for aircraft system components and in particular, those associated with complex electronic, instrumentation and mechanical systems, (see Leaflet 10–5) necessitated the development of techniques for controlling contamination which in various forms is a common cause of component failure. It also became necessary to apply these techniques to selected areas of manufacturing and aircraft operating organisations in which the various processes of manufacture, overhaul and testing can be carried out under controlled environmental conditions. Such selected areas are referred to as Clean Rooms, the design and manufacture of which form part of an independent and highly specialised field of work to British Standard BS 5295 Parts 1, 2 and 3.

1.1   The information given in this Leaflet is intended purely as a guide to the subject of Clean Rooms. Subject headings are as follows:

2   Sources of Contamination

Any substance that causes failure or malfunctioning of a component is a contaminant, the particles of which may take a variety of forms and stem from many sources.

2.1   **Air**

The air which continually surrounds the components may be considered as a contamination storehouse containing dirt and dust particles, organic and inorganic vapours.

2.2   **Manufacture**

Contaminants are produced during all manufacturing processes. Particles, such as swarf resulting from a machining operation, or particles forced into the surface of a component during a pressing or heating process, can be of such a nature that their effect can be immediate or delayed. Depending on the composition of the particle and component materials, the alloys or compounds formed by interaction can result in serious loss of a component's structural strength over a period governed by the rate of diffusion.

2.3   **Assembly**

During the assembly process the possibility of introducing contaminants is probably greatest because of exposure to the highest levels of contaminant sources. In the soldering process for example, the vapourisation of flux causes particles to escape into the surrounding air which, on cooling, condense as droplets on a nearby cold surface of the component. Depending on the location of the particles and the forces applied to them, they can act as a contaminant with an immediate or delayed effect.

2.3.1   The use of jointing adhesives can also produce contamination similar to that of a soldering process. In addition, vapours can be given off which can migrate to other parts of an assembly and act as a delayed-action contaminant.

2.3.2   Assembly of components using threaded joints can produce fibre-shaped fragments or flakes as a result of an effect similar to wire drawing. For extremely close fit or for balancing purposes, it may be necessary to fit individual parts of a component together by grinding, lapping or honing operations. In any such operation, contaminant particles can be dispersed in the atmosphere, suspended in fluids, adhere to the surfaces of component parts, or become embedded into the surfaces.

2.3.3   Assembly of components in jigs, or while being handled or supported by tools, may result in deformation of surfaces and production of contaminant particles. For example, if during tightening of a bolt, slippage of the spanner jaws occurs, particles are produced from the bolt head. Particles are also produced from the heads of bolts or screws and component surfaces during final tightening.

2.4   **Storage and Transit**

During the second period of assembled components and of associated independent parts, contamination can occur in several ways notwithstanding the use of protective coverings or containers. Particles from the air may be deposited as a result of gravitational settling and also as a result of electrostatic effects. Improperly cleaned containers or covers may transfer particles to components, in particular where padded containers and plastics containers are used. In the first case, the contours of the container may trap particles which are not released until the component causes deformation of the padding. In the second case, plastics containers may pick up particles from the air due to electrostatic charging and hold them until transferred to the packed component.

2.4.1   Containers which are not hermetically sealed are subject to a 'breathing' cycle as the temperature of the container varies. During the intake portion of the cycle, particles in the air surrounding the container may be drawn into a position where they can contaminate the component.

2.4.2   The movement of packed containers during transit is also a source of contamination since it may dislodge contaminant particles not previously cleaned off, or create new particles by abrasion.

2.5   **Component Cleaning Processes**

A cleaning process is actually a process of transforming contamination from a high level of concentration to a lower one; therefore, tolerance levels must be considered relative to the component's function and required operational accuracy.

2.5.1   The transfer of contaminant particles is dependent on the methods used in the cleaning process, i.e. whether wiping or polishing with an absorbent or collecting material (dry cleaning transfer) or cleaning by means of a liquid (wet cleaning transfer). Problems exist in each of these processes.

2.5.2   The ways in which dry cleaning can contaminate include the following:

a) Removal of fibrous particles from the cleaning material.

b) The material, after use, may have a particle concentration sufficiently high so that as much contamination is left on the component as is removed.

c) Wiping or polishing action can cause particle adhesion as a result of electrostatic charges.

d) Particles can be moved about on a component surface without necessarily being lifted from the surfaces.

2.5.3   In the wet cleaning process, the contaminated surfaces are exposed to clean fluid which will wet the particles and the surfaces. The fluid or the component is then agitated so as to pull particles from the surfaces. After a specified period the component is withdrawn and the surfaces are dried. The ways in which wet cleaning can contaminate include the following:

a) It is often difficult to obtain clean fluid and to keep it clean when handling it.

b) Agitation of the fluid is normally done by ultrasonic means, but there is a possibility of re-contamination of the amplitude if agitation is not large enough to remove particles an appreciable distance from the surface of the component.

c) Often a wet surface may have particles in the liquid layer that can easily be moved laterally over the surface but are removed from the liquid layer only with great difficulty.

d) Until the component is dried, any airborne particles will collect on the wet surface and remain.

2.6   **Personnel Activity**

The activity of personnel is probably the greatest single cause of contamination which arises from several sources. The act of walking, or other movements required at a work bench, produces transient air currents which re-distribute airborne particles and the brushing off of particles from many surfaces. Another contaminant source is the shedding of skin and hair particles. The outer layers of skin flake off almost continuously, the flake rate and size depending on the amount of abrasion to which the skin is exposed and its condition.

2.6.1   Exhaled air is another source of contamination since it contains moisture-retaining solid particles and is usually acidic in nature. Perspiration from the skin is a similar hazard.

3 Control of Contamination

Control of contamination is effected in two ways: by establishing a clean room, which will provide a clean atmosphere and working conditions and by rigid routines adopted by personnel to prevent process, transfer and associated sources of contamination while working within the area of the clean room.

3.1 The manufacture of a clean room and its air handling system (see paragraph 8) must be designed to control airborne particles over a range of sizes and suited to the nature of the work performed in the room. Control is accomplished by filtration of the air entering the room, changing the air to remove generated particles, designing walls, floors and furnishings to be resistant to particle generation and retention, protecting components from impact and settling of particles and providing additional areas for cleaning of parts and personnel.

4 Size of Contaminants

The degree to which contaminants are effectively controlled is determined by measurements of the size of particles and the number in a given volume. The conventional unit of measurement is the micrometre (μm). In general, the filtration systems of clean areas are designed to control particles of 0·5 μm and larger in size.

5 Classification of Air Cleanliness

In addition to all principles of air-conditioning, certain specialised cleanliness requirements are defined by standards which establish classes of contamination level to be achieved in the design of a clean room for a specific task. Classifications relate to the number of contaminant particles 0·5 μm and larger in size, present in one cubic metre of air. Four classes of contamination level are generally adopted and these are shown in descending order of cleanliness in Table 1. Special classifications may be used for particle count levels where special conditions dictate their use. A summary of the cleanliness requirements for some typical products is given in Table 2.

Table 1

Controlled Environment (Clean room, work station or clean box)	Recommended Air Flow Configurations	Recommended Periodicity for Air Sampling and Particle Counting	Max. Permitted Number of Particles per m³ (equal to, or greater than, stated size)					Final Filter Efficiency %
			0·5 μm	1 μm	5 μm	10 μm	25 μm	
Class 1	Unidirectional	Daily or continuous by automatic equipment	3,000[1]	Not applicable	Nil	Nil	Nil	99·995
Class 2	Unidirectional	Weekly	300,000	Not applicable	2,000	30	Nil	99·95
Class 3	Unidirectional or conventional	Monthly		1,000,000	20,000	4,000	300	95·00
Class 4	Conventional	3-monthly			200,000	40,000	4,000	70·00
Controlled Area	Normal ventilation	—	—	—	—	—	—	—
Contained Work Station	Unidirectional	To suit required class and application						99·997
Portable Clean Boxes	As selected	To suit required class and application		To suit required class				To suit required class

1. Subject to maximum particle size of 5 μm

6   Classification of Clean Rooms

The cleanliness achieved by a clean room is dependent on the air-handling system's capacity to purge the room of contaminant particles. This includes not only effectiveness of the filters and the number of air changes per hour but also the distribution of the air within the room. There are two main methods of distributing air into clean rooms namely, conventional clean rooms and unidirectional-flow clean rooms, and these also serve as the basis of clean room classification.

6.1   Conventional Clean Rooms

Conventional clean rooms are based on recognised air-conditioning techniques. The conditioned air is highly filtered and distributed through ceiling-mounted diffuser outlets and then exhausted from return airducts located near the floor around the periphery of the room (see Figure 1). In addition to direct emission from the diffuser outlets, spreading of conditioned air throughout the room is obtained by secondary mixing of the air caused by thermal effects of warm and cool air currents. This is an advantage from the point of view of maintaining conformity of room temperature conditions, but the turbulence created gives rise to the problem of contaminant particles being re-introduced to the airstream.

Table 2

Class	Particles/m^3	Product
2	0·5μm to 10 μm	Air bearings Miniature ball bearings Miniature contacts Floated gyros Hydraulic and pneumatic systems Optics Semi-conductor networks Miniature timing devices
3	1 μm to 25μm	Hydraulic and pneumatic systems Precision timing devices Stable platforms Gyros
4	5μm to 25μm	Ball bearings Electronic components Engine pumps Aerospace instruments Printed circuits Valves Hydraulic and pneumatic systems Precision measuring equipment

NOTE: Class 1 is outside the scope of this Leaflet and would not normally be used.
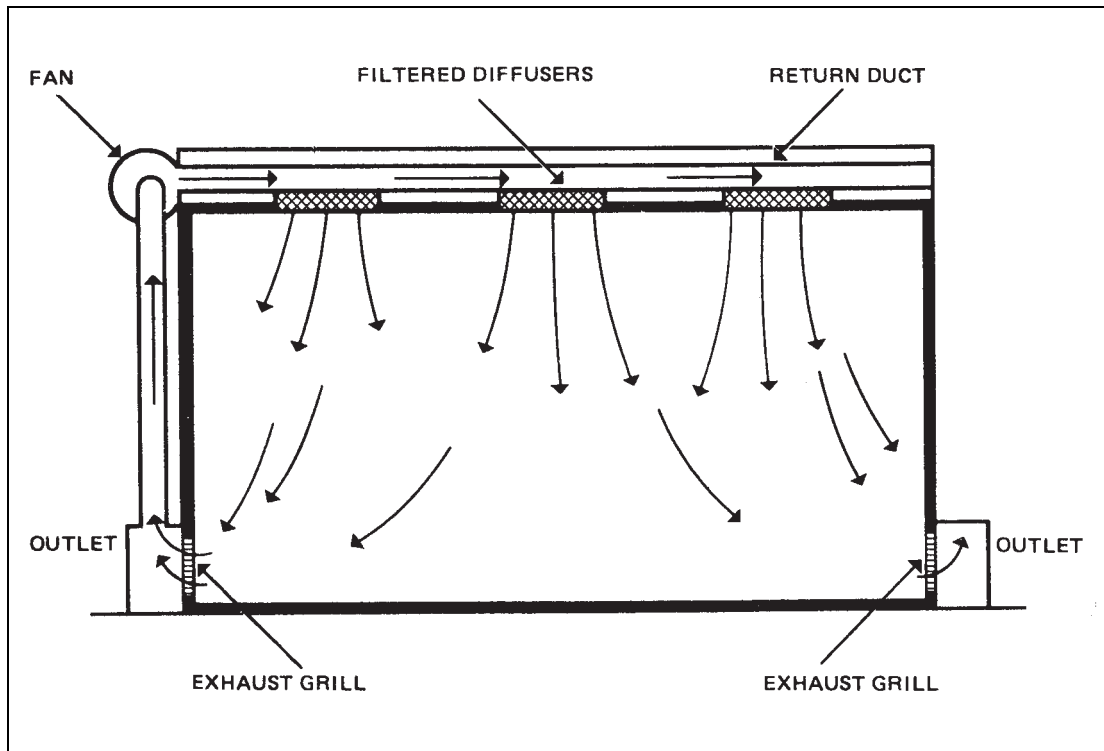
Figure 1   Conventional Flow System

6.2   **Unidirectional-flow Clean Rooms**

These rooms have been developed from the conventional type of clean room and are designed to overcome three primary deficiencies associated with it; lack of self clean-up capabilities to effect contamination brought in by personnel and equipment, non-uniformity of airflow patterns and the requirement for rigid control of personnel. The major differences between the layout and operation of the two types of clean room result from the method of air distribution adopted. In a unidirectional-flow room air is introduced through a large filtered diffuser area, moves through the room and is exhausted through an outlet opposite to the diffuser and of equally large area. Such an arrangement ensures that the air moves in a straight or unidirectional-flow. The outlet is connected to return air ducts thus permitting re-cycling of the air. Two alternative airflow systems exist and are illustrated diagrammatically in Figure 2. In the vertical unidirectional-flow (down-flow room) system, the diffuser forms the complete ceiling of the room and the floor is grated to provide the outlet to return ducts. The diffuser of a horizontal flow (cross-flow room) system forms one of the end walls of the room. After passing through the room and then through an exhaust grill, the air is deflected upwards into the return ducts.

6.2.1   In some designs the use of separate return ducting may be eliminated by adopting the twin cross-flow technique of air distribution as shown in Figure 3. The total clean room area required is divided in half by a wall, with flow in one direction on one side of the wall and flow in the opposite direction on the other side. The end walls are made up of filtered diffusers and exhaust grills and are disposed so that the clean room itself acts as a return duct.

7   Environment and Comfort Control

The temperature, humidity and pressure characteristics of the air passing through the air handling system (see paragraph 8) should be controlled to establish an environment suitable for work processes to be carried out in a clean room and for the comfort of clean room personnel.

7.1   Temperature and Humidity

The selection of temperature and humidity ranges to be controlled are dependent on the design of the component or system and the effects on their functional accuracy under varying environmental conditions. Normally a suitable temperature for working conditions is $20 \pm 2°C$ ($68 \pm 36°F$). Humidity should be controlled and maintained at a relative humidity of 35 to 50% for all classes of clean rooms, contained work stations and clean boxes.

7.2   Pressure

Clean rooms are always slightly pressurised in order to maintain the required outward flow of air under closed working conditions and to prevent the entry of contaminant airborne particles when entryways or doors are opened.

7.2.1   Unidirectional-flow rooms should normally have an air velocity of 0.45 ± 0.1 m/s for horizontal flow rooms and 0.30 ± 0.05 m/s for vertical flow rooms. Air pressure for conventional flow rooms should be such that the number of air changes, including re-circulated air, should not normally be less than 20 per hour except for Class 4 rooms where not less than 10 changes per hour may be acceptable.
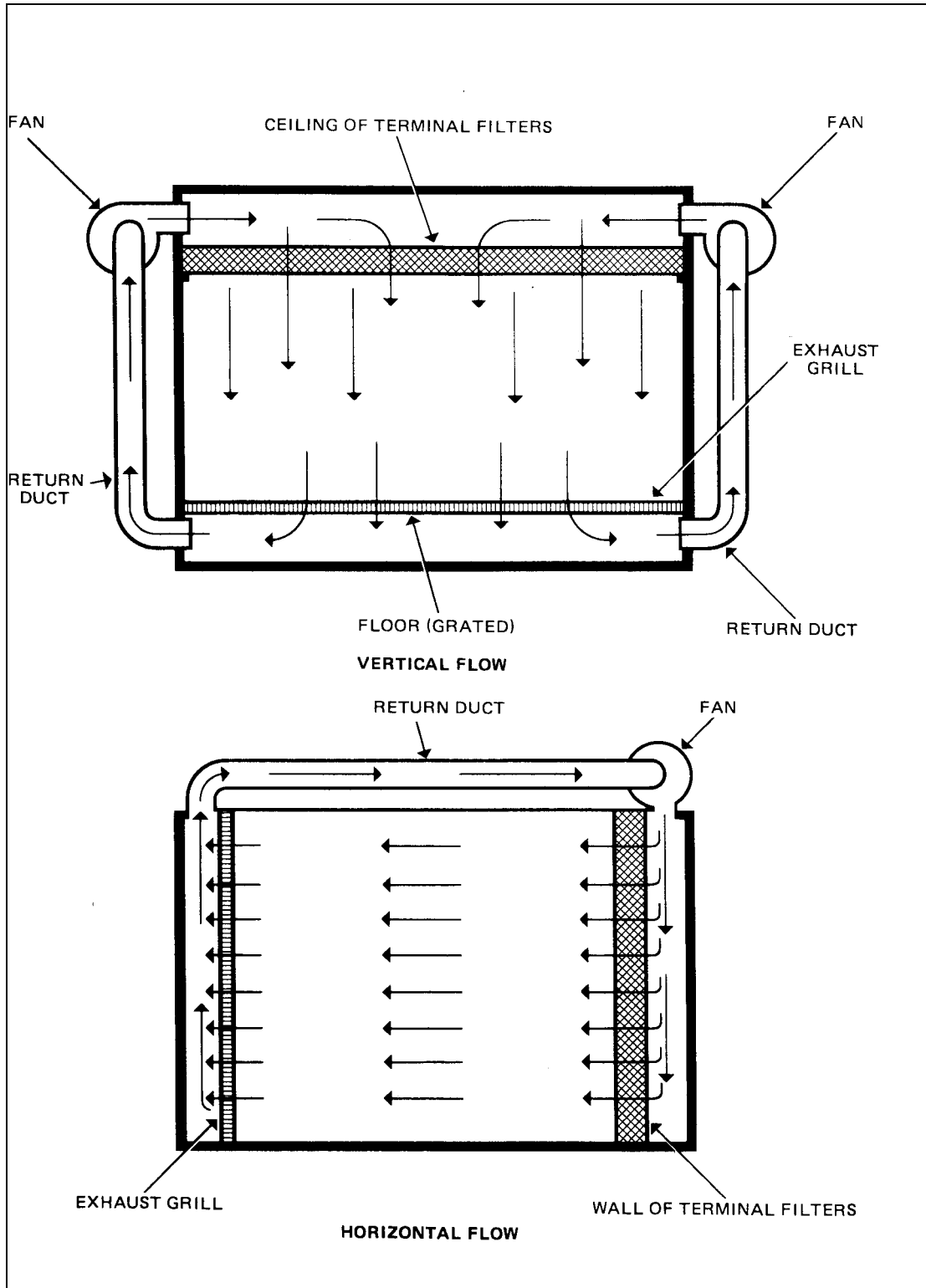
Figure 2   Unidirectional-flow Systems
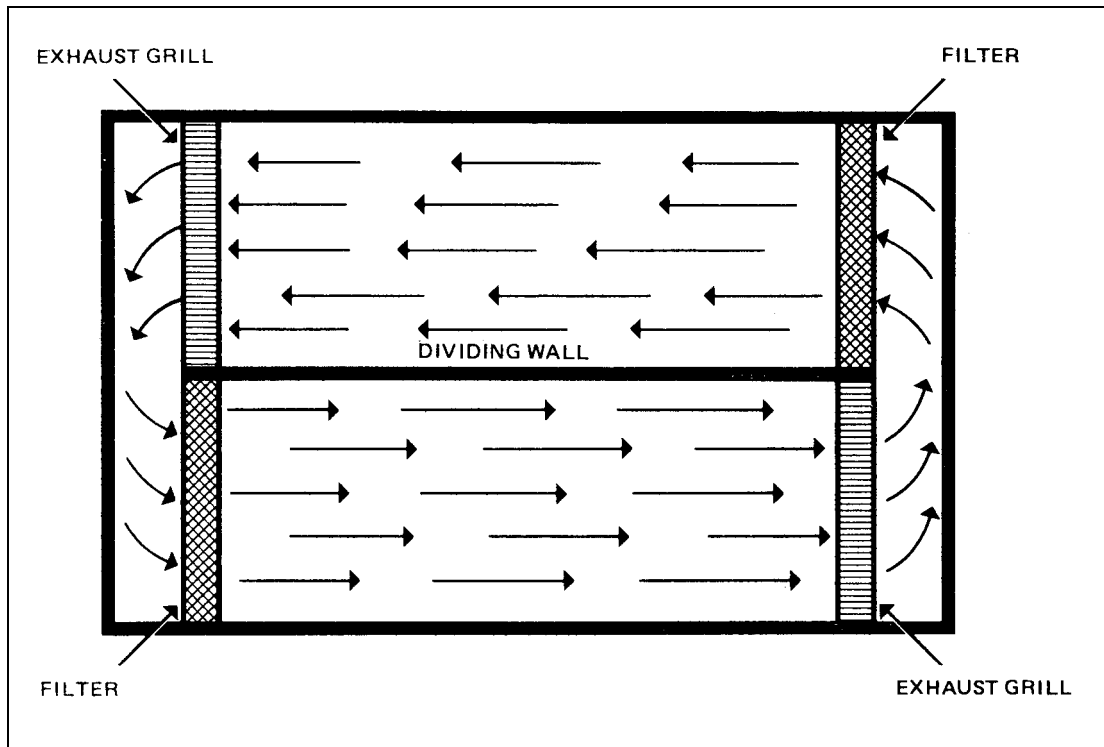
Figure 3   Twin Unidirectional Cross-flow System

7.2.2   Arrangements should also be made to ensure that excessive turbulence is not produced, and every precaution should be taken to obviate the possibility of contaminated air being carried back to the work stations. Contained work stations and portable work boxes should normally conform to the requirements of the type of air flow selected. Air pressure and graduations between successive pressure areas should not normally be less than 15 Pa (1·5 mm water gauge).

> **NOTE:**   25 Pa (2.5 mm water gauge) is normally regarded as adequate but, when selecting the actual pressure, care should be taken to ensure that in-leakage is prevented.

8   Air Handling Systems

The primary function of an air handling system for any type of clean room is to control the level of airborne contaminant particles by constantly filtering and re-circulating the air. The arrangement of a system depends on whether it is to be a conventional clean room, unidirectional vertical or horizontal flow clean room. In the basic form, however, it consists of a fan, ducting for inlet and exhaust air and an air filtration system. In some instances, the use of ducting may be minimised by adopting a false ceiling arrangement and by blowing air through the plenum chamber formed between two ceilings, and also by adopting a twin cross-flow system (see paragraph 6.2.1). The air is conditioned to the required temperature and humidity values (see paragraph 7.1) by adopting recognised air-conditioning principles and by the integration of an appropriate air-conditioning plant.

8.1   Fans

Fans are usually of the electrically-operated type designed to deliver a constant airflow rate through the clean room as the filter pressure drop increases. They should be mounted external to the ducting, where possible, to avoid heat loading of the air

and introduction of further contamination. Care should also be taken to avoid contamination of the atmosphere by gaseous effluents.

8.2 **Ducting**

Ducting is manufactured from materials which are non-flaking and corrosion-resistant, stainless-steel and aluminium being commonly used, or should normally be treated to prevent the introduction of contaminants from the duct.

8.3 **Filtration System**

Filtration of airborne contaminant particles is selected on the basis of cleanliness level required and, generally, a system is made up of two principal stages: pre-filter stage and final filter stage. Pre-filtering is carried out at the inlet to the air handling system and at one or more points upstream of the clean room, and final filtering directly at the inlet to the clean room. The filters are specifically designed for clean room systems and are graded at each stage, thus providing control of diminishing size particles. Filtering action depends on the particles contacting and adhering to the fibres or collecting surface of the filter medium which is made from such materials as glass-fibre and asbestos. The filters utilised for final filtering are variously known as super-inception, absolute or high-efficiency particulate air (HEPA) filters and may be used as individual units or assembled to form a filter bank or module. In the latter case, each unit is connected to a common plenum chamber incorporating its own fan. The number of individual units in a bank is governed by design requirements for the air handling system.

9 Layout of Clean Rooms

The layout of a clean room is governed by many factors arising principally from the manufacturing processes and test procedures to be carried out on specific types of equipment. As a result there are a variety of design and layout specifications to meet the requirements of individual manufacturers and operators of equipment. In their basic form, however, layouts are directly related to the accepted methods of air distribution, i.e. unidirectional-flow and conventional.

9.1 **Unidirectional Clean Rooms**

The layout of a typical clean room facility is illustrated in Figure 4. The area devoted to the facility is arranged in accordance with the operating practices common to all clean rooms, i.e. components and personnel flow progressively from an uncontrolled or 'dirty' environment to one in which the desired level of cleanliness is maintained.

9.1.1 **Personnel Cleaning**

Entrance to the clean room is via a change room the purpose of which is to decontaminate personnel without introducing removed contaminant particles into the clean room. A change room is divided into three distinct areas; an uncontrolled or 'dirty' area, a wash-up (semi-contaminated) area and a change (uncontaminated) area. These areas are arranged so that personnel must follow a definite path for entry into the clean room.

a) In the uncontrolled area lockers are provided for housing outdoor clothing such as overcoats and raincoats, and also shoe cleaning machines. From the uncontrolled area, entry to the wash-up area is made via an air shower compartment, the purpose of which is to remove gross contaminant particles from personnel. The size of the compartment may be large enough to accommodate only one person or a group of persons depending on the number that must enter the clean room in a given length of time. The design of the air shower may vary but, in general, it

consists of an air inlet system and an exhaust system operated by independent fans. Air flows through the compartment from air inlet nozzles or louvres mounted in the ceiling or in one wall of the compartment. The entrance and exit doors of the compartment are interlocked so that only one of them can be opened at a time. The closing of the entrance door starts the fan and, until the cleaning cycle is completed, the exit door remains locked. The cycle may, in some cases, be interrupted by a safety override system in the event of an emergency. Air velocities are sufficiently high to cause 'flapping' of clothing but without discomfort to personnel.

b) On leaving the air shower, personnel proceed to the change area via the semi-contaminated area in which washing and toilet facilities are located. These facilities include foot-controlled washstands, liquid-soap dispensing units and heated air hand-drying machines to prevent contamination from towelling. A section of the change area is provided for changing into special clean room garments (see paragraph 12) stored in racks or lockers. The entrance to this section is guarded with a tacky or sticky mat designed to remove residual contaminant particles from the undersurfaces of shoes. Entrance to the clean room after changing is made via another air shower compartment.
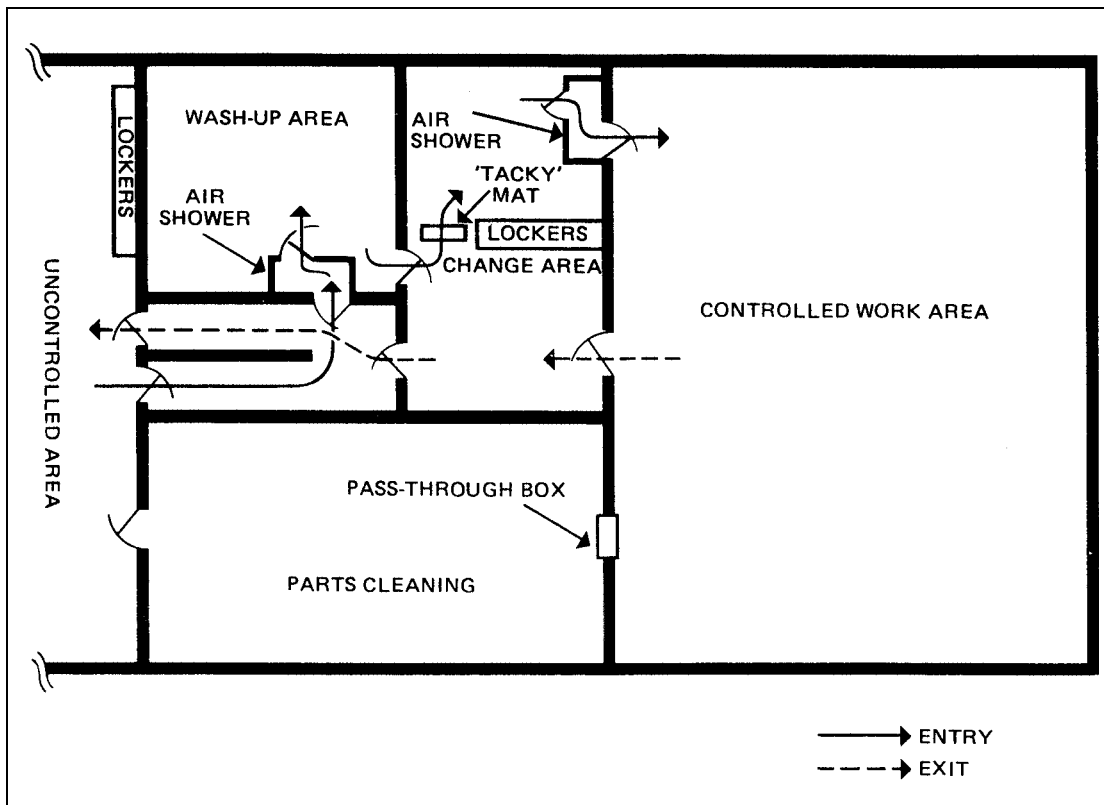
Figure 4   Layout of a Unidirectional Clean Room

9.1.2   **Parts Cleaning**

Prior to entry into a clean room, all parts, tools, equipment, and material must also be decontaminated and it is therefore necessary to provide an additional area adjacent to the clean room. The layout of a parts cleaning room depends largely on the types of component and the number of work processes involved. Similarly, the cleaning methods adopted depend on the type of contaminant, the materials used in the manufacture of components, and the level of cleanliness required. In general, the

room is equipped with the required number of work tables, specialised equipment, cleaning machines and washing facilities for personnel.

a) The transfer of cleaned components to the clean room is effected by means of a 'pass-through' box forming an air lock in the wall dividing the appropriate areas. Boxes are provided with double windows and doors; an interlock system ensures that only one door can be opened at a time. In some clean room facilities a 'pass-through' box may be of the circular type with a single opening so that the box must be rotated through 180º to insert or remove a component. Since the boxes are designed to prevent a direct opening between rooms, a means of verbal communication between relevant personnel must be provided adjacent to the box. This can be an intercommunication system, a voice diaphragm, or a speaking tube.

9.1.3   **Additional Support Rooms**

Since unidirectional clean rooms require more rigid control to prevent contamination entering, it is usual to make provision for additional support rooms such as offices, lunch rooms, rest rooms, etc. The manufacture of these rooms follows a similar pattern to that of a clean room (see paragraph 10) although the air handling system is usually not so elaborate.

9.2   **Conventional Clean Rooms**

The use of conventional flow clean rooms eliminates the necessity for support areas such as air showers and special changing rooms and, as may be seen from the typical conventional layout illustrated in Figure 5, increased working area is available and entry procedures are much simpler. The main entrance is situated at the air outlet or 'dirty' end of the room and personnel can pass through this directly from a locker room and change area. Work benches and equipment are disposed so that the cleanest operations are carried out closest to the filter bank forming the end wall, while dirty operations such as soldering, cleaning, etc., are performed toward the outlet end of the room. Parts cleaning and preparation may be performed in a manner similar to that adopted for a unidirectional clean room (see paragraph 9.1.2) or carried out in a parts cleaning room situated within the clean room itself.

10   Manufacture of Clean Rooms

The manufacture of clean rooms involves the application of specifically developed building techniques, air-conditioning installation practices and careful selection of manufacture materials. This is normally undertaken by a specialist organisation working to the detailed BS 5295 Parts 1, 2 and 3 and the specification of a user organisation. The details given in the following paragraphs are therefore intended as a guide to the factors related to general constructional features.

10.1   **Noise and Vibration**

Careful consideration must be given to clean room location in relation to other work areas and the effects of noise and localised ground vibrations. Noise and vibration generated by equipment, machinery, support and administrative areas must also be considered. If vibration insulation devices are to be employed these must not generate or collect dust. Special attention must be given to the framing system of super-structures in order to prevent vibration transmission through ceilings, walls and floors into the main structure. The maximum noise level of the room, work station or clean air device, in an operational but unmanned state should not normally exceed 65 dB.

10.2 **Floors**

Floors should have long life and be highly resistant to breakdown under the shear forces created when personnel walk across them. Vinyl is particularly suitable for floors since it is tough and resilient. Floors should have a smooth surface which is easy to clean and will not collect dust. The junction between floors and walls should be radiused to facilitate cleaning operations. Joints between floor sections should be tight and sealed.
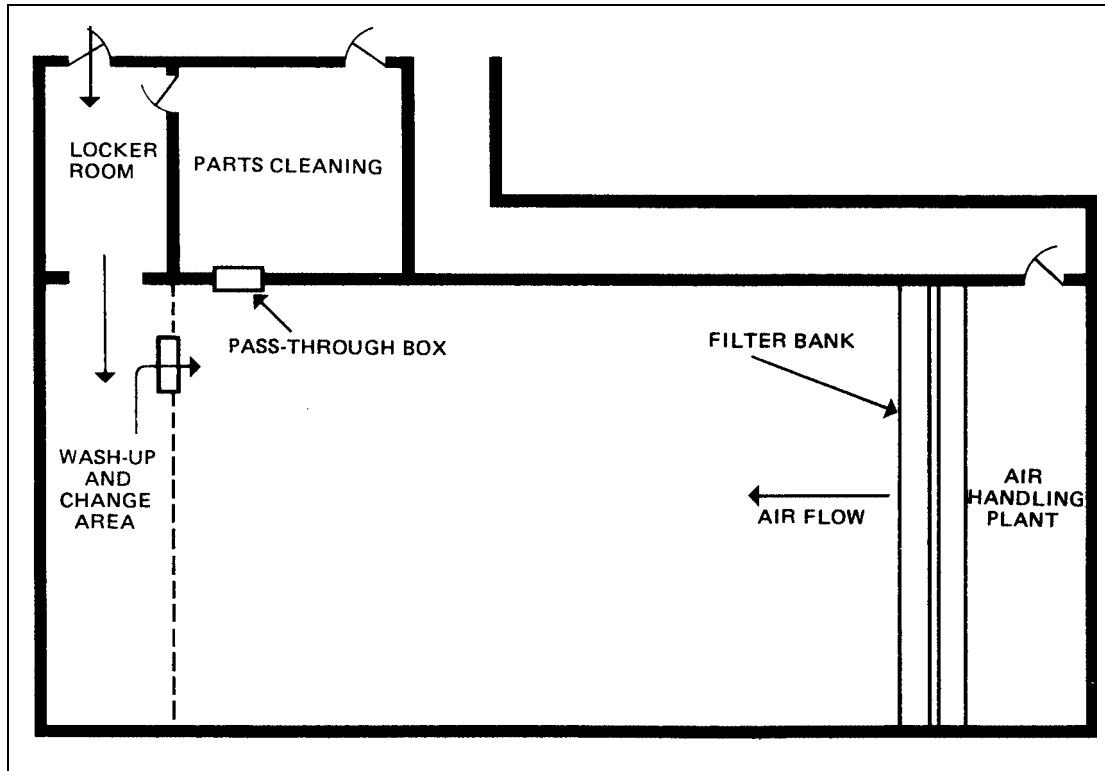
Figure 5   Layout of a Typical Conventional Clean Room

10.3 **Walls**

Walls should be covered with materials which will produce a smooth, durable surface which does not chip or flake. Stainless steel, vinyl coating, high-gloss paint, melamine decorative laminate, painted hardboard and tiles are some of the materials which are suitable. Window frames, doors and door frames may be manufactured of steel, aluminium or other highly durable material, and should be set flush with the interior of the walls. The use of timber in structural elements is discouraged because it is unstable in areas where there is a change in humidity. The introduction of large volumes of console type equipment can increase the heat load of a clean room and provide possible collection and sources of contamination. Such equipment may be built into a wall thus placing the heat load outside the room and also permitting maintenance of the equipment without the necessity of entering the clean room. Gaskets should be fitted around the equipment to prevent excess loss of room air.

10.4 **Ceilings**

Since ceilings are not subjected to potential impact, they may be surfaced with any material that is easily cleaned and does not produce or collect dust. Ceiling panels should be provided with gaskets and clamped to ensure adequate sealing, allowance being made for subsequent removal and replacement.

10.5 **Lighting**

Lighting fixtures of the fluorescent type should be used and of ratings which will provide adequate light intensity at bench level of not less than 3,000 lux. Fixtures may be installed to permit servicing from within the clean room, or supported in tracks above the ceiling so that they can be slid out for servicing without entering the clean room.

10.6 **Utilities**

The distribution of utilities such as water, electrical power, vacuum and compressed air supplies must be properly planned to ensure that all required work locations are served without interference with room air distribution and work flow.

11   Clean Room Furnishings

Furnishings such as work benches, chairs and containers for component parts require careful selection, design and choice of materials for their manufacture. The main structure of work benches and chairs should be of metal and designed in such a way that contaminant particles cannot accumulate. Items that can expect to be bumped, knocked, abraded, etc., by personnel should possess a tough, resilient, low-particle generating surface such as stainless steel, melamine decorative laminate type material, or material of equivalent surface qualities.

12   Clean Room Garments

Clean room products can be readily contaminated by particles from clothing and it is therefore necessary to make provision for the wearing of protective garments. These take the form of smocks, overalls, caps and hoods. In addition, 'boottee' type shoe covers, separate clean room shoes and gloves must also be provided. The extent to which all the garments are used depends on the type of clean room, class of cleanliness to be achieved and the work processes carried out.

12.1 **Design**

The garments are of special design to prevent the transfer of contaminant particles from personnel and at the same time to provide the maximum of comfort. The materials from which they are fabricated are usually selected from the range of available man-made fibres which exhibit such properties as non-flammability, limited linting, and negligible electrostatic generation. These materials are available under a variety of trade names. Typical design requirements for clean room garments are given in the following paragraphs.

12.1.1 **Smocks**

Smocks should be of simple design, with no pockets and with as few seams as possible. Seams should leave no open end of material which might become frayed and give off lint or loose strands. In addition, seams should be double-stitched with thread of the same fibre as the garment. Adjustable neck bands and cuffs should be provided in preference to collars and loose sleeves and must provide a snug fit when worn.

12.1.2 **Overalls**

Overalls should have a full-length zip fastener with flap front and be provided with adjustable neck bands and cuffs. If overalls are to be used with shoe covers, the overalls should fit inside the covers. Overalls to be used with clean room shoes

should be designed so that the legs of the overalls meet and slightly overlap the shoes.

12.1.3 Caps

These should be of the style worn in hospital operating rooms. They should fit snugly around the head, covering the hair to prevent hair particles and dandruff falling into the clean room area.

12.1.4 Hoods

Hoods should be designed to confine all hair under them to eliminate contamination by hair particles and dandruff, and to fit snugly inside overalls to provide complete coverage of personnel; if beards are permitted, masks must also be provided.

NOTE: Garments are usually white although in some cases a sea green colour may be chosen to minimise glare. As a means of identifying selected personnel, e.g. supervisors or personnel in charge of certain work processes, smocks and overalls may be provided with distinctively coloured neckbands. Coloured caps may also be used as a means of identification.

12.1.5 Shoe Covers and Shoes

Covers should be worn over normal shoes and should be high enough to hold the legs of overalls. Covers should have a reinforced sole and be of a type which will prevent personnel from slipping and falling on smooth floors and, for reasons of durability and economy, nylon is recommended as the material. To provide proper fit and comfort, and to achieve optimum cleanliness, covers should be provided with snap fasteners, and laces which can be tied around the legs and above the ankles. As an alternative to shoe covers, shoes can be issued to personnel for exclusive wear in the clean room. They should be simply designed, comfortable, washable and fabricated from materials which will not shed particles due to abrasion and wear.

12.1.6 Gloves

Where there is a risk of contamination from contact with the hands or fingers, gloves or finger stalls must be used. Such coverings should be comfortable and should enable the user to maintain a delicate finger touch. If the use of plastics is necessary for the 'touch' portion of gloves the remainder should be made of a material that will allow 'breathing' thus preventing overheating of the hands.

12.2 Garment Storage and Cleaning

When not in use, clean room garments should not be allowed to come into contact with any possible contaminant. They should always be stored on individual hangers in the lockers provided in changing rooms. Three sets of garments per person should normally be provided: one set in use, one set being cleaned, and one set in reserve.

12.2.1 Cleaning of garments is a specialised technique based on conventional laundering and dry-cleaning processes. Ideally, a laundry should be established as a specialised unit supporting clean room operations and functioning under similar conditions of decontamination as a clean room. A typical unit is divided into three distinct areas: soiled garment receiving area, washing and dry-cleaning area, and an inspection and packaging area. Soiled garments are placed in polythene bags and transferred to the receiving area through an air lock. The garments are then emptied into specially built tubs and transported to the washing and dry-cleaning area equipped with the appropriate machines. After cleaning and drying, the garments are transferred to the third area for inspection, sampling of contamination level, and packaging and sealing in polythene bags.

13   Clean Work Stations

These stations are work benches specifically designed to incorporate their own filtered air supply system. They may be utilised in a clean room, in addition to benches or tables based on conventional patterns, or in an uncontrolled environment.

13.1   The design of work stations has been developed from bench-mounted 'dust-free' cabinets, typical examples of which are illustrated in Figure 6. Although these cabinets provide low contamination levels, depending on the type of filter, the problem of contamination while operations are performed inside arises. Contaminants move about in turbulent air and find their way out of the cabinet only at random intervals. Another design, commonly referred to as a 'glove box' is also illustrated in Figure 6. It utilises a recirculating air system and although it produces lower contamination levels than other forms of cabinet, it has the disadvantage of requiring an operator to work through arm ports and the attached gloves.
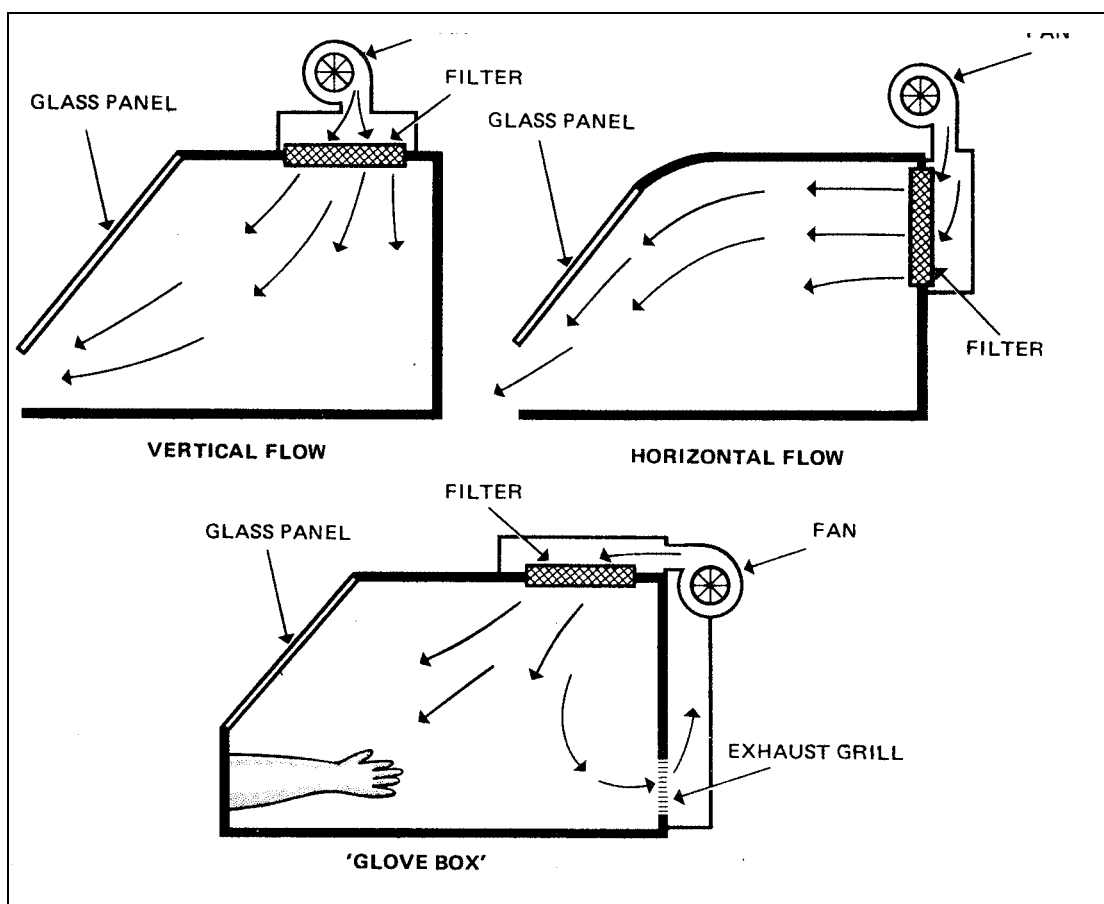
Figure 6   Clean Work Boxes

13.2   Work stations overcome the deficiencies of 'dust-free' cabinets by incorporating an air distribution system which operates on principles similar to those employed in a undirectional-flow clean room (see also paragraph 6.2). The air distribution system consists of a fan and a pre-filter mounted below the work surface, and an outlet with a super-interception filter, mounted so as to produce either a horizontal flow or a vertical flow over the work surface. Figure 7 illustrates both airflow techniques as they are applied to a typical console type of work station. Glass panels form the sides of the work area which, on account of the undirectional-flow technique, is open at the front thus permitting unrestricted movement at the work surface. Illumination of the

work area is provided by lighting units enclosed in the canopy above the work surface. Individual switches for lighting units and fans are located at convenient points as also are the controls for the various services required for relevant work processes.
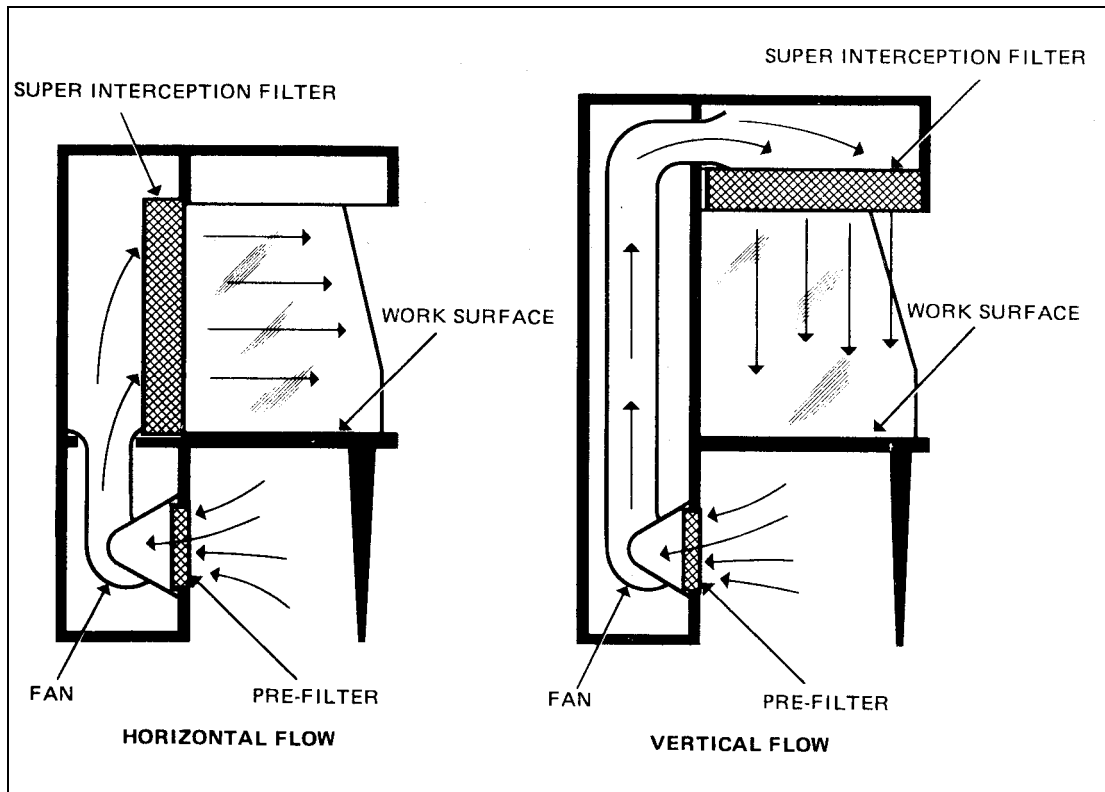
Figure 7   Clean Work Stations

13.3   The selection of a work station best suited to a specific application involves such factors as type of airflow, size of work area, space available, and design and performance of the air distribution system. Units employing horizontal flow are generally less costly than vertical flow units for equal size of work area and can usually be provided with lower overall heights thus making them more suitable when vertical space is a critical factor. When work processes require the exhausting of fumes from the work area, or when recirculation of the air is required, vertical flow units provide for these functions more easily than horizontal flow units. Horizontal flow units, on the other hand, provide better 'clean-up' of a work area than vertical flow units of equal size.

13.4   The most important consideration in selecting a particular size of work station is to ensure that it will provide undirectional-flow over a work area of sufficient width, depth and height to accommodate the component being assembled or tested, and the necessary associated equipment. If several items of equipment must be sited around a component, a vertical flow unit tends to produce less turbulence and moves clean air in the most direct fashion from the filter to the component. The filters are of a type similar to those used in unidirectional clean rooms (see paragraph 8.3).

14   Clean Room Operation

In addition to the air handling system, the contamination level in a clean room is kept at an acceptable level by two other methods, namely limiting the contamination entering the room and limiting the contamination generated within the room. Both

these methods are controlled to a large extent by the personnel selected for clean room operations. The contamination entering the room is limited by the wearing of proper garments (see paragraph 12), personnel cleaning, parts and equipment cleaning, etc. The contamination generated is limited by restricting movement, proper work techniques, etc. It is therefore necessary to establish routines and disciplines related to personnel selection, personal hygiene, entry procedures, and control of working activities. The extent to which certain of these routines and disciplines are applicable depends on the type of clean room; for example, a undirectional-flow clean room requires more rigid control of entry and clothing procedures than a conventional clean room due to the air handling system used (see paragraphs 9.1 and 9.2).

14.1   Personnel Selection

The selection of personnel for clean room duties involves consideration of both physical and human factors, including manual dexterity, visual acuity, patience, concern for detail, attitude toward repetitive operations and reaction to the rigid disciplines that accompany confinement in a controlled environment. Certain physiological problems must also be considered and some examples which are detrimental to clean room operations are: allergies to synthetic fabrics; allergies to solvents used in cleaning processes; profuse nasal discharge; skin conditions that result in above normal skin shedding or flaking and dandruff; high amounts of acid found in the hands; severe nervous conditions such as itching, scratching or claustrophobia.

14.2   Personal Hygiene

The development of personal hygiene is of great importance in clean room operations, not only to limit contamination of vital components but also to maintain a healthy working environment. Personnel with colds, temporary coughing and sneezing, should be assigned to temporary jobs outside the clean room until they are sufficiently recovered. This also applies to personnel having received severe sunburn, to prevent peeling skin from contaminating a component or the surrounding area.

14.3   Entry Procedures

Clean rooms are necessarily restricted areas and entry must only be allowed to personnel assigned to them. The procedure to be adopted is governed by the type of clean room. Typical activities associated with entry procedures are as follows:

a) Removal of outdoor clothing such as overcoats and raincoats and stowage in the lockers provided in the 'dirty' or uncontrolled area.

b) Checking clothes and shoes for visible contamination such as mud, dirt, sand, etc. Removal of such contamination.

c) Washing of face and hands using foot-controlled washstands, liquid soap dispensers and air driers.

d) Passing through air showers and air locks to ensure adequate air scrubbing.

e) Walking over sticky or tacky mats.

f) Changing into the requisite clean room garments. In connection with undirectional-flow clean room operations, changing is done in the uncontaminated section of the change room adjacent to the clean room. In conventional clean rooms changing is done in an area located at the 'dirty' end of the clean room.

14.4   General Rules for Operation

The following are general rules which should be enforced to assist in the successful operation of clean rooms.

14.4.1 **Personal Activities**

a) Hands should be washed often and fingernails kept clean.

b) The specified clothing should always be worn in the approved manner.

c) Personal items such as keys, coins, cigarettes, matches, pencils, handkerchiefs and combs should be deposited in lockers prior to changing into clean room garments. Valuable items such as wallets may be carried into a clean room in jacket or trouser pockets provided they are not removed inside the clean room.

d) Foodstuff should not be taken into a clean room.

e) Smoking is strictly forbidden.

f) The wearing of jewellery such as large rings, bracelets, watches, necklaces, earrings, lockets, etc., should be avoided.

g) Nervous mannerisms such as scratching the head, rubbing of hands or similar actions should be avoided.

h) Movement of personnel should be restricted as much as possible to prevent stirring settled particles on the clean room floor. This applies particularly to conventional clean rooms.

i) Solvent contact with hands should be avoided as many solvents remove natural skin oils causing excessive skin 'peeling' or flaking.

j) Female personnel should not wear or apply fingernail polish or cosmetics in a clean room.

k) Visitors or clean room maintenance personnel must be authorised to enter a clean room and must follow the specified entry procedures.

14.4.2 **Work Activities**

a) All tools including personal tool kits should be kept clean and in good condition and should undergo cleaning processes in accordance with a periodic cleaning schedule. Tools not essential to specific work processes should be excluded from tool kits.

b) Paper materials should not be allowed in a clean room unless the paper is plastic-coated or covered, sprayed to prevent linting or is a special limited-linting paper. Papers should not be subjected to excessive shuffling, handling, rolling or bending as they can generate excessive amounts of small particles under these conditions.

c) Pencils and erasers are not allowed. All writing should be with ball-point pens.

d) Parts of components should be kept in their individual containers until ready for assembly. They should not be left exposed on a work bench or station.

e) Containers and any component parts surplus to requirements should always be returned to a parts cleaning area for cleaning and re-issue.

f) Metal objects such as wire clippings and solder splashes should be deposited in waste boxes at the end of each process.

g) Where cleaning of parts is to be carried out inside a clean room, the type of cleaning equipment and its location within the room should be carefully selected.

15   Maintenance of Clean Rooms

In order to maintain clean rooms to the necessary standards, good housekeeping practices and monitoring of the air handling system are of prime importance. The frequency of cleaning is usually determined by taking into account the change in contamination level that can occur due to the cleaning operation, and the number of air changes per hour. Monitoring of the air handling system should be carried out at the time a clean room is put into initial operation and at regular periods thereafter, when filters have been changed, and when it is evident that down-grading of its operating level is taking place (see Table 3).

Table 3

Controlled Environment	Sampling for Particulate Contamination	Temperature	Humidity	Air Pressure
Class 1	Daily or continuous by automatic equipment	Continuous	Continuous	Continuous
Class 2	Weekly	Continuous	Continuous	Continuous
Class 3	Monthly	4-hourly	4-hourly	Continuous
Class 4	3-monthly	12-hourly	12-hourly	Continuous
Contained Work Station	Daily or to suit the product or as Class 2	Dependent on use		Not applicable
Controlled Area	Dependent on use	To meet requirements of personnel and product		Not applicable

15.1   **Cleaning**

Rooms should be cleaned when no work processes are being performed. Minor dry floor and bench vacuuming can be done, if necessary, during normal room operation if the equipment and procedures used ensure a minimum of disturbance to settled particles.

15.1.1 Cellulose mops and sponges can be used with water which meets specific particle-count requirements. High-grade plastics buckets which are not subject to flaking should be used. If ladders are required, they should preferably be of the anodised aluminium type. The use of detergents should be restricted to those which produce the minimum amount of residue after drying. For vacuum cleaning, a central vacuum cleaning system or a specially designed portable vacuum cleaner should be employed.

15.1.2 Cleaning apparatus and utensils are prevalent sources of contamination and their movement in and out of clean rooms should be carefully scheduled. They should be thoroughly cleaned and vacuumed prior to their entry.

15.1.3 The responsibility for cleaning work benches or stations should be delegated to personnel assigned to the benches to prevent improper handling of components and equipment by room maintenance personnel.

15.1.4 Inspection, maintenance and testing of air handling system components should be carried out in accordance with the relevant maintenance instructions, at periods determined by the type of clean room operations, and when downgrading of the contamination level begins to occur.

15.2 Monitoring of Clean Rooms

Monitoring refers to the procedures adopted for checking the factors influencing clean room environment. Such factors are the level of contamination, temperature, humidity and pressure. The exact requirements for monitoring and methods to be employed depend on the type of clean room and classification of cleanliness level, and are therefore determined on an individual basis (see Table 3).

15.2.1 Contamination Monitoring

This is the most difficult monitoring problem of clean room operation owing to the variations in contamination level throughout a room and also to the many factors which must be considered in selecting a specific monitoring technique. Some of the factors causing variations in contamination level are: filtered air entering a room at one or more locations; contamination being generated in various amounts throughout a room; contaminated air exhausted from a room at one or more locations. The highest level of contamination is not necessarily at the air exhaust locations, since air from a highly contaminated area may be diluted with filtered air prior to its being exhausted. Higher and lower levels of contamination can thus readily exist within a given room. The areas of most concern are those immediately surrounding the component on which work processes are to be carried out.

a) The locations within a clean room at which sampling of the air is to be taken should be carefully considered in order to obtain a representative contamination level. Samples should be taken at identical times or as near as possible, since contamination levels of areas vary at different periods.

b) Various techniques may be applied to contamination monitoring and some of those most widely accepted, together with details of principles, are listed in BS 5295 Parts 1, 2 and 3.

15.2.2 Humidity Monitoring

This may be achieved by the use of conventional wet and dry bulb thermometers and psychrometric charts. The thermometers may be supplemented, if necessary, by automatic recording devices. Humidity can become troublesome if it is allowed to reach a level where static charges are generated by personnel or where corrosion may be a problem. In general, a humidity level of not less than 40% is desired. For those components where humidity tolerance is critical, special control measures should be employed.

15.2.3 Pressure Monitoring

A clean room should always be slightly pressurised and it is therefore necessary to monitor the pressure difference between the room and its outside surroundings. Monitoring may be achieved by a simple U-tube manometer, or a differential pressure gauge calibrated in mm water gauge.

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Leaflet 2-3   Timber Conversion – Spruce

1   Introduction

1.1   A good basic knowledge combined with many years' experience in the handling of timber is essential for the accurate assessment of the characteristics and defects which make it either suitable or unsuitable for aircraft parts.

1.2   This Leaflet is not intended to give guidance on how to select timber; it outlines the CAA's recommended method of converting it into aircraft parts and mentions common defects which may be encountered during conversion.

2   Seasoning

2.1   Timber which has been cut from selected trees is stacked, prior to shipment, for approximately 60 days. During this time, the timber loses much of its free moisture and it is in this condition that it should be transported.

2.2   Timber is usually seasoned in air-drying sheds for periods ranging from one to three years, or longer. If it is required for immediate use, it may be artificially seasoned (i.e. kiln-dried).

2.3   The process of seasoning reduces the moisture content of timber to a point where it is in equilibrium with the surrounding atmosphere and enables protective treatments to be applied more effectively.

3   Characteristics

After the timber has been properly seasoned, samples should be cut and tested to determine its suitability for use on aircraft. Before taking the samples from a plank of timber, approximately 6 inches should be cut from the end and discarded as this piece may be drier than the remainder.

3.1   **Moisture-Content**

The moisture-content of the sample should be determined by weighing it and then drying it in an oven at a temperature of 100° to 105°C (212° to 221°F) until two successive weighings yield the same result. Care should be taken to ensure that when the sample is split up, no material is lost and that the weighing is done promptly so as to avoid false results. The moisture-content should be calculated from the following formula:

$$\frac{W_1 - W_2}{W_2} \times 100$$

where W_1 = the weight of the sample prior to drying

and W_2 = the weight of the sample after drying.

3.2   A quicker method of determining the moisture-content of timber is by the use of the Marconi Moisture Meter. This instrument will record the moisture-content in a few seconds, whereas the method of weighing, drying and calculating takes much longer. The meter should however, be checked periodically to ascertain that it remains accurate. For general guidance, the correct moisture-content should be 15% with a tolerance of ± 2%.

3.3   **Density**

The density should be determined by weighing and measuring the volume of a sample cut from the plank. A practical method of calculating the density in imperial units is to cut the sample 96 mm (3.8 inches) long, by 25 mm (1 inch) square, and determine its weight in grammes. The figure for the weight of the sample in grammes is equal to the figure for the density in pounds per cubic foot. The weight of spruce generally varies between 320 kg and 577 kg per cubic metre (20 lb. and 36 lb. per cubic foot). For Grade A spruce, the density should not be less than 384.45 kg per cubic metre (24 lb. per cubic foot) when the moisture-content is 15%.

3.4   **Brittleness**

3.4.1   A notched test piece, the sides of which are cut radially and tangentially, of the dimensions 133 mm (5¼ inches) long by 22 mm (⅞ inch) square, should be broken in an impact test machine of the Izod type, the blow being applied tangentially; the test piece should absorb not less than 6.78 Joules (5 foot-pounds). Care should be taken that the blow is applied in the right direction, for if broken the opposite way a false reading will be obtained. A tolerance of 0.68 Joules (0·5 foot-pounds) is generally allowed, provided the fracture shows a satisfactory amount of fibre.

3.4.2   The weight-dropping machine provides an alternative method of testing timber for brittleness. A plain test piece, 305 mm (12 inches) long by 25 mm (1 inch) square, should be cut radially and tangentially, and parallel to the grain. When placed in the testing machine, the test piece should withstand one blow of 17.63 Joules (13 foot-pounds) without showing signs of tension failure on the vertical sides. Where doubt exists, a further blow of 8.81 Joules (6.5 foot-pounds) may be applied and there should be no sign of failure. The opening out of a few fibres should not be interpreted as a failure.

3.5   **Splitting Test**

The object of this test is to determine the inclination of the grain. The sample should be split with a very blunt chisel so that the wood will be split and not cut. The split surfaces give the true direction of the grain. The split should be made some distance from the edge of the sample, otherwise a misleading result may be obtained.

3.6   **Rate of Growth**

The number of annular rings per 25 mm (1 inch) varies to some extent. Timber with a rate of growth of less than 6 rings per 25 mm (1 inch) should be rejected.

3.7   **Recording of Tests**

The results of the above-mentioned tests should be recorded and related to the plank of timber to which they refer. The actual test pieces should also be kept for a period of not less than 2 years.

4   Conversion

After the bulk timber has been tested and graded, it may be converted into structural members for use on aircraft. This conversion should be done with every possible care, for much depends on the way in which timber is sawn.

4.1   Rift-Sawing

The process of cutting timber along the radius of the annular rings is known as rift-sawing. An illustration of this is given in Figure 1. Rift-sawing and near-quarter-sawing are very much the same.
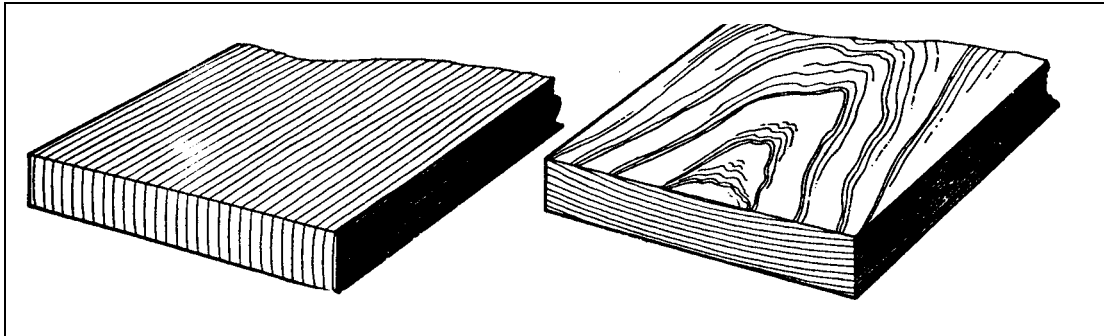
Figure 1   Figure 2

4.2   Tangential-Sawing

The process of cutting at a tangent to the annular rings is known as tangential-sawing. An illustration of this is given in Figure 2. Tangential-sawing (slashing) produces what is commonly known as a 'flower-face'.

4.3   General

4.3.1   Before a piece of bulk timber is converted, the end section of the plank should be noted, particularly the direction of the annular rings. It will be seen from this whether the plank is tangential-sawn, rift-sawn or quarter-sawn.

4.3.2   The actual method of converting timber is best described by the use of an example as follows. Assuming that spar members of a rough finished size of 102 mm (4 inches) by 51 mm (2 inches) are required and a 102 mm (4 inch) rift-sawn plank of timber is available, it should be cut tangentially to give a size of 102 mm (4 inches) by 102 mm (4 inches), after which a radial cut will give rift-sawn pieces 102 mm (4 inches) by 51 mm (2 inches) (allowance should, of course, be made for the saw-cut). The main advantage of rift-sawn timber is that it shrinks chiefly in one direction only, and does not warp very much.

5   Defects

After timber has been converted it should be examined for defects. Some of the more common defects are outlined in the following paragraphs.

5.1   Dote Disease

This is the worst of all defects and does much damage to the wood. It is an inherent disease which only occurs at the base of the living tree. When the tree is felled it is cut at a point ten feet or more above the ground as a precaution against the possibility of dote. Converted pieces of timber should be examined not only on the sides but also

on the ends; dote will be recognised by the presence of brownish yellow patches, somewhat similar to thin mineral oil spots. Dote is contagious and any infected wood should be burnt.

5.2   **Decay or Rot**

A defect similar to dote disease can develop after a tree has been felled if the timber is exposed to excessive soaking and partial drying. Dry-rot fungus requires a certain amount of moisture to thrive on but once the disease is established it thrives on the moisture already in the wood. The decayed wood is brown in colour and appears as though it had been charred; the timber is rendered soft and dry, and will flake off easily.

5.3   **Incorrect Grain Inclination**

The limit of grain inclination for spruce is 1 in 15 for grade A, and 1 in 12 for grade B. The inclination should be checked to ensure that the above limits are not exceeded. The most usual method of determining the inclination of the grain is by examining the flower-face of the timber to find the resin ducts. It will readily be seen whether they are straight or inclined. If the inclination exceeds the limits specified, the timber should be classified in a lower grade.

5.4   **Heart-Shake**

This defect usually follows the course of a sap duct longitudinally, and is usually visible on the tangential surface. The use of a small size feeler gauge will assist in finding the depth of the shake. The defect should be cut out of the timber.

5.5   **Ring-Shake**

This defect is indicated by a parting of the annular rings. Ring-shakes are usually caused by frost, particularly after a heavy rainfall. The defect should also be cut out of the timber.

5.6   **Compression-Shake**

This defect appears on a cross-section and usually takes the form of a thin wavy line. Compression-shakes are most dangerous as they are a partial fracture of the timber and any future loads may cause the fracture to be completed.

5.7   **Knots**

There are several kinds of knots which may be encountered when examining converted timber; these are the dead-knot, the bud-knot and the pin-knot. The presence of any of these knots can have a detrimental effect. Generally they should not be more than a quarter of an inch in diameter but no hard and fast rules can be specified; each case must be decided on its merits. Timber with 'clusters' of pin-knots in it should be rejected.

5.8   **Pitch Holes**

There are two kinds of pitch holes, one being the horizontal type which usually appears at the base of a knot, and the other the vertical type which is sometimes referred to as a gum pocket. Gum pockets may either be 'alive' (the gum-seam has not dried out) or 'dead', and in the case of the latter, the timber should be rejected. Tests on 'live' gum pockets have shown that the timber in the region of the gum pocket usually gives a better result than the remainder of the timber.

5.9   **Blue Stain**

This defect only occurs in sapwood which should not be used in aircraft parts.

Leaflet 2-4   Synthetic Resin Adhesives

1   Introduction

This Leaflet provides guidance and advice on the gluing of wooden structures and on the adhesives which can be used for this purpose.

1.1   Synthetic resin adhesives are used extensively for joints in wooden structures to avoid the localised stresses and strains which may be set up by the use of mechanical methods of attachment; the strength of such structures depends largely on the effectiveness of the glued joints and cannot be verified by means other than the destruction of the joints. Acceptance has therefore, to be governed by adequate inspection at various stages throughout the gluing process and by assessment of the results obtained from representative test pieces (see paragraph 9).

1.2   Synthetic resin adhesives used for gluing aircraft structural assemblies must comply with the requirements prescribed in an acceptable Specification, usually British Standard 1204 Part I, for Weather and Boil Proof (WBP) or Moisture Resistant (MR) adhesives.

1.3   Information on the inspection of glued joints for evidence of deterioration under service conditions is given in Leaflet 6–1.

1.4   The terminology used in this Leaflet is that given in BS 1204, entitled 'Synthetic Resin (Phenolic and Aminoplastic) Adhesives for Constructional Work in Wood'. For those not familiar with the terminology, a glossary of terms not explained in the text, is given in paragraph 13.

2   General

Synthetic resin adhesives (see paragraph 13.12) usually consist of two separate parts, i.e. the resin and the hardener. The resin develops its adhesive properties only as a result of a chemical reaction between it and the hardener, and will not harden without it. With some adhesives, an inert filler may be added to increase viscosity and to improve gap-filling properties.

3   Preparation of Adhesives

Synthetic resins (see paragraph 13.11) can be obtained in either liquid or powder form. In general, powder resins have the longer storage life, since they are less susceptible to deterioration which can result from high ambient temperatures.

3.1   Powder Resins

Powder resins should be mixed with water in accordance with the manufacturer's instructions before they can be used in conjunction with a hardener and to obtain satisfactory results it is essential that they should be properly mixed. Once mixed, the resin should not be diluted unless this is specifically permitted by the manufacturer.

3.2   Liquid Resins

When resins are supplied in liquid form, they are ready for immediate use in conjunction with the hardener. Liquid resin should not be diluted unless this is permitted by the manufacturer.

3.3 **Hardeners**

When mixing the hardener (paragraph 13.7) with the resin, the proportions should be in accordance with the manufacturer's instructions. Hardeners should not be permitted to come into contact with the resin except when the adhesive is mixed just prior to use, or, as is necessary with some adhesives, when the joint is assembled by coating one face with resin and the other with hardener. When the latter method is employed, the surface to which each is applied should be in accordance with drawing requirements (see paragraph 6).

3.4 **Mixed Adhesives**

In many instances, manufacturers specify a definite period of time which must elapse between the mixing and the application of the adhesive and during this period the adhesive should be kept covered to prevent contamination.

3.5 **Utensils**

The utensils used for hardener should not subsequently be used for resin, and vice versa. These utensils and those used for the mixed adhesive should be acid-proof and should be kept scrupulously clean. After use and before the adhesive has had time to set, they should be cleaned with warm water containing 5% sodium carbonate (washing soda).

4   Preparation of Surfaces

4.1 **Plywood Surfaces**

All areas of plywood surfaces to be glued should first be 'sanded' in order to remove surface glazing and loose fibres. Sanding should be done lightly and uniformly either in the direction of the grain or diagonally across it, using a medium grade of glasspaper; local scratching or roughening, use of too coarse a paper and undue pressure, should be avoided. The sanding should not be excessive otherwise the fit of the joint may be affected.

4.2 **Timber Surfaces**

Timber surfaces should be suitably roughened so as to form a firm key for the adhesive and a medium grade of glasspaper or a wood scraper is suitable for this purpose. To form a strong efficient joint, it is essential that the mating surfaces should be a good fit. This is particularly important in the case of blind joints, the members of which may be chalked on their gluing surfaces before being assembled dry as a check on the fit; the chalk should be completely removed before application of the adhesive.

4.3 **Moisture Content**

It is important that the parts to be joined should have approximately the same moisture content, since variations may cause stresses to be set up as a result of swelling or shrinkage and thus lead to the failure of the joint. The moisture content should, additionally, be within the specification limits for the particular timber. A safe range would be 8 to 16%, but with resorcinols this could be extended to 20% from a gluing viewpoint; however, this would not be satisfactory for aircraft components as joints would be likely to shrink after manufacture.

4.3.1 The moisture content of timber can be determined by taking a sample of the timber to be glued, weighing it, and then drying it in an oven at a temperature of 100° to 105°C (212° to 221°F) until two successive weighings yield the same result. The moisture content can be determined by the formula:

$$\frac{W_1 - W_2}{W_2} \quad \times \quad 100$$

where W_1 = the weight of the sample prior to drying

and W_2 = the weight of the sample after drying.

4.3.2   A method of determining the approximate moisture content is by the use of an electrical meter working on either the resistance or the capacitance principle. When this instrument is used, its accuracy should be checked periodically against a sample, the moisture content of which is determined by the weighing method described in paragraph 4.3.1.

4.4   **General**

The surfaces to be joined should be clean and free from grease, oil, wax, crayon, paint and varnish; it is advisable not to handle the joint faces once they have been prepared. Where old timber is to be re-used, all traces of the previous adhesive should be removed and the timber beneath cleaned; local staining of the wood by previous hardener or casein cement may be disregarded. Where any painting operations are to be carried out, all surfaces which are to be glued should be adequately masked.

5   Conditions for Gluing

Synthetic resin adhesives are very sensitive to variations in temperature and the usable (pot) life of the adhesive, choice and proportion of hardener and clamping times, all depend largely on the ambient temperature at the time of gluing; it is, therefore, important to ensure that the manufacturer's instructions regarding these factors are followed.

5.1   The timber to be glued should be allowed sufficient time to attain the temperature of the room in which the gluing is to take place; it should not be overheated or raised too quickly from a low temperature, since this affects the surfaces of the timber and reduces the efficiency of most synthetic resin adhesives. It is important, therefore, that timber should be kept clear of radiators and other sources of heat prior to gluing.

6   Application of Adhesive

With certain exceptions, adhesives are used in the mixed form and the recommendations given in this paragraph apply only to the use of such adhesives.

6.1   It is generally desirable to apply adhesive to both surfaces of a joint. This applies particularly where plywood is to be glued to a fairly robust member, where the glue line (see paragraph 13.6) is likely to be variable or when it is not possible to apply uniform pressure to the joint after gluing.

6.2   Ordinary glue spreaders are satisfactory for the application of synthetic resin adhesives, but those having slightly grooved rubber rollers give the best results. Brushes may also be used provided they are perfectly clean.

6.3   The amount of adhesive required depends largely on the type of timber and the accuracy of machining; dense timbers require less adhesive than soft or porous types. Side-grained surfaces may be satisfactorily glued with thin spreads, and while end-grain joints have virtually no structural value, generous spreads may be applied for gap

filling and sealing purposes. The general rule is that the adhesive should completely cover the surfaces to be glued and should be tacky when pressure is applied to the joint.

6.4   Difficult gluing conditions may sometimes occur when a soft timber is to be glued to one which is much denser, because the adhesive tends to flow into the more porous timber. In such instances, unless otherwise specified by the manufacturer of the adhesive, pre-coating and partial drying of the softer surface, prior to normal spreading, is recommended.

7   Assembly

Care should be taken before the adhesive is applied to ensure that the surfaces make good contact and that the joint will be correctly positioned, since once contact is made after the adhesive is applied, the joint will be below strength if further movement is necessary. The interval between the application of the adhesive and assembly of the joint under pressure should, unless otherwise permitted, be kept as short as possible. Pressure should be applied quickly and should be even. All devices used to bring the glued surfaces together should be checked (this applies particularly to clamps) to ensure that the pressure is uniformly applied over the entire area; uneven pressure may cause uneven contact and a gaping joint.

> **NOTE:**   Some adhesives contain solvents which should be allowed to evaporate before the joint is made. If this is not done, bubbles may be created and a weakness caused. For adhesives of this type the manufacturer will specify a time interval which should elapse before the joint is closed.

7.1   High clamping pressures are neither essential nor desirable provided that good contact between surfaces being joined is obtained. For parts which are flat and unstressed it is not always necessary to maintain the pressure until the full joint strength is developed, but for work which is shaped by pressure, longer times may be required to guard against opening stresses. The tightness of clamps should be checked approximately 10 minutes after assembly.

7.2   If the parts are thin and the pressure is uniformly distributed, only a slight pressure is required and small pins or screws will generally provide this; care should be taken not to pump the adhesive out of the joint when hammering pins through closing strips.

7.3   When pressure is applied, a small even quantity of glue should be expressed from the joint and this should be wiped off before it dries. The pressure should be maintained and the joint should not be disturbed during the full setting time; this is important as the adhesive will not re-unite if disturbed before it is fully set.

7.4   When large 'glue-face' areas are to be joined, e.g. when joining two ply surfaces, the drawing usually specifies the drilling of small vent holes at regular intervals to prevent air being trapped between the two surfaces. After the joint has been made, these holes should be checked to ensure that adhesive has exuded from them.

8   Setting Times and Temperatures

The setting time depends on the temperature at which the jointing operation is carried out; an increase in temperature results in a decrease in the setting time. Conversely, a decrease in temperature causes a considerable increase in the setting time and with some adhesives a temperature below 15°C (60°F) is not recommended. It is, therefore, generally advantageous to apply heat during pressing whenever possible so as to effect reasonably quick and strong adhesion. Heat may be applied by means

of an electrically or steam heated platen such as would be used for special presswork. Local warmth may be applied with electrically heated blankets, electric fires, a battery of electric bulbs, or drying kilns. The temperature may generally be raised to approximately 80°C (176°F) for very rapid setting; intense surface heating should be avoided as this may scorch the timber and cause the glue to bubble, the latter resulting in the production of a very weak joint. It must be remembered that it is the temperature of the glue line which determines cure rate and not the surface or ambient temperature. The warming of a cold assembly may cause the exuded glue to harden quickly, giving a false impression that the complete joint has cured (see also paragraph 5.1).

8.1   Full joint strength and resistance to moisture will only develop after conditioning for a period of at least 2 days, depending on the temperature and the type of hardener used. However, when repairs are made on aircraft, the joint should be of sufficient strength after one day. When it is necessary to ensure maximum resistance to moisture it is generally recommended that the assembled structures should be kept at room temperature of 21° to 24°C (70° to 75°F) for 2 to 3 weeks so that complete chemical reaction can take place.

8.2   Further assembly work can be carried out immediately the clamps have been removed provided the joint is not subjected to additional stress, otherwise the conditioning period recommended by the manufacturer is necessary. The degree of setting of the adhesive which has squeezed from the glue line is not necessarily an indication of the strength of the joint, and precautions should be taken to ensure that the joints are handled with due care until they have attained full strength.

8.3   After the joint has been conditioned and all work completed, all unprotected parts should be treated in accordance with drawing requirements.

9   Testing

Frequent tests should be made to ensure that joining techniques are satisfactory. Wherever possible, tests should be carried out on off-cuts of actual components from each batch. Where off-cuts are not available tests should be carried out on representative test pieces glued up with each batch of mixed adhesive. In addition, the glue strength of component rejected for faults other than gluing should be checked periodically.

9.1   **Test Samples**

The test samples should be cut from the timber used for the component and should not be less than 50 mm (2 in) long and 25 mm (1 in) wide with one member over-hanging the other by 12 to 18 mm (½ to ¾ in). The glued test sample should, when conditioned, be put in a vice and the joint should be broken by leverage exerted on the overhanging member. The fractured glue faces should show at least 75% of wood fibres, evenly distributed over the fractured glue surfaces. A typical broken test piece is shown in Figure 1.

9.2   **Wet Tests**

When specified, wet tests should be made for the purpose of testing the efficiency of the adhesive after immersing the test samples in water at different temperatures and for different times. Such tests are prescribed in British Standard 1204, but the results are only valid if BS 1204 test pieces are used. However, testing joints, in a manner similar to that outlined in paragraph 9.1, after immersion in cold water (15° to 25°C (60° to 77°F)) for 24 hours, will give a good indication of whether they are cured.

Such tests should only be carried out on joints which have been conditioned for 2 to 3 weeks as in paragraph 8.1.
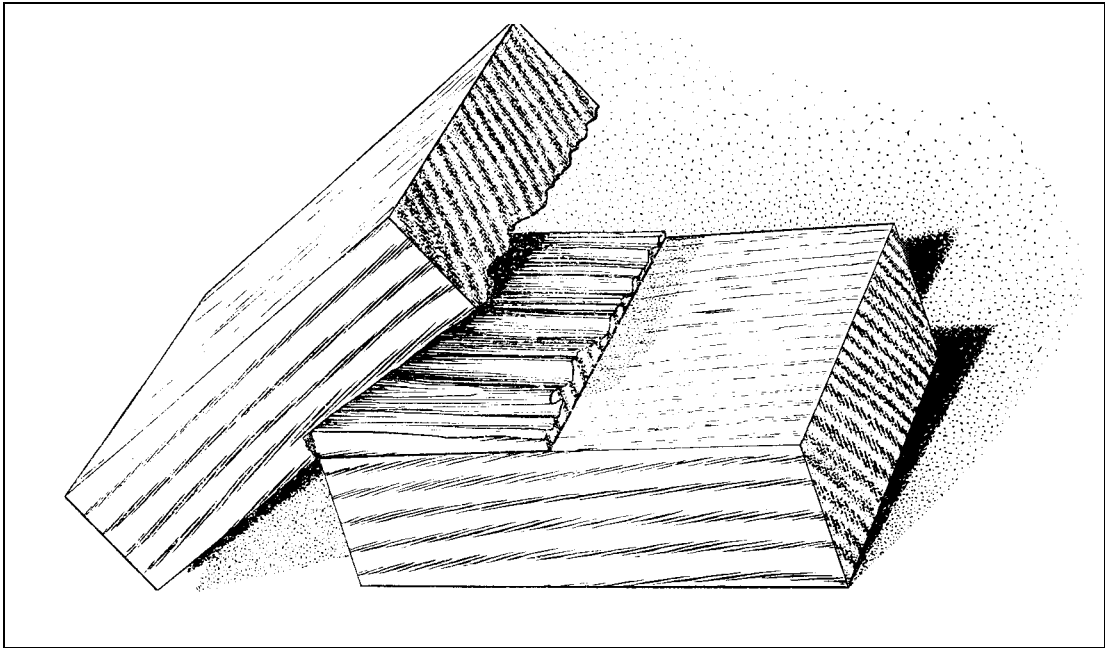

Figure 1   Broken Test Piece

10   Failure of Glued Joints

Glued joints are designed to provide their maximum strength under shear loading. If a glued joint is known to have failed in tension it is difficult to assess the quality of the joint, as these joints may often show an apparent lack of adhesion. Tension failures often appear to strip the glue from one surface leaving the bare wood; in such cases, the glue should be examined with a magnifying glass, which should reveal a fine layer of wood fibres on the glued surface, the presence of which will indicate that the joint itself was not at fault. If examination of the glue under magnification does not reveal any wood fibres but shows an imprint of the wood grain, this could be the result of either pre-cure of the glue prior to the application of pressure during the manufacture of the joint, or the use of surface-hardened timber. This latter condition is particularly common with plywood and with other timbers which have been worked by high speed machinery and have not been correctly prepared in accordance with paragraph 4.1. If the glue exhibits an irregular appearance with star-shaped patterns, this may be an indication that the pot-life of the glue had expired before the joint was made or that pressure had been incorrectly applied or maintained. In all such instances other joints in the aircraft known to have been made at the same time should be considered to be suspect.

11   Aircraft Repairs

Where repairs are to be carried out on old aircraft in which the wooden structure is joined with a casein glue, all traces of the casein should be removed from the joint, since this material is alkaline and is liable to affect the setting of a synthetic resin adhesive; local staining of the wood by the casein can however be disregarded. Where urea formaldehyde (UF) glues are to be used, the surface should be wiped with a solution of 10% w/w acetic acid in water, and allowed to dry before applying.

NOTE:　This process must only be used with urea formaldehyde (UF) glues. If used prior to the application of, for example, resorcinol formaldehyde (RF) glues, the joint strength could be seriously impaired.

12　Storage

Apart from the very limited pot-life of the mixed adhesive, the resin itself will not keep indefinitely, even under ideal storage conditions. Under no circumstances should the shelf life specified by the manufacturer be exceeded. Furthermore, resins in powder form which show signs of caking or corrosion of the container and liquid resins which show signs of 'gelling' or have become excessively viscous, should be rejected even if the shelf life has not been exceeded. During storage, a temperature of 21°C (70°F) should not be exceeded.

13　Glossary of Terms

For the benefit of those not familiar with the terms used in relation to synthetic resin adhesives and their application, a glossary is given below.

13.1　**Cold Setting Adhesive.**　An adhesive which sets and hardens satisfactorily at ordinary room temperature, i.e. 10° to 32°C (50° to 86°F), within a reasonable period.

13.2　**Close Contact Adhesive.**　A non-gap-filling adhesive suitable for use only in those joints where the surfaces to be joined can be brought into close contact by means of adequate pressure and where glue lines (see paragraph 13.6) exceeding 0·125 mm (0·005 in) in thickness can be avoided with certainty.

13.3　**Closed Assembly Time.**　The time elapsing between the assembly of the joints and the application of pressure.

13.4　**Double Spread.**　The spread of adhesive equally divided between the two surfaces to be joined.

13.5　**Gap Filling Adhesive.**　An adhesive suitable for use in those joints where the surfaces to be joined may or may not be in close or continuous contact, owing either to the impossibility of applying adequate pressure or to slight inaccuracies of machining. Unless otherwise stated by the manufacturer, such adhesives are not suitable for use where the glue line (see paragraph 13.6) exceeds 1·25 mm (0·05 in) in thickness.

13.6　**Glue Line.**　The resultant layer of adhesive effecting union between any two adjacent wood layers in the assembly.

13.7　**Hardener.**　A material used to promote the setting of the glue. It may be supplied separately in either liquid or powder form, or it may have been incorporated with the resin by the manufacturer. It is an essential part of the adhesive, the properties of which depend upon using the resin and hardener as directed.

13.8　**Open Assembly Time.**　The time elapsing between the application of the adhesive and the assembly of the joint components.

13.9　**Single Spread.**　The spread of adhesive to one surface only.

13.10　**Spread of Adhesive.**　The amount of adhesive applied in order to join two surfaces, usually expressed in g/m^2 or $lb/100\ ft^2$.

13.11　**Synthetic Resin.**　A synthetic resin (phenolic) is derived from the reaction of a phenol with an aldehyde. A synthetic resin (aminoplastic) is derived from the reaction of urea, thiourea, melamine or allied compounds with formaldehyde.

13.12   **Synthetic Resin Adhesive.**   A composition substantially consisting of a synthetic resin of either the phenolic or aminoplastic type, but including any hardening agent or modifier which may have been added by the manufacturer or which may be required to be added before use, according to manufacturer's instructions.

Leaflet 2-5   Locking and Retaining Devices

1   Introduction

The purpose of this Leaflet is to provide guidance and advice on the methods of locking screw-threaded components, and the retention or location of circular parts in various assemblies. Chapter D4–1 and JAR 25.607 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 2–13, on the assembly and inspection of critical bolted joints in Leaflet 6–7, and on stiffnuts in Leaflet 3–4.

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 as 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.
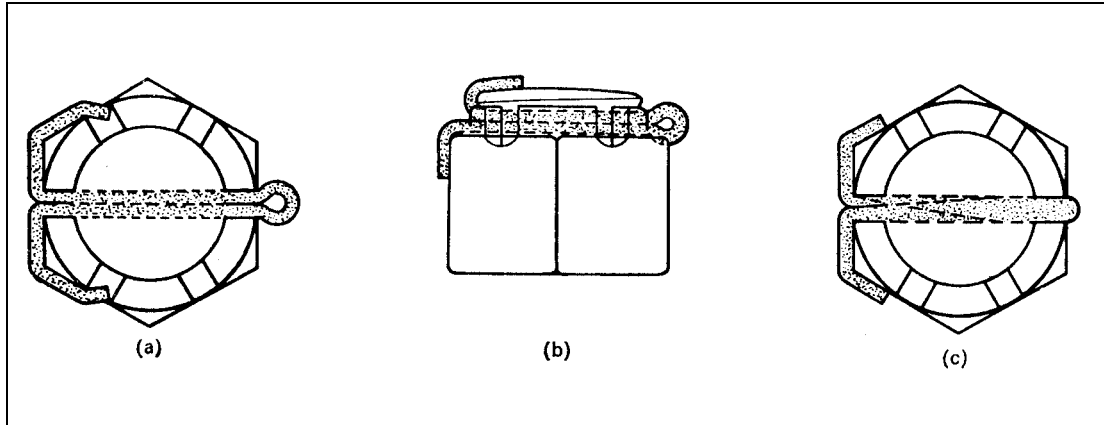
Figure 1   Split Pinning

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.
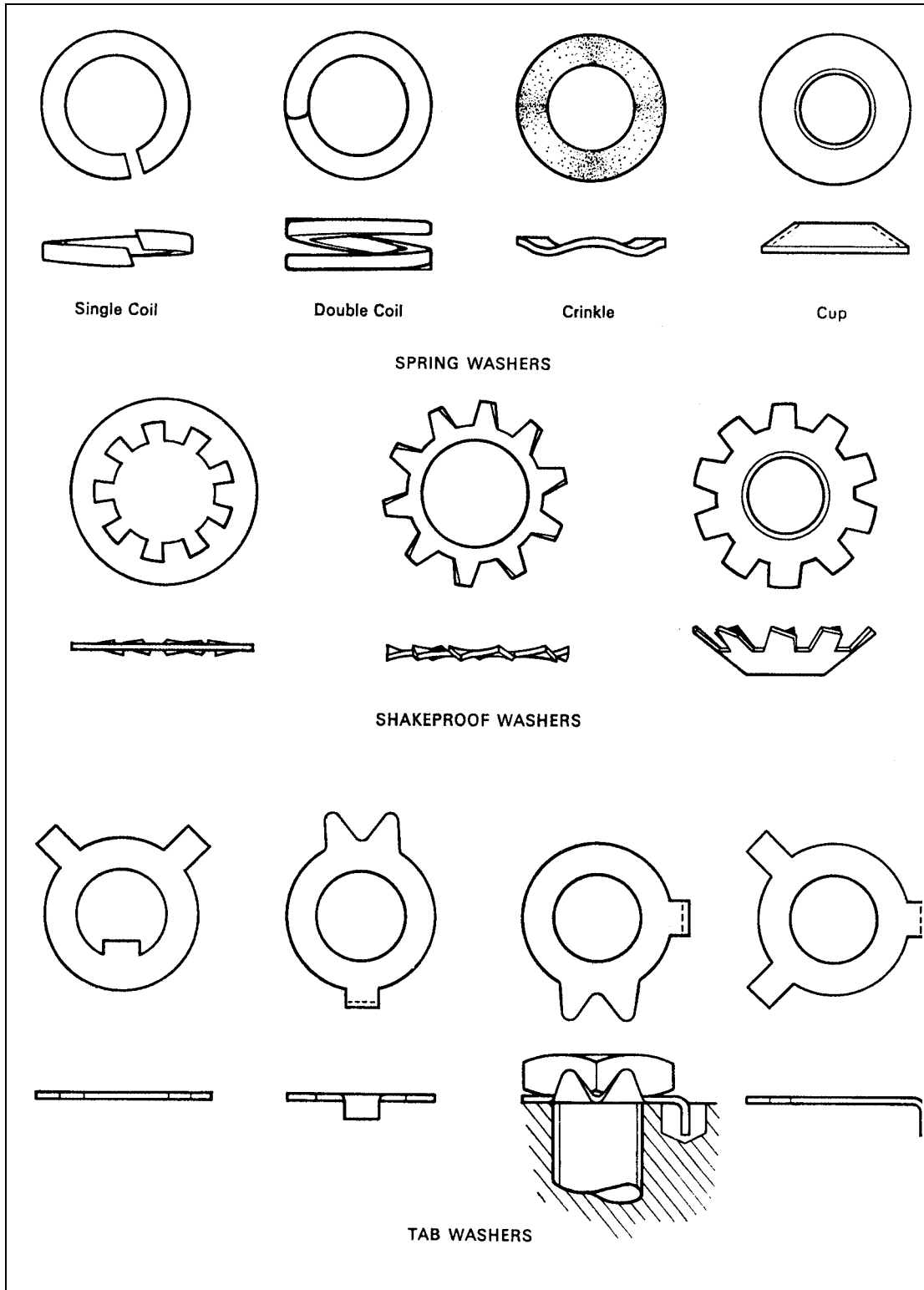

Figure 2   Types of Washers

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.

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.
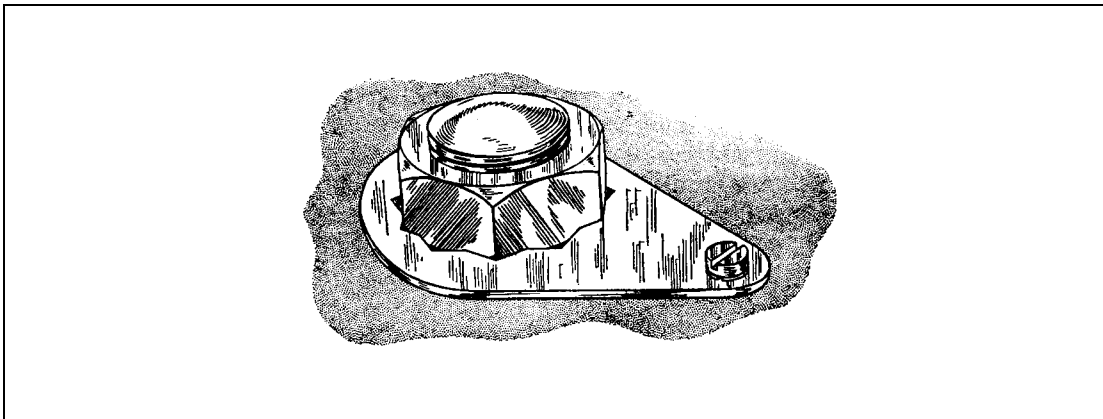

Figure 3   Locking Plate

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 countersunk 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. 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 as such 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 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 13 mm (½inch) 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 9·5 mm (3/8 inch) and lengths of unsupported wire should not normally exceed 76 mm (3 inches).
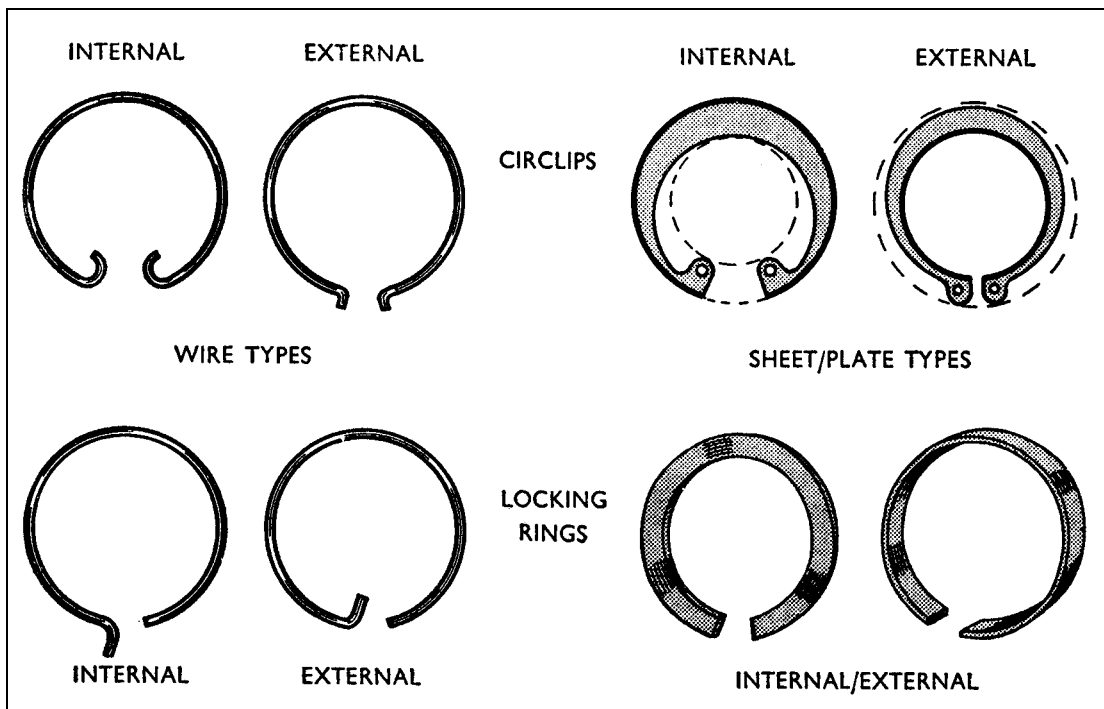

Figure 4   Circlips and Locking Rings

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 (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.
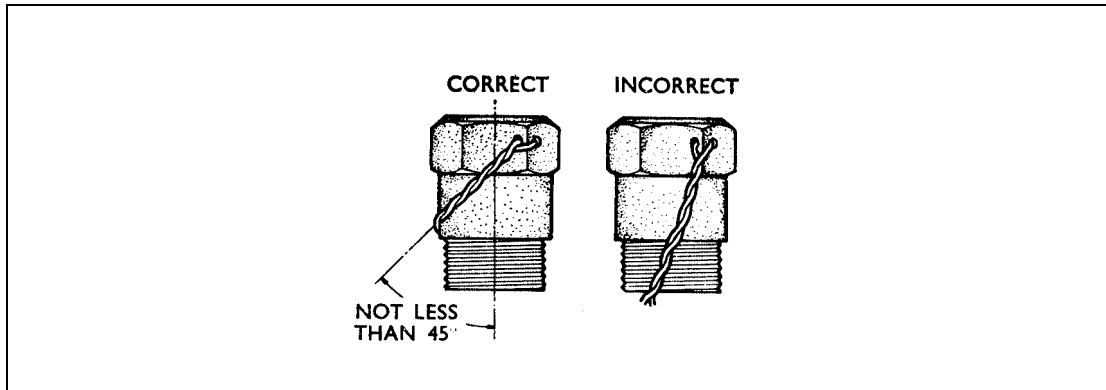
Figure 5   Angle of Approach
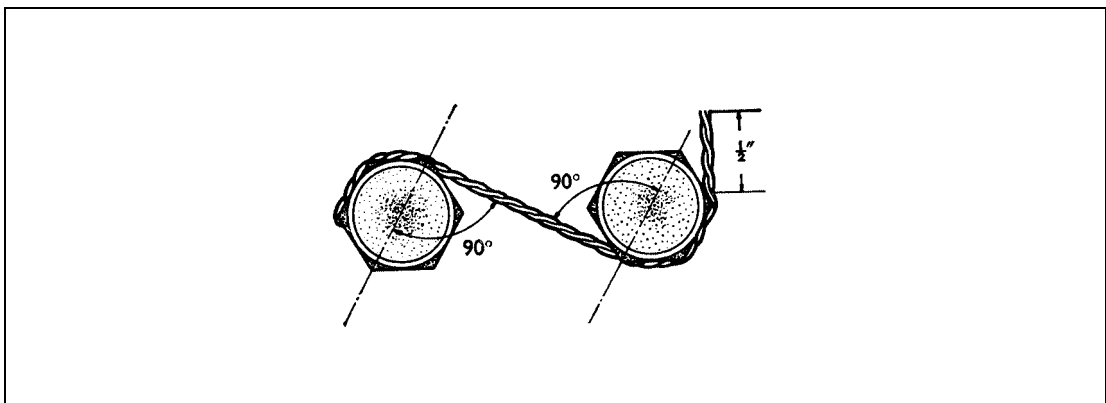
Figure 6   Tangential Approach

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.
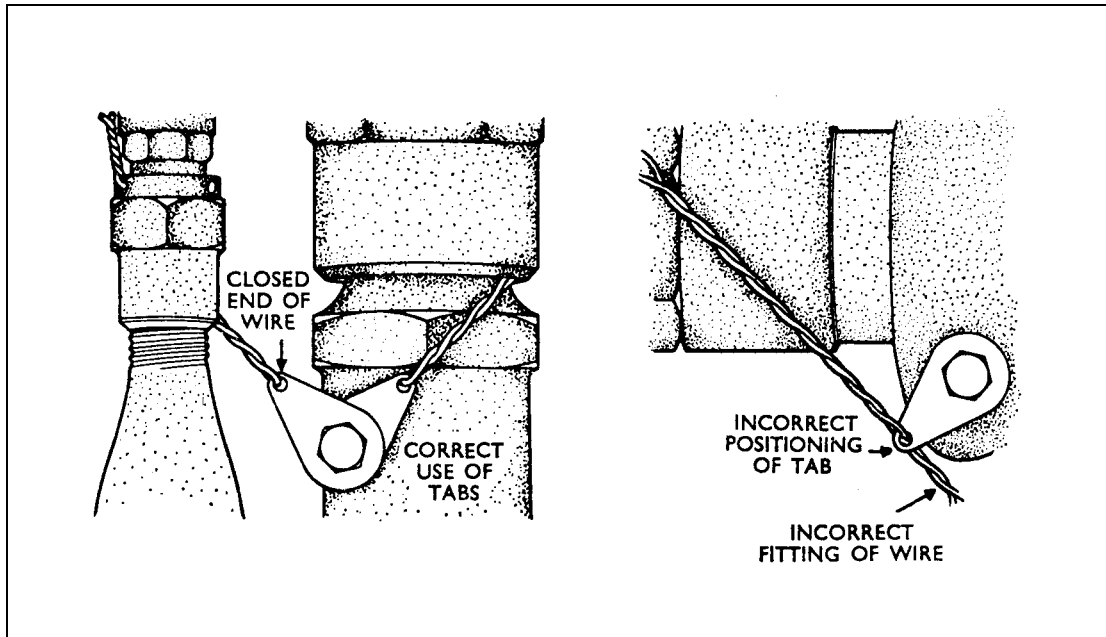
Figure 7   Correct and Incorrect Use of Locking Tabs

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 2–11.

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. 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.
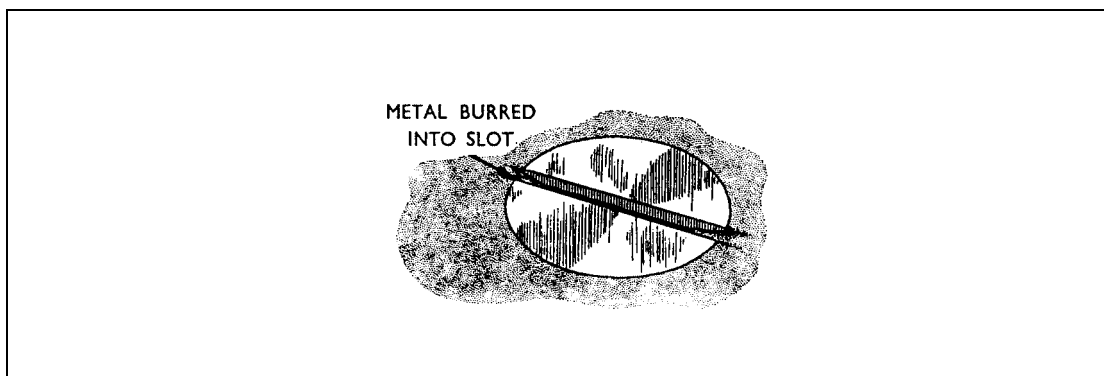
Figure 8   Peening to Lock Countersunk Screws

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 predetermined 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 manufacturer. In these cases a 15% 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.

Leaflet 2-6   Cleanliness of Aircraft

1   Introduction

The degree of cleanliness achieved, both internally and externally, during the manufacture 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 manufacture 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 5–1 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 1–8.

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 cleaning procedures.

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-atomising 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.

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 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 6–2 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 A6–2.

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 reopened, except of course for assembly purposes and test flight adjustments etc. 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 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 suitably 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 overemphasised. 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:
> 5–5 Hose and Hose Assemblies,
> 5–6 Installation and Maintenance of Rigid Pipes,
> 5–8 Wheels Brakes.

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 are 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 an adverse effect on the plastic material. The possibility of slivers of plastic 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; 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 practice to carry out a final inspection for loose articles immediately following the first flight after manufacture 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.

Leaflet 2-7 Paint Finishing of Metal Aircraft

1 Introduction

The purpose of this Leaflet is to provide guidance and advice on the application of paint to metal aircraft and aircraft parts. The treatment of wooden structures is described in Leaflet 2–8, and the doping of fabric-covered aircraft is described in Leaflet 2–9. 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 powerplant 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 an early stage of manufacture, before the inclusion of heat-sensitive parts. One stoving scheme (DTD 56D) 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. 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. 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 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 911C. The treatment consists of dipping the parts in one of several types of chromating baths and is usually followed by a surface sealing process. 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 be taken to ensure that the solvent will not cause hydrogen embrittlement or stress corrosion (see DEF STAN 03–2/1). When titanium is to be painted, an etch primer is normally used.

3.5   **Steel**

Non-stainless steels are generally cadmium plated, 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-ketone (MEK) should be used for other types. The surface to be painted should then be rubbed down with fine emery cloth and the dust 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 stabilise 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 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 2–9), 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 bylaws, 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 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 completely.

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 ISO flow cups (see BS 3900 Part A6).

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. 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 overspray 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 however more expensive 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 2.75 to 5.5 Bar (40 to 80 lbf/in^2), 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 ·3 to 1·03 Bar (5 to 15 lbf/in^2) 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. This 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.

Leaflet 2-8   Fabric Covering

1   Introduction

The purpose of this Leaflet is to provide guidance and advice 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 2–9.

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 (61°F to 70°F) and a relative humidity of not more than 70%.

NOTE: Information on the method of determining relative humidity is given in Leaflet 2–9, 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 575A.

3.1.2   A light cotton fabric complying with BS F114 (referred to as Madapolam) 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   **Tapes**

Linen tapes complying with B8 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.

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 5620 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 (68°F) 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 discolouration, 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. 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 (e.g. sides, top and bottom, 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, 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.
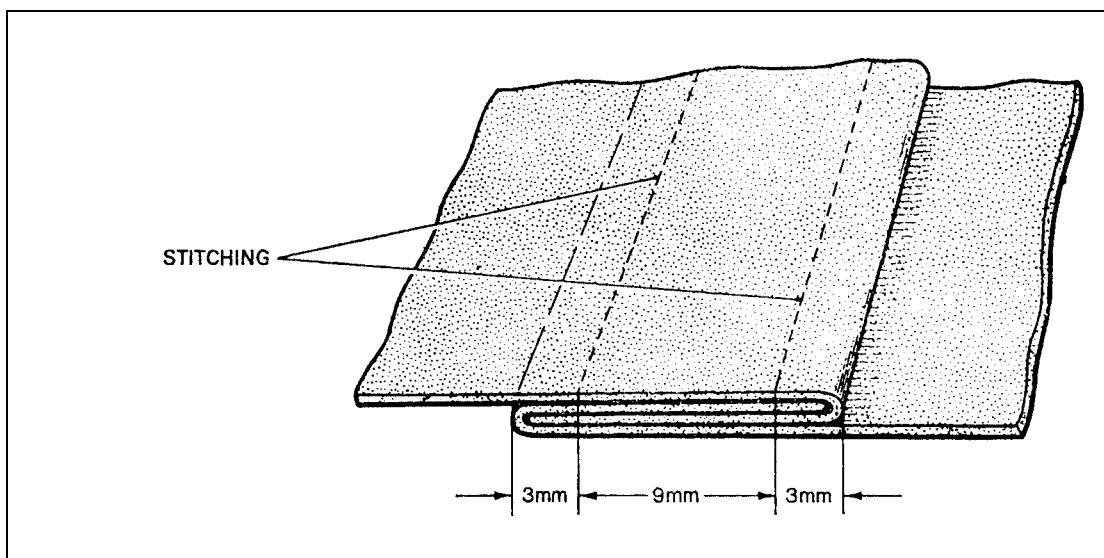

Figure 1   Balloon Seam

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.
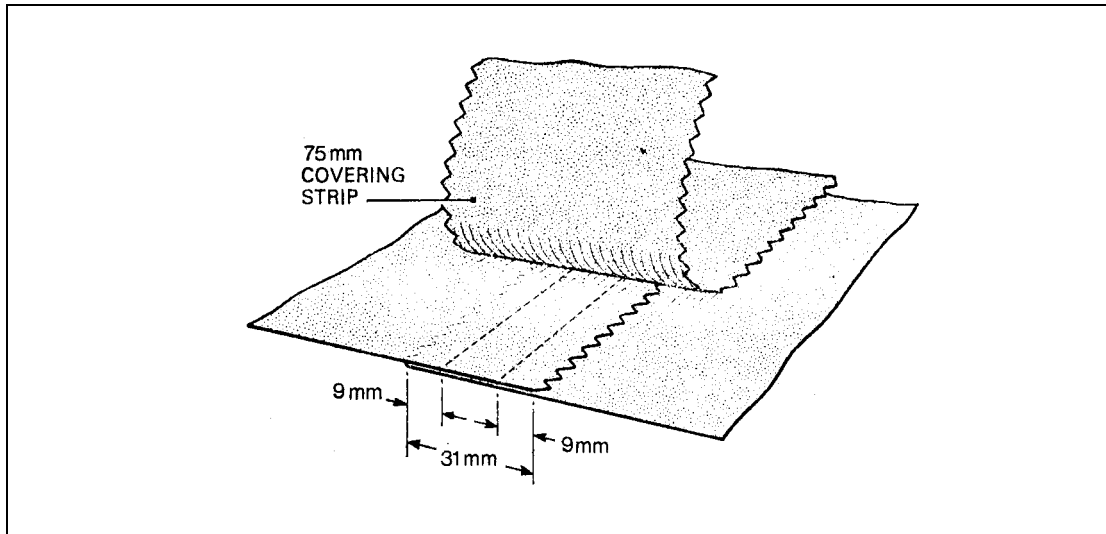
Figure 2   Lap Seam

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.
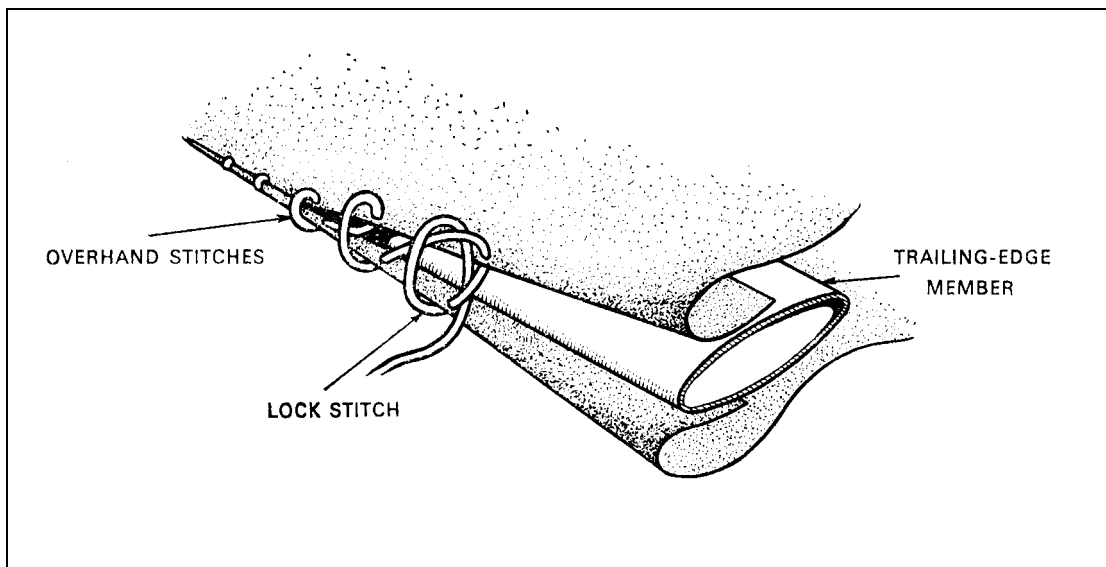

Figure 3   Overhand Stitch

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.
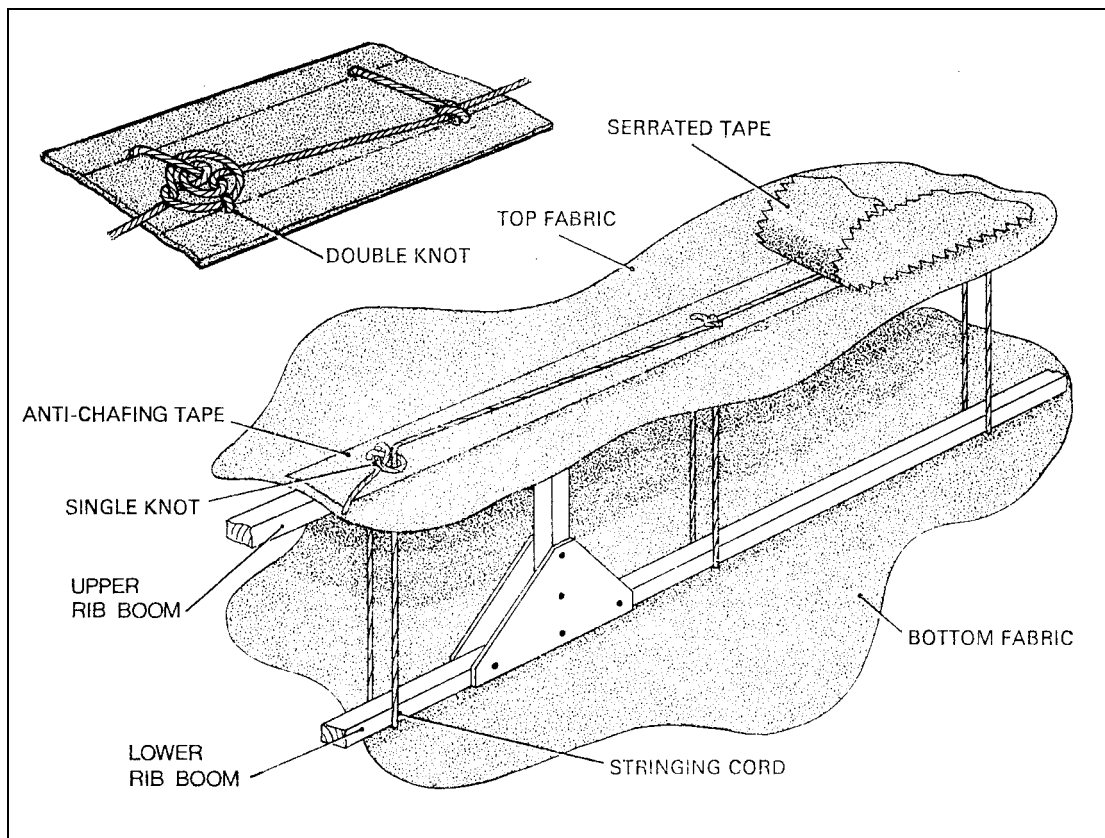

Figure 4   Typical Stringing

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.
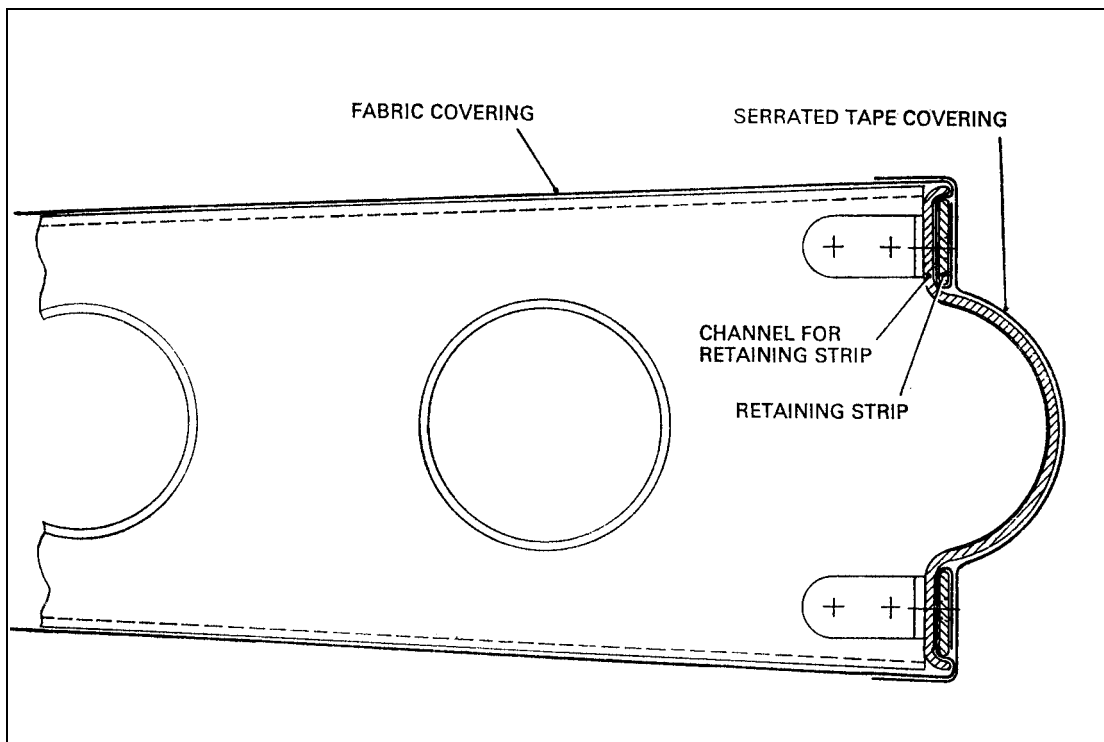

Figure 5   Attachment of Fabric by Strip

7   Miscellaneous Methods of Fabric Attachment

In addition to the standard methods of fabric attachment described in paragraph 6, other methods are sometimes employed. The 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.
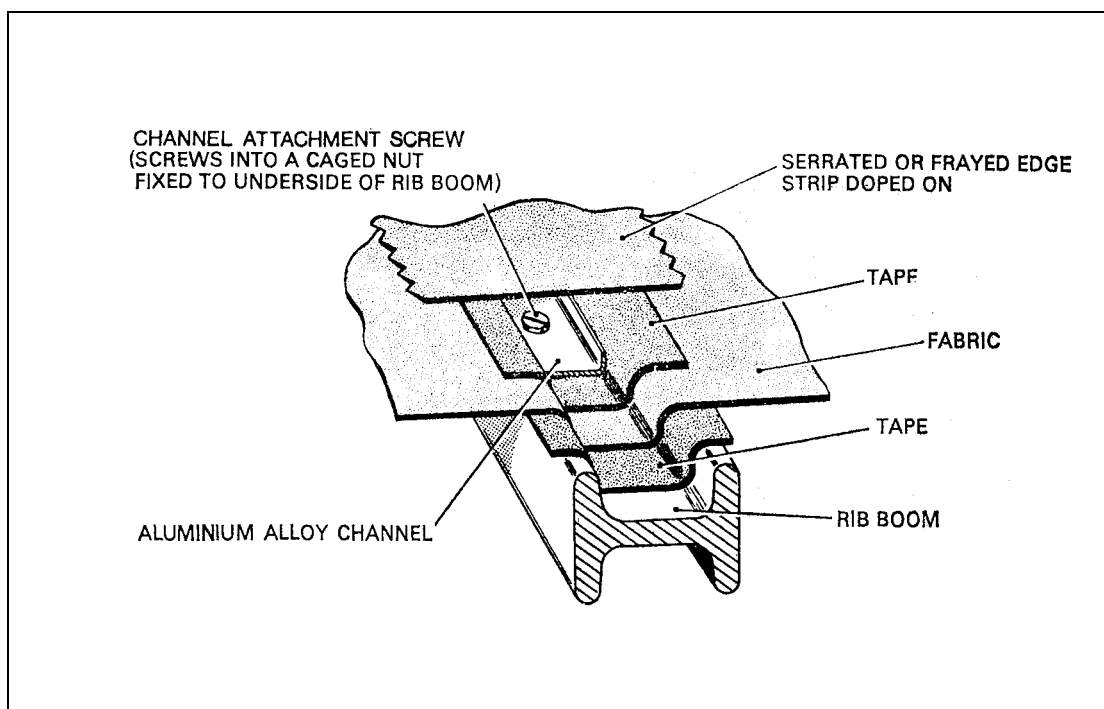

Figure 6   Special Stringing

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 manufacture 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 minimise 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 equalise 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 onto 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.
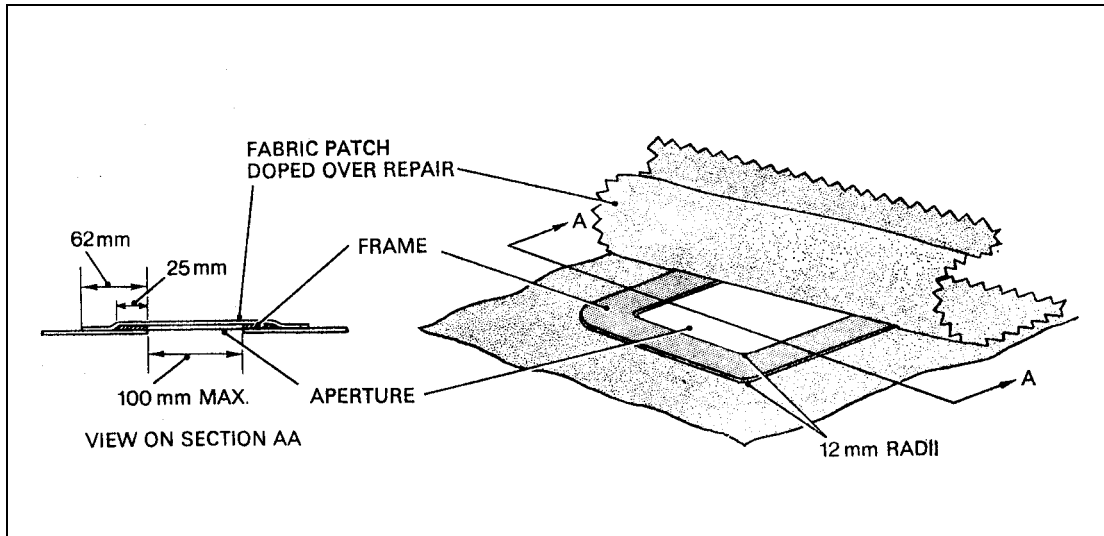
Figure 7   Woods Frame Inspection Panel

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, is the spring panel which 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.
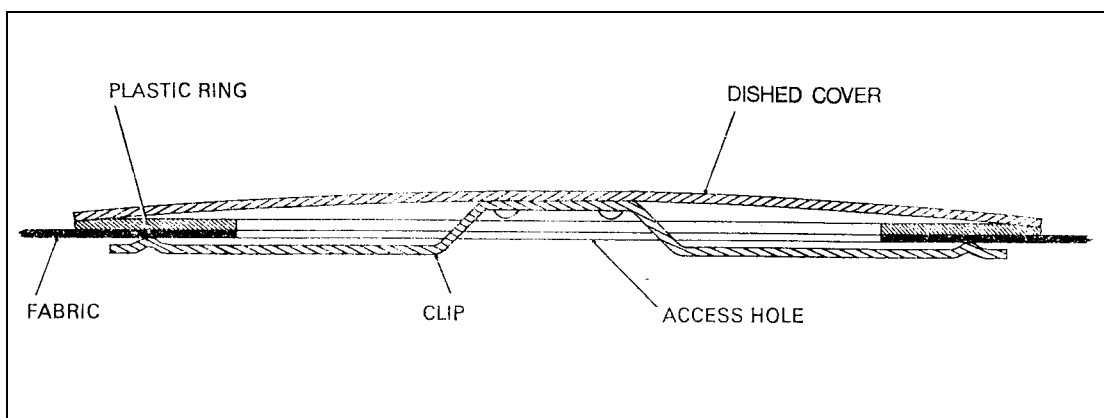

Figure 8   Cross-section of Spring Panel

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 any 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.
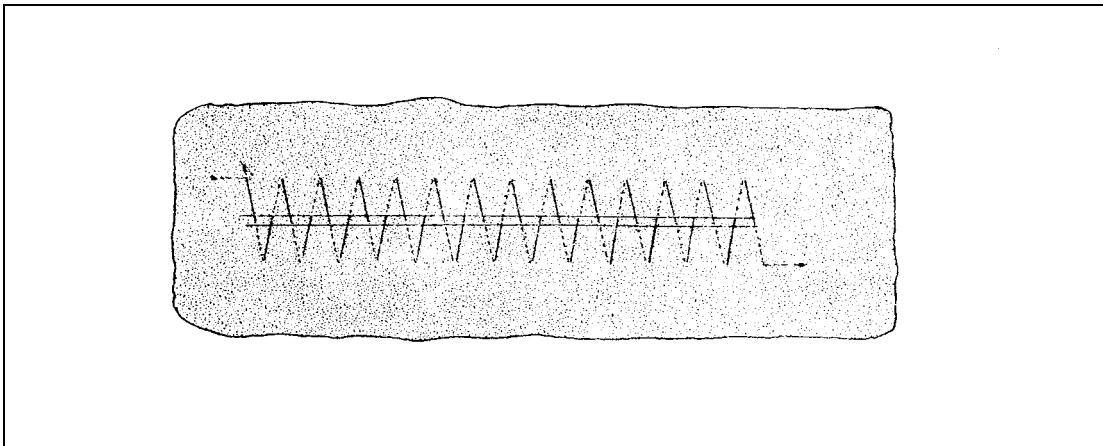

Figure 9   Herring-Bone Stitch

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.

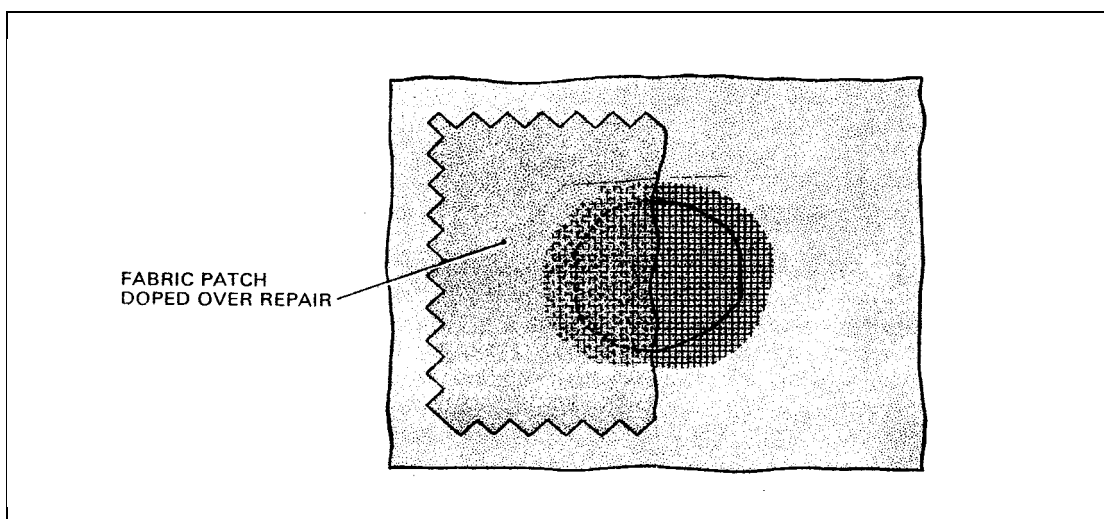FABRIC PATCH
DOPED OVER REPAIR

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.
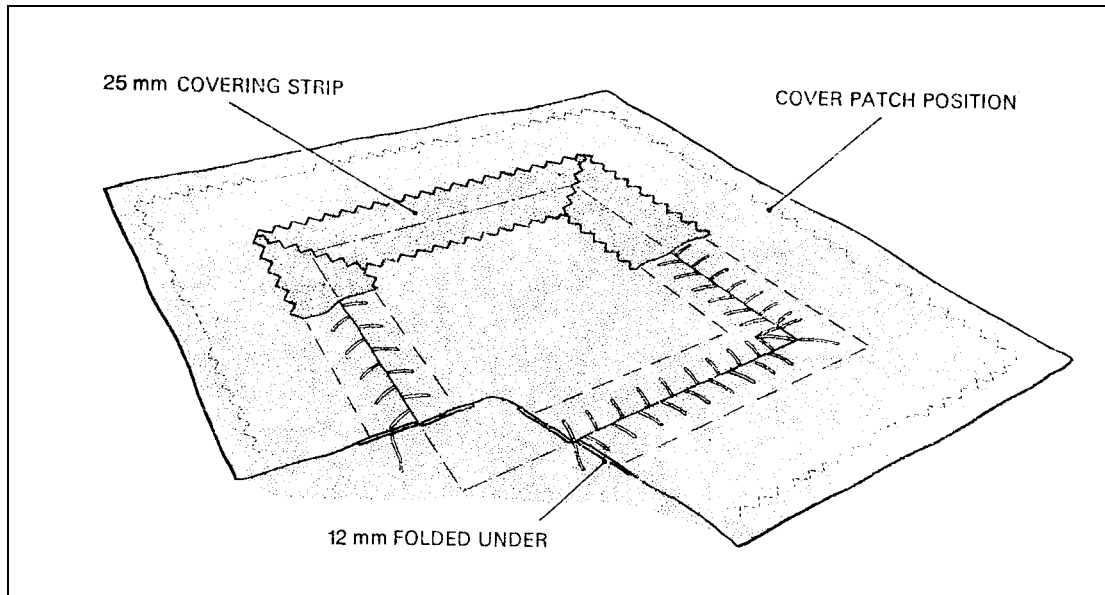

Figure 11 Normal Insertion Repair

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.
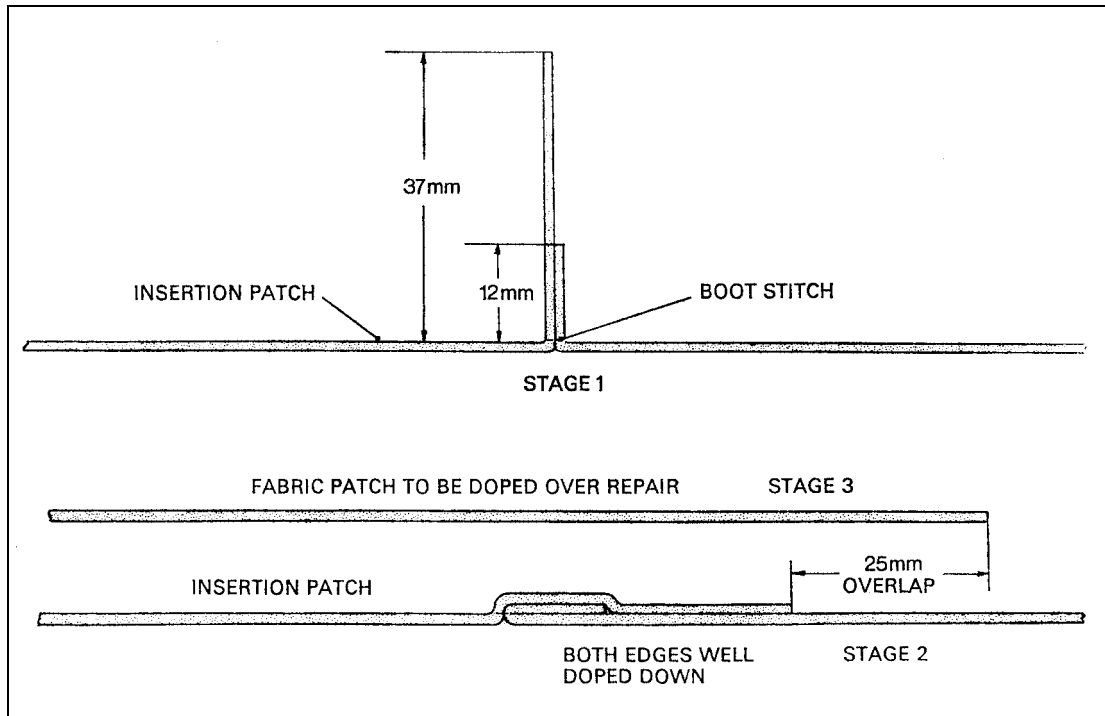
Figure 12 Alternative Insertion Repair
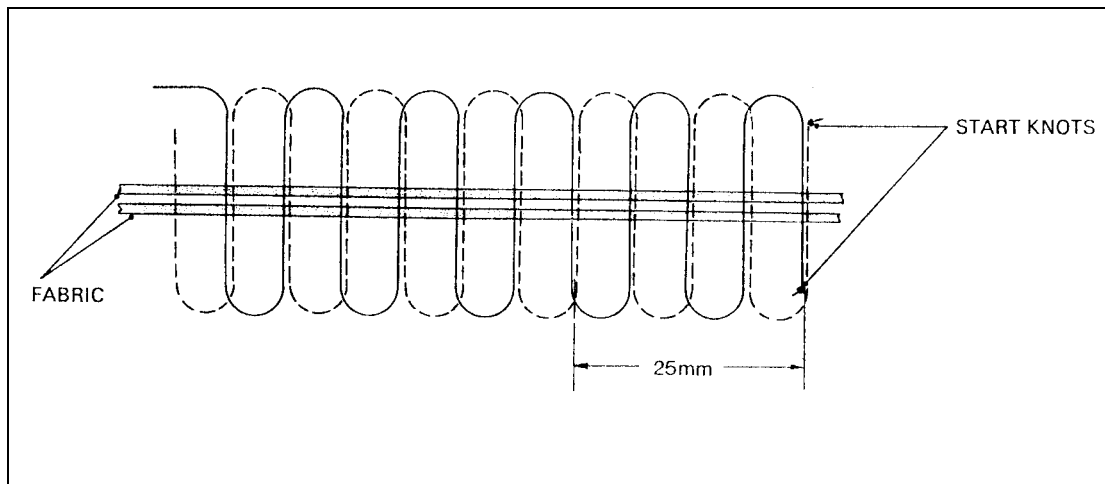
Figure 13 Boot Stitch

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 90º 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 (AMS, TSO 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.
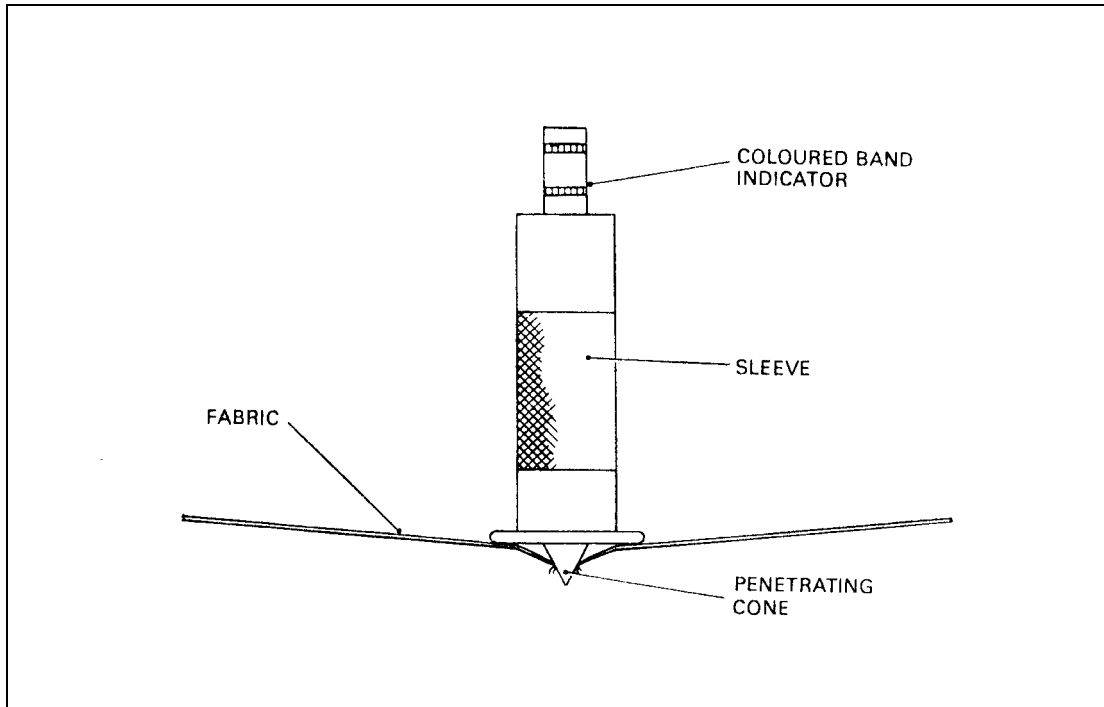
Figure 14 Fabric Tester

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 x 300 to 400 mm (2.5 in x 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.

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Leaflet 2-9   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 purpose of this Leaflet is to provide guidance and advice on the appropriate working conditions and methods of application of dope to aircraft fabric. Other Leaflets with related information are 2–7 Paint Finishing of Metal Aircraft and 2–8 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 plasticisers 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 plasticisers in the two dopes are also different, as are the resin balance and solvent balances. Dope must be stored under suitable conditions (see Leaflet 1–8), 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.

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.
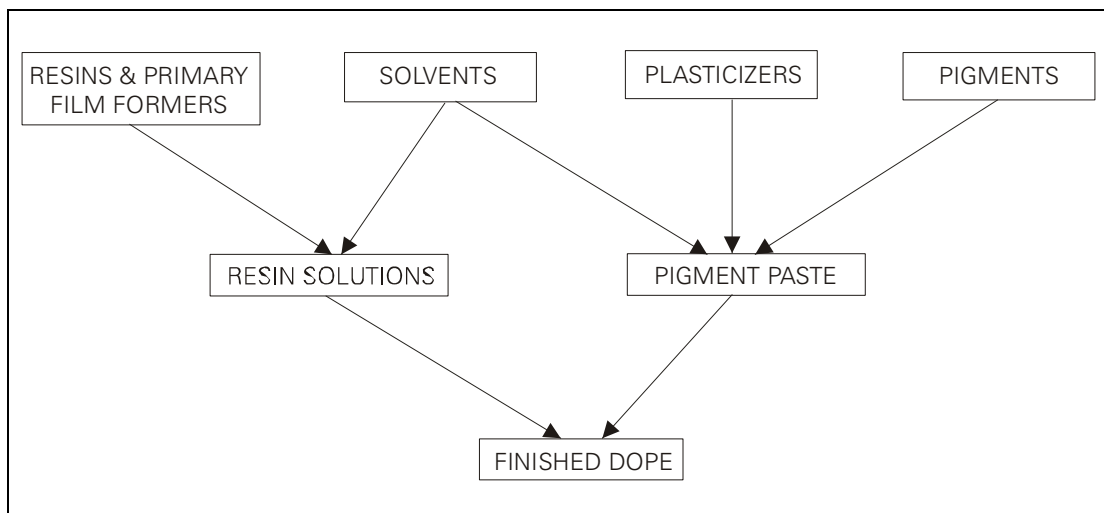
Figure 1   Dope Constituents

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 2–8).
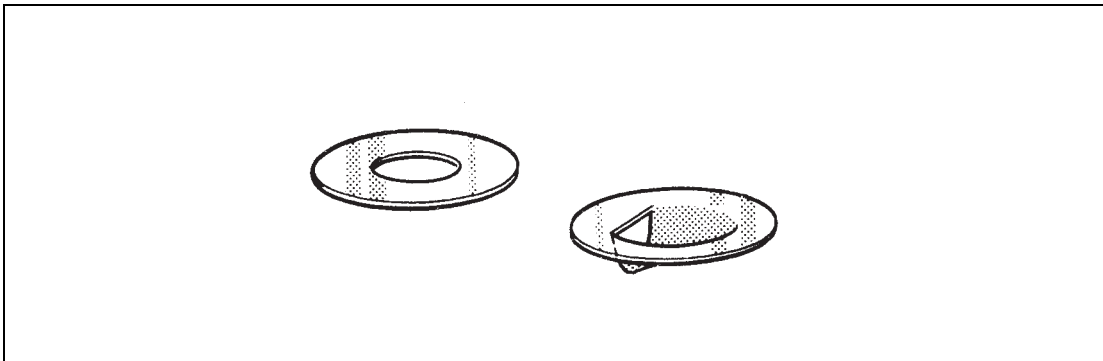

Figure 2   Plain and Shielded Drainage Eyelets

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 air flow through the shop to remove the heavy vapours caused by atomisation and evaporation of the solvents used.

4.1   To maintain a suitable air flow 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 (70° to 79°F) 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.

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	43	48	44
35	93	87	81	75	70	64	59	54	49	44

NOTE: Intermediate values may be obtained by interpolation.

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.

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 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/m^2	oz/yd^2	
(a) Transparent tautening dope	68	2·0	3 or 4
(b) Aluminium non-tautening finish	34	1·0	2
(c) Pigmented non-tautening finishes Where a glossy finish is required, follow with:	34	1·0	1 or 2
(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/m^2	oz/yd^2	
(a) Red oxide tautening dope	68	2·0	3
(b) Aluminium tautening finish	34	1·0	2

(c) Pigmented non-tautening finishes
    Where an aluminium finish is
    required, the scheme should be:
	34	1·0	1 or 2

(d) Red oxide tautening dope	102	3·0	4

(e) Aluminium non-tautening finish
    Where a glossy finish is required,
    follow with:
	34	1·0	2

(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/m^2	oz/yd^2	
(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
    Where an aluminium finish is
    required, the scheme should be:
	34	1·0	1 or 2

(e) Red oxide tautening dope	25·5	0·75	1
(f) Transparent tautening dope	195	5·75	8

(g) Aluminium non-tautening finish
    Where a glossy finish is required,
    follow with:
	34	1·0	2

(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 2–8 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 fullbodied cross-coats of clear butyrate dope. After these coats 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

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

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.

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/m^2 (4.75 oz/yd$^{2)}$). 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 1–4).

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.

Leaflet 2-10 Thread Inserts

1 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 large 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. The possibility of thread failure from vibration, fatigue, corrosion or seizure is also 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.
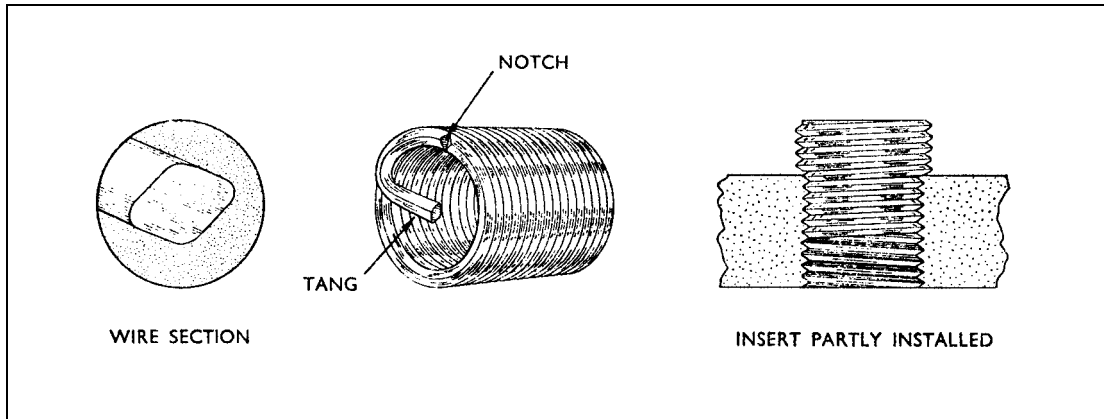
Figure 1   Typical Wire Thread Insert

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.

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.
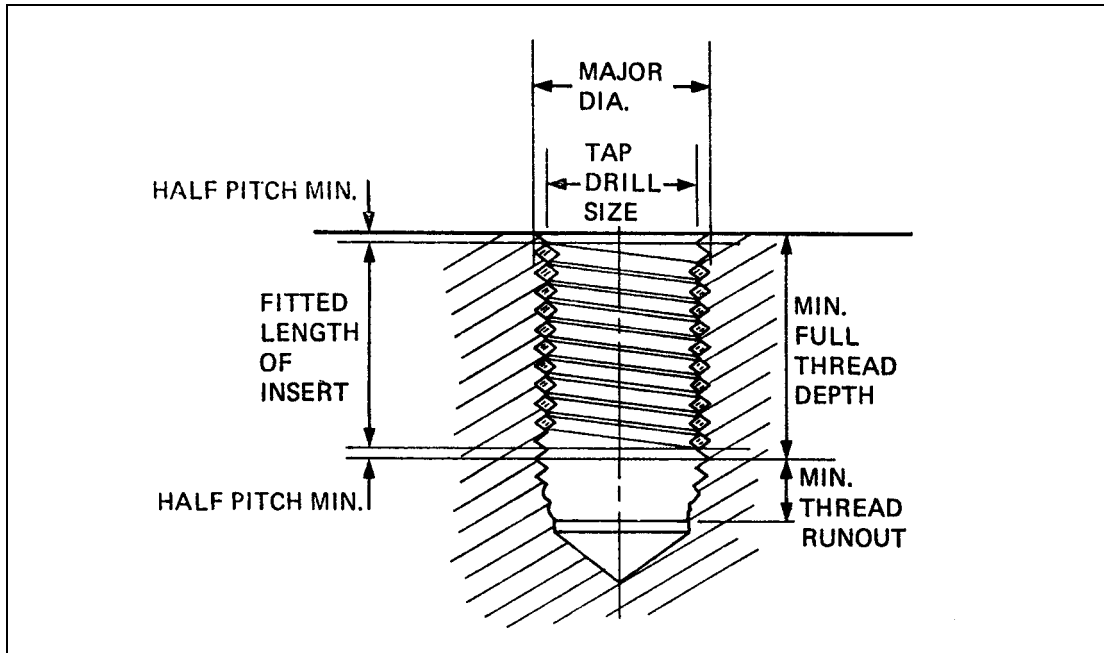
Figure 2   Wire Thread Insert Hole Data

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.

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 forefinger of one hand while turning the key with the other hand; no downward pressure should be applied on the key. The insert will find 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.
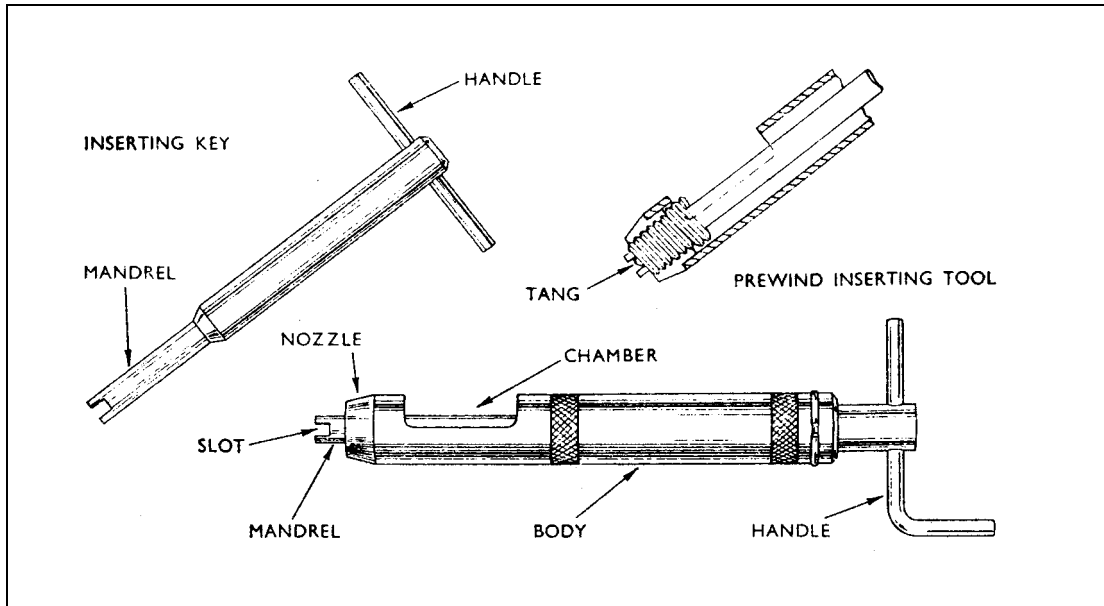
Figure 3   Inserting Key and Prewind Inserting Tool

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 and 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.
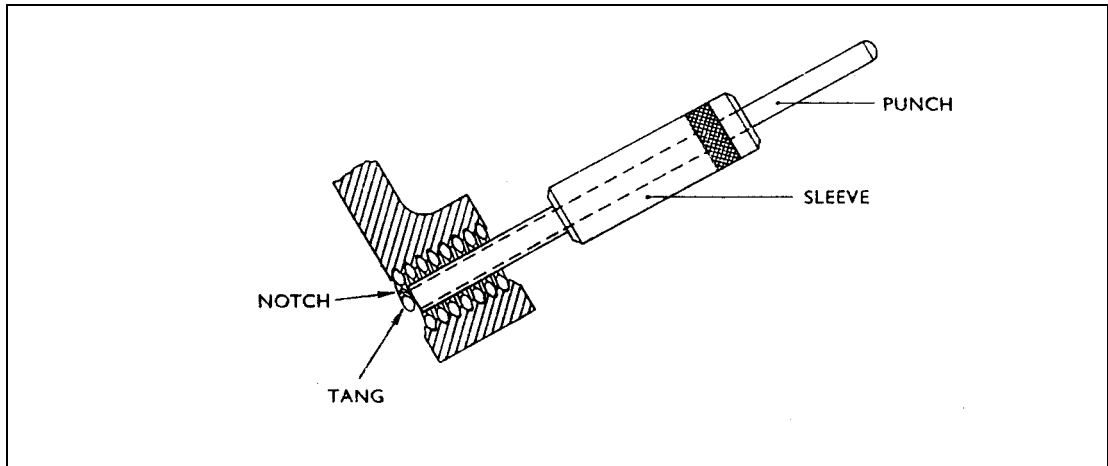
Figure 4   Tang Break-off Punch

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.
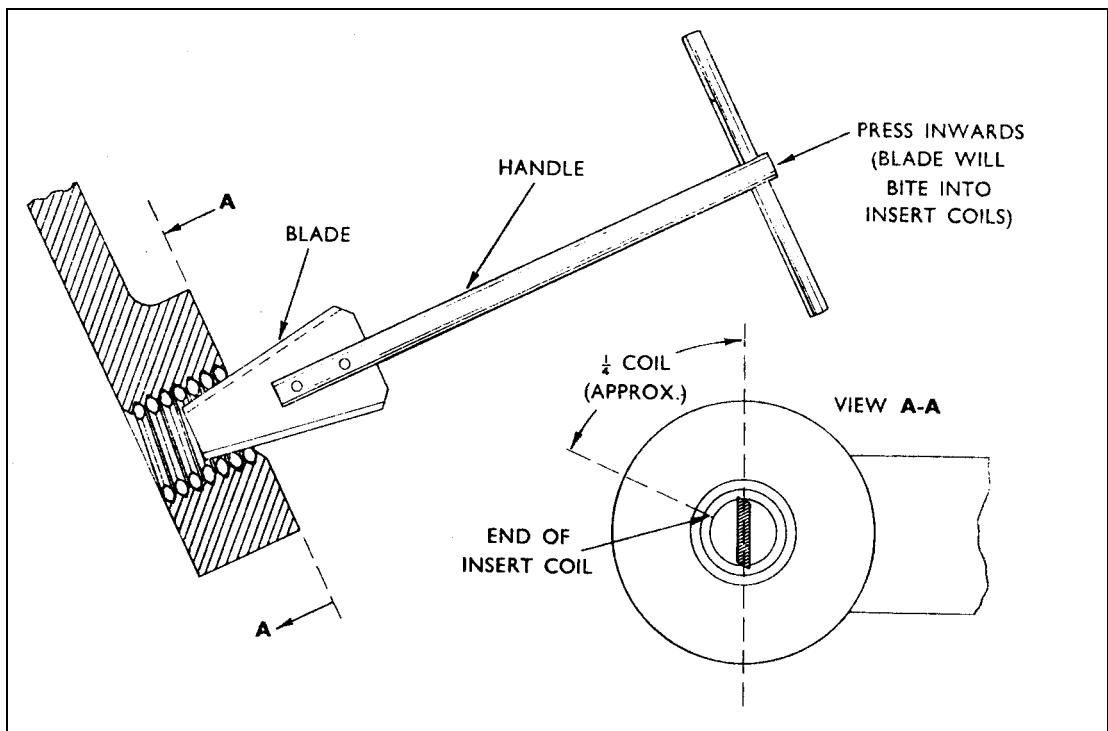

Figure 5   Typical Extractor Tool

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.
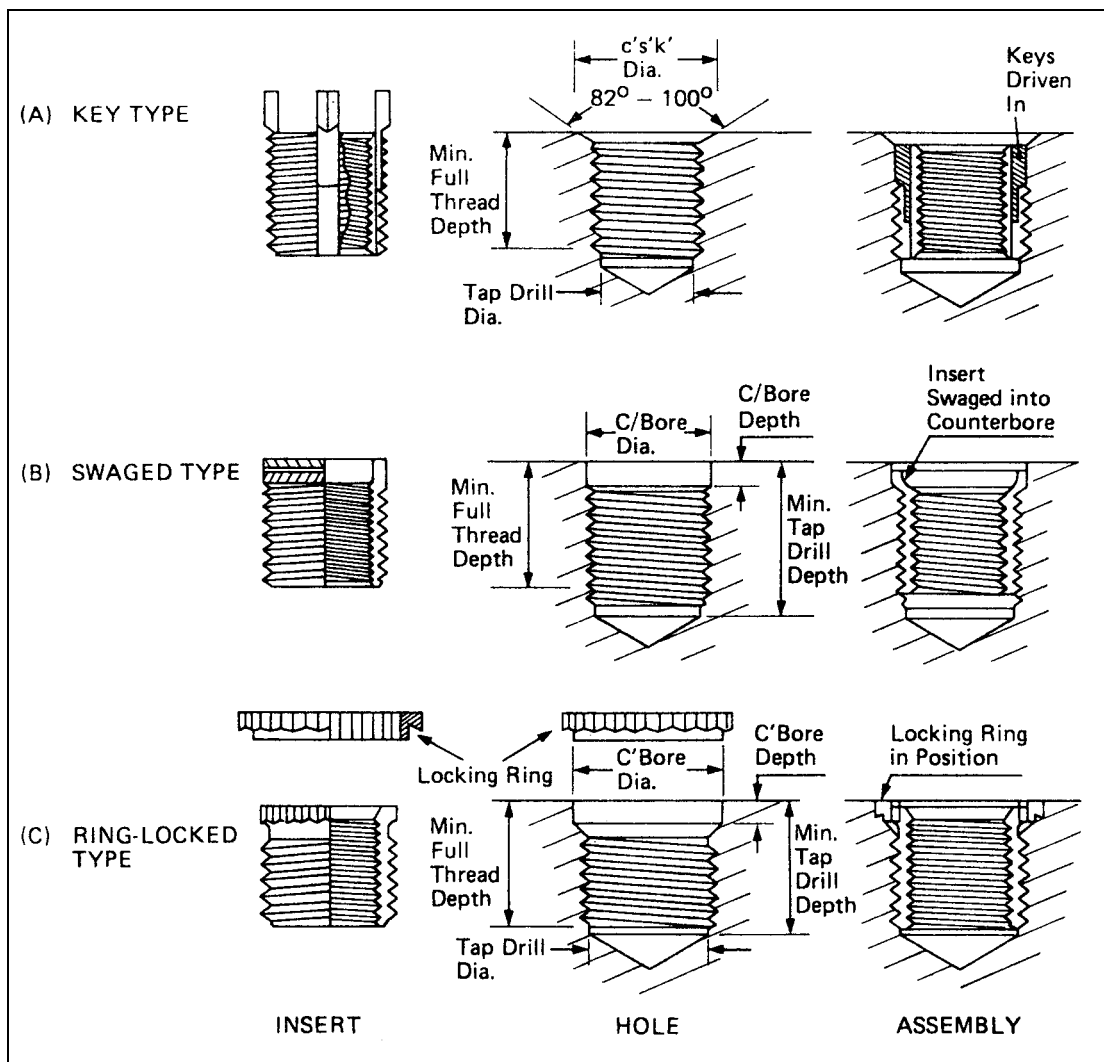

Figure 6   Thin Wall Inserts

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.

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.

b) 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.
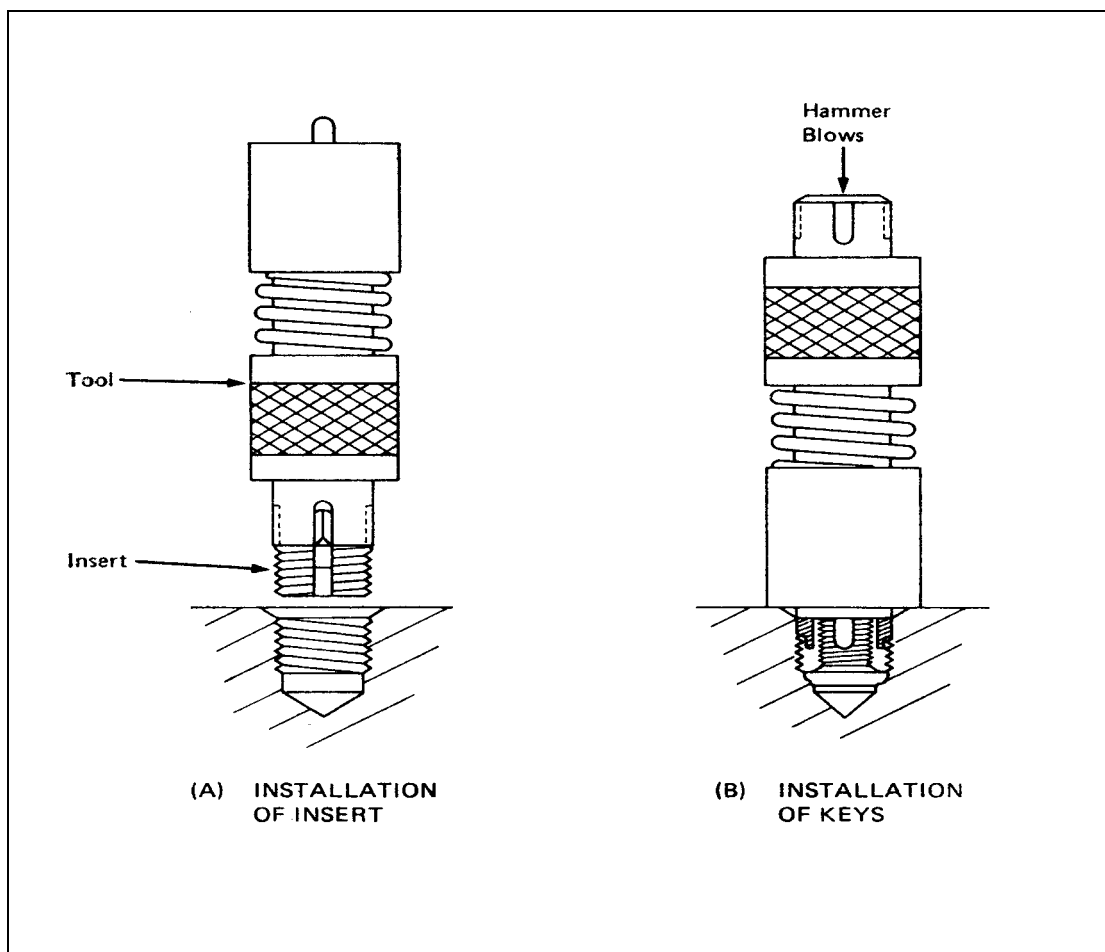

Figure 7   Installation Tool (Key-locked Inserts)

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.

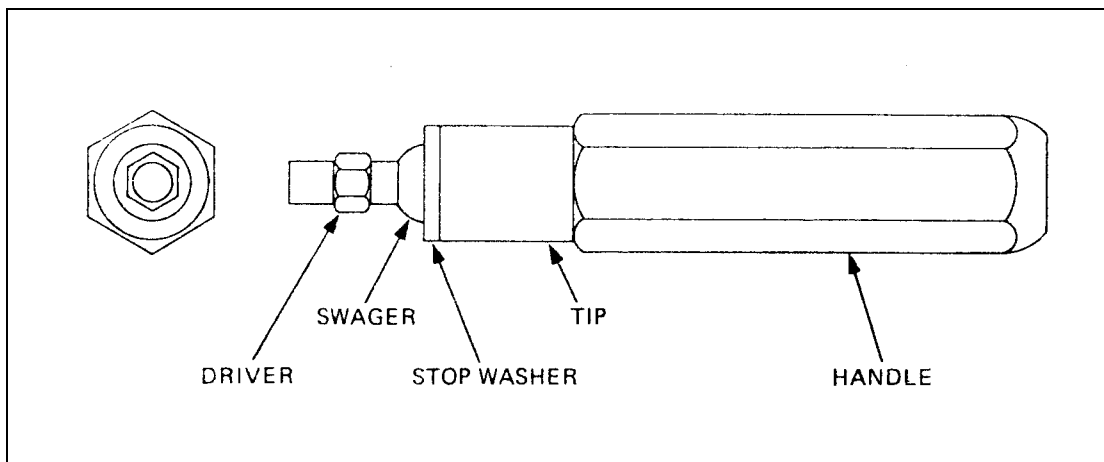NOTE: Insertion tools for the larger sizes of inserts are power operated.

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.
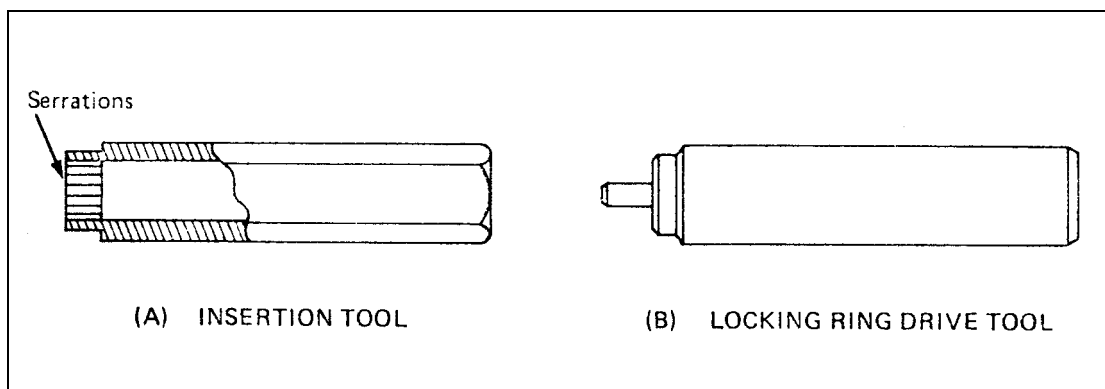

Figure 9   Tools For Ring-locked Inserts

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.

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Leaflet 2-11 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:**

5–9   Oxygen Systems

6–7   Assembly and Maintenance of Critical Bolted Joints

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 6–7.

2.2   'Standard' torque loading values are those generally applied to steel fasteners used in tension applications on aircraft. Lower values are generally quoted for shear nuts or nuts used in shear applications. Lower torque values are also necessary for pipe 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.

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 5-9.

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.
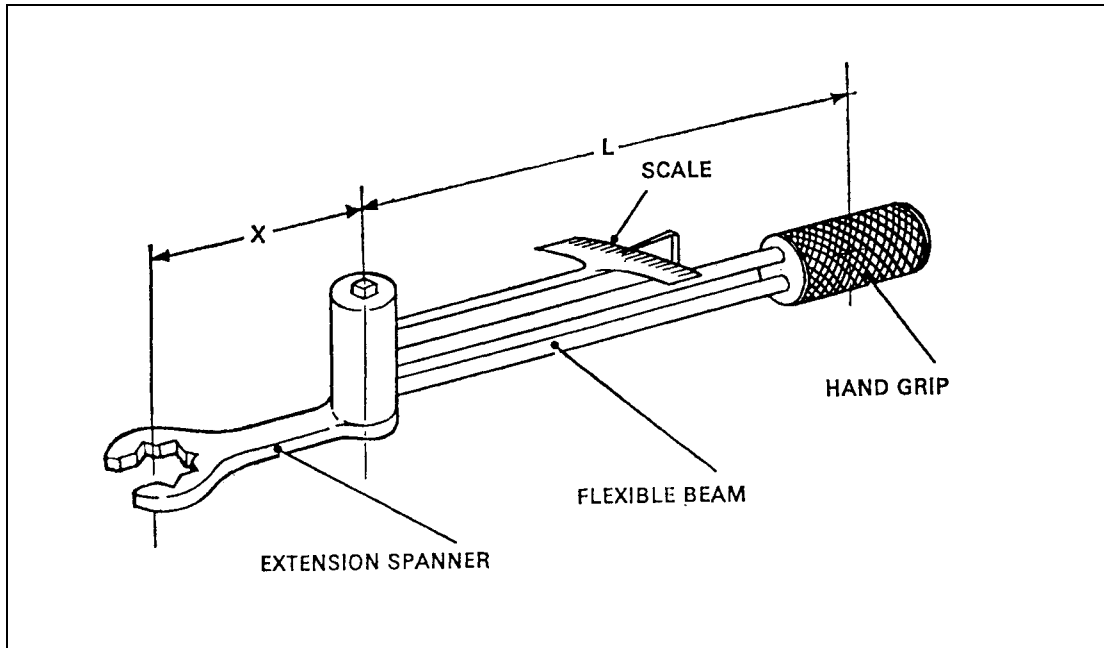
Figure 1   Typical Beam-type Torque Wrench

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,

$$\text{which is, } \frac{300 \text{ lb in}}{10 \text{ in} + 5 \text{ in}} = 20 \text{ lb}$$

b) Scale reading when force on handle is 20 lb is, 20 lb x 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.

4.4.3   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 an 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 $\times \frac{L}{D}$
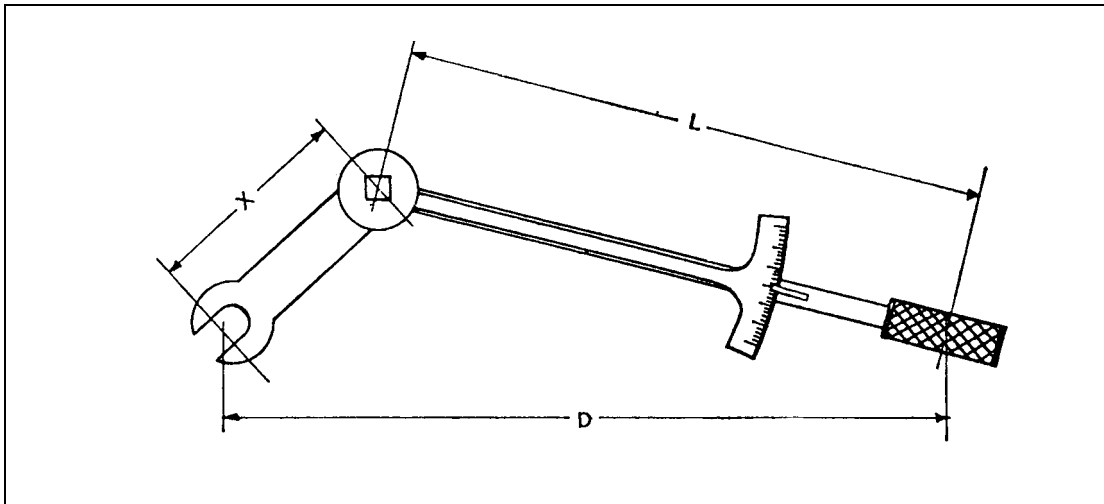

Figure 2   Alternative Method Of Use

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 re-tightened 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 6 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.

Leaflet 2-12 Cable – Splicing and Swaging

1   Introduction

1.1   This Leaflet provides guidance and advice 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 3–1.

1.2   To obviate the need for the revision of this Leaflet when new issues of specifications referred to are published, the prefix or suffix indicating the issue number of the specification has been omitted.

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 manufacture 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 x 19, consists of 7 strands, each strand containing 19 wires. Wires are wound round a king wire in one or two layers. 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 manufacture are illustrated in Figure 1 and the manufacture of the various sizes of cable is included in Tables 1 and 2.
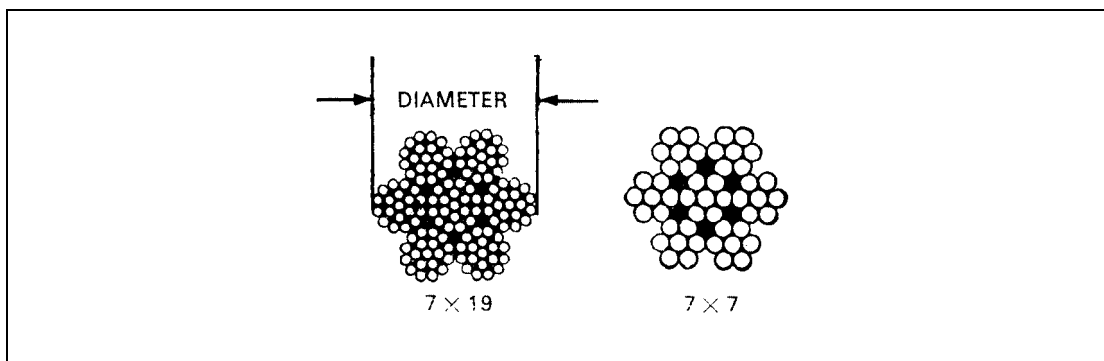

Figure 1   Steel Wire Cable

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)	Manufacture	Maximum diameter of cable (in)	
		BS W9	BS W11
3	4 x 7	0·065	0·065
5	7 x 7	0·08	0·08
10	7 x 14	0·12	0·12
15	7 x 19	0·15	0·15
20	7 x 19	0·16	0·16
25	7 x 19	0·18	0·18
30	7 x 19	–	0·21
35	7 x 19	0·21	–
40	7 x 19	–	0·24
45	7 x 19	0·24	–
55	7 x 19	–	0·27
60	7 x 19	0·27	–

Table 2   Cable Classified By Nominal Diameter

Nominal diameter of cable		Manufacture	Minimum breaking load[1]		
			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 x 7[2]	480	480	2·15
3/32	2·4	7 x 7[3]	920	920	4·10
1/8	3·2	7 x 19	2000	1760	7·85
5/32	4·0	7 x 19	2800	2400	10·70
3/16	4·8	7 x 19	4200	3700	16·50
7/32	5·6	7 x 19	5600	5000	22·25
1/4	6·4	7 x 19	7000	6400	28·40

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

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, 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 not 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 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.
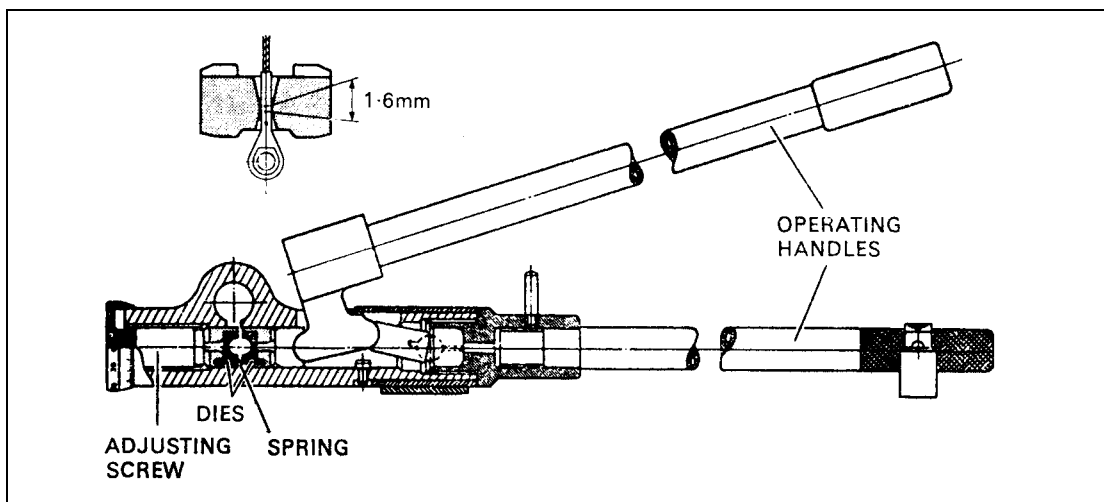

Figure 2   Portable Swaging Machine

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. The swaging machine 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 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 (0·0625 in) and repeat the cycle of squeezing and turning.

i) 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.

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

k) 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 3–1, or a cylindrical sleeve lightly swaged onto the shank of the end fitting.

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

m) 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 as such 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 x 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.
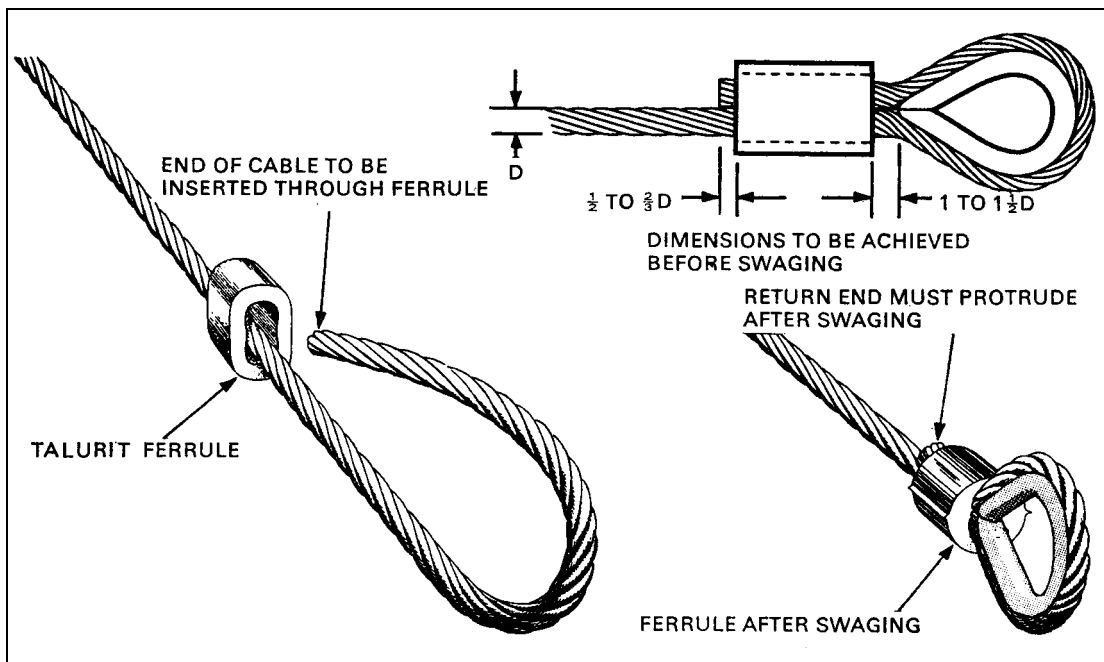

Figure 3   'Talurit' Swaged Splice

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 firmly locking 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.

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, this 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 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 (1/8 in) diameter and 30 cm (12 in) should be allowed for each splice in cable between 4·0 mm (5/32 in) and 6·4 mm (3/4 in) diameter.
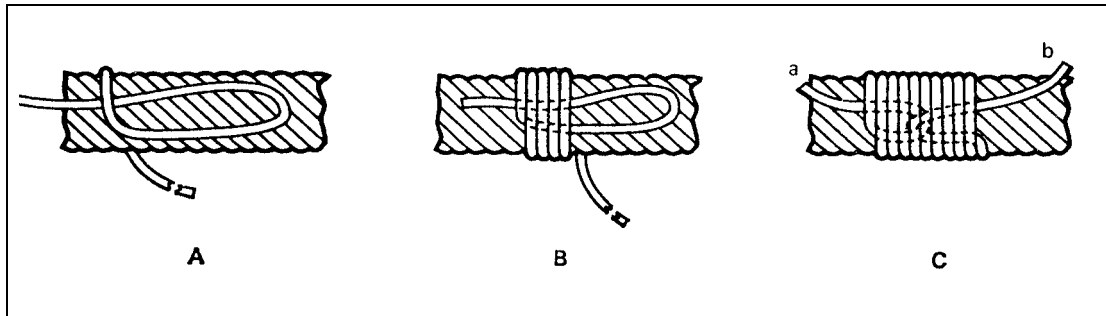
Figure 4   Method of Whipping
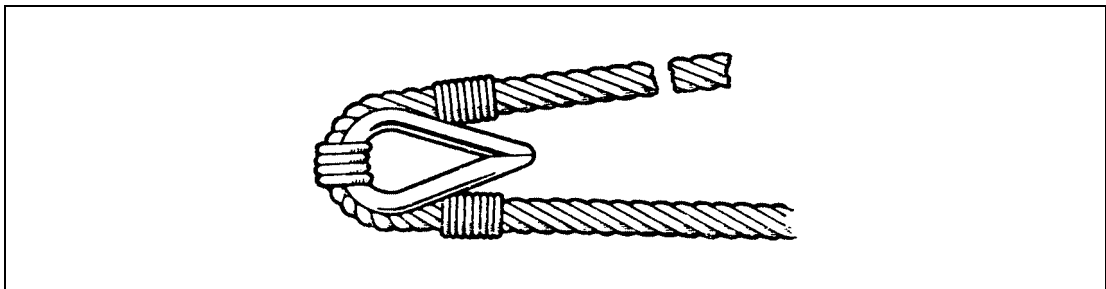

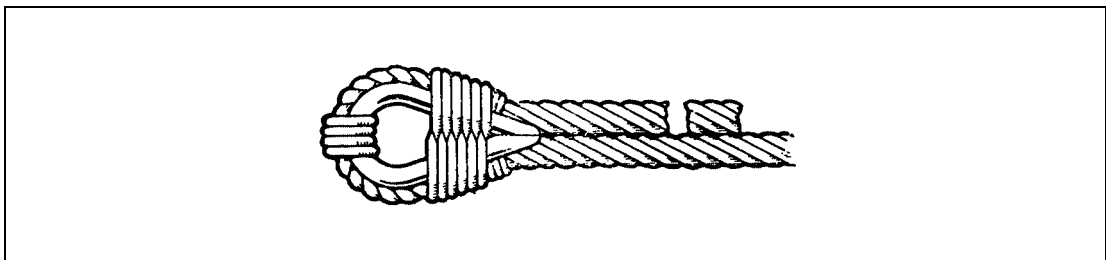**Figure 5**   Whipping of Cable

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.
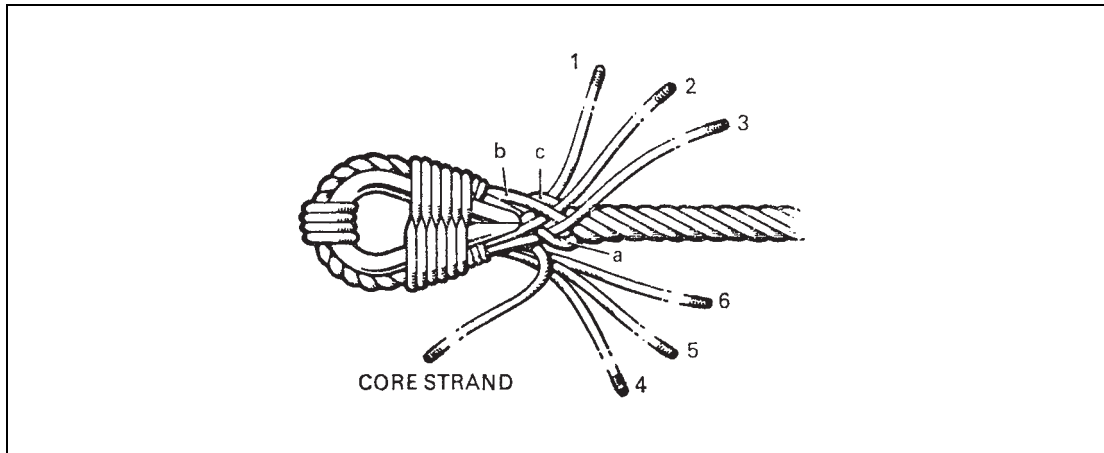
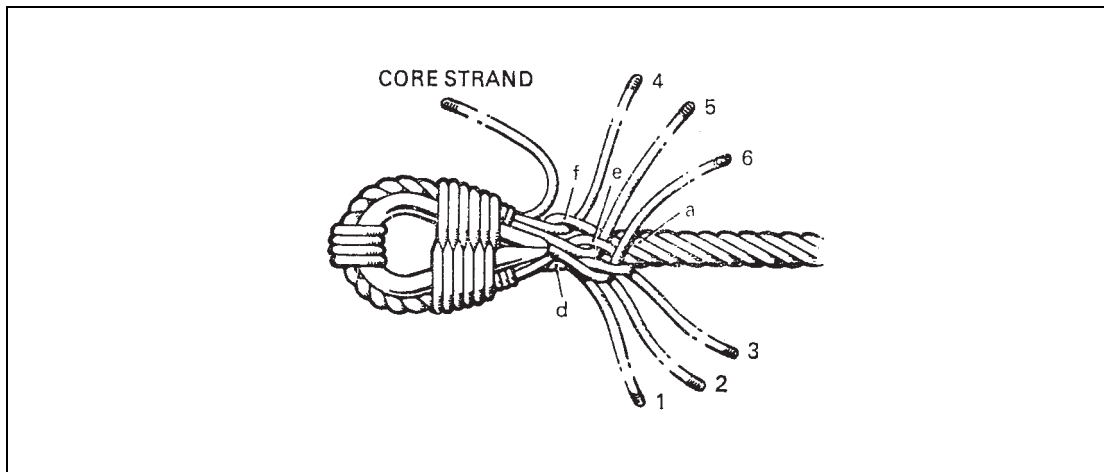**Figure 7**   First Round of Tucks (Front)

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.
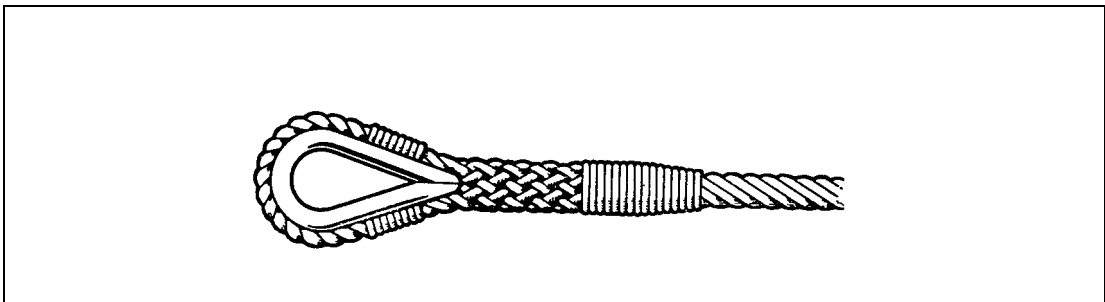

Figure 9   Typical Spliced Joint

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 loadings 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. 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.
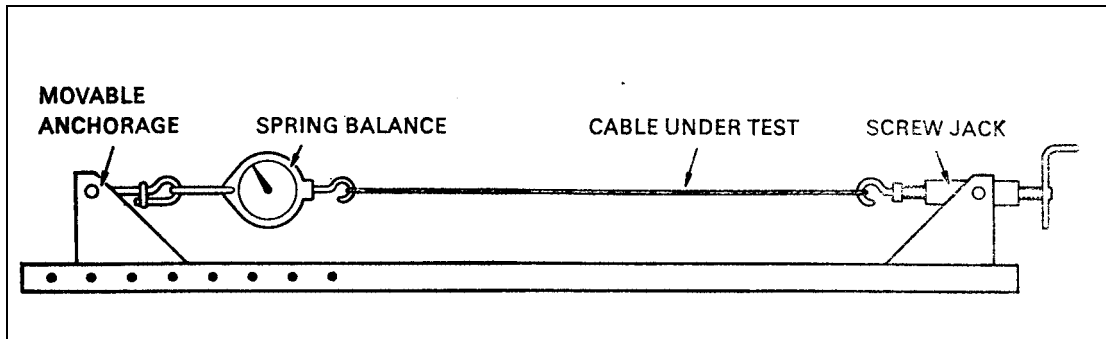

Figure 10   Test Rig for Proof Loading

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)

$\left. \begin{array}{l} +9\text{·}6 \text{ mm} \ (\frac{3}{8} \text{ in}) \\ -3\text{·}2 \text{ mm} \ (\frac{1}{8} \text{ in}) \end{array} \right\}$ over 6 m (20 ft)
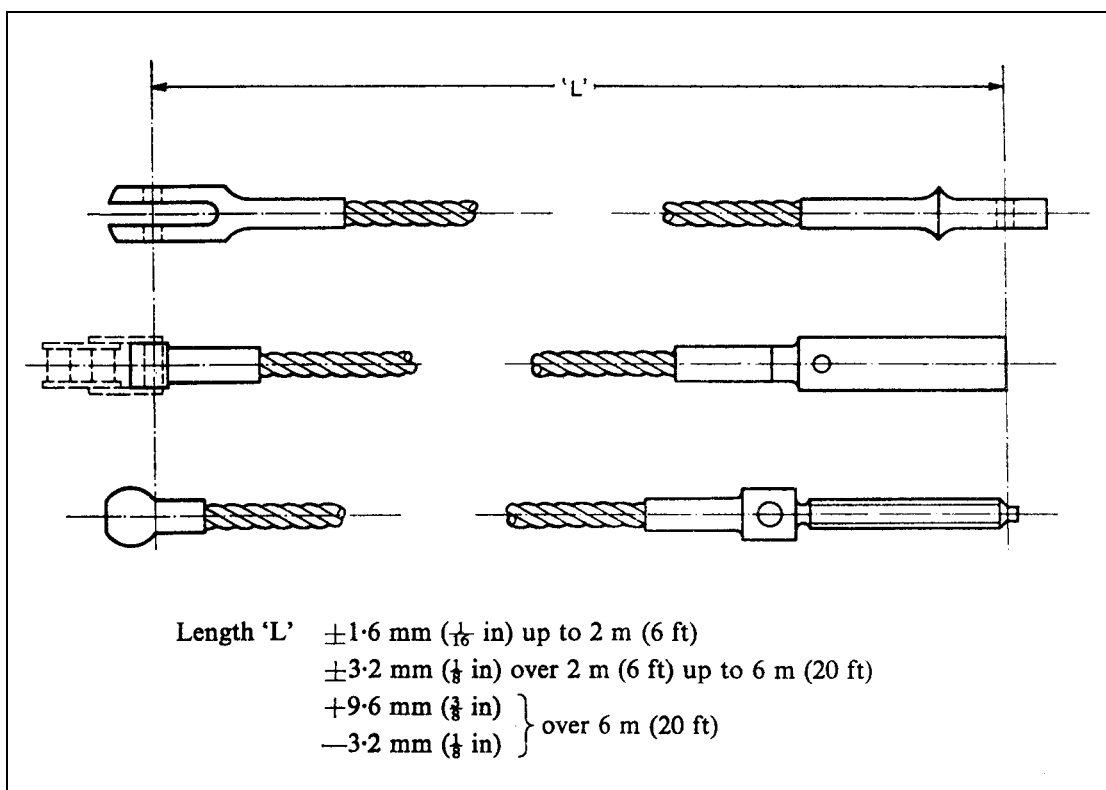
Figure 11   Length of Assemblies

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 4–5) or, if the fitting is of stainless steel, a penetrant dye process (Leaflet 4-2).

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.

Leaflet 2-13   Control Systems

1   Introduction

The purpose of this Leaflet is to provide general guidance and advice on the inspection procedures for control systems which are either manually operated, power assisted or power operated. The Leaflet should be read in conjunction with the relevant approved drawings and manuals for the aircraft concerned.

2   Control Systems

A control system is defined as a system by which the flight attitude or the propulsive force of an aircraft is changed (BCAR Section A, Chapter A6–2).

2.1   For the purpose of duplicate inspection (see paragraph 2.2), the flight control system includes the main control surfaces, lift and drag devices and trim and feel systems, together with any flight control lock systems and the associated operating mechanisms and controls. In the case of rotorcraft, the flight control system includes the mechanisms used by the pilot to control collective pitch, cyclic pitch and yaw. The engine control system includes the primary engine controls and related control systems (e.g. throttle controls, fuel cock controls, oil-cooler controls) and the mechanisms used by the crew to operate them.

2.2   **Duplicate Inspection**

A duplicate inspection of a vital point/control system is defined as an inspection which is first made and certified by one qualified person and subsequently made and certified by a second qualified person.

> **NOTE:**   **Vital Point**. Any point on an aircraft at which single malassembly could lead to catastrophe, i.e. result in loss of aircraft and/or in fatalities (see BCAR Section A, Chapter A5–3).

2.2.1   Components, systems or vital points subject to duplicate inspection, must not be disturbed or re-adjusted between the first and second parts of the inspection and the second part of the inspection must, as nearly as possible, follow immediately after the first part.

2.2.2   In some circumstances, due to peculiarities of assembly or accessibility, it may be necessary for both parts of the inspection to be made simultaneously.

3   Inspection of Control System Components

3.1   Control system components, the parts of which are concealed during bench assembly before installation, shall be inspected in duplicate on assembly during manufacture, overhaul or repair.

3.2   Both parts of the duplicate inspection and the results of any tests made during and after final assembly shall be certified on the Inspection Record for the part concerned.

4   Duplicate Inspection of Control Systems

4.1   A duplicate inspection of the control system in the aircraft shall be made:

a) before the first flight of all aircraft after initial assembly,

b) before the first flight after the overhaul, replacement, repair, adjustment or modification of the system. The two parts of the duplicate inspection shall be the final operations and as the purpose of the inspection is to establish the integrity of the system, all work should have been completed. If, after the duplicate inspection has been completed, the control system is disturbed in any way before the first flight, that part of the system which has been disturbed shall be inspected in duplicate (paragraph 2.2) before the aircraft flies.

4.2   In some instances it may not be possible after complete assembly of the aircraft to inspect all parts of the system because some sections of the system may get progressively 'boxed in' and sealed during assembly operations. In such cases the condition and security of any section which is liable to be sealed must be established to the satisfaction of the persons named in paragraph 5 before the section is sealed and the related Inspection Record endorsed accordingly.

4.3   Inspection Records should be carefully prepared to ensure that any duplicate inspection required at an early stage during assembly operations is clearly indicated, thus avoiding unnecessary dismantling at later stages.

4.4   The correct functioning of control systems is at all times of vital importance to airworthiness. It is also essential that suitably licensed aircraft engineers and members of approved inspection organisations responsible for the inspection or duplicate inspection should be thoroughly conversant with the systems concerned. The inspection must be carried out systematically to ensure that each and every part of the system is correctly assembled and is able to operate freely over the specified range of movement without risk of fouling. Also that it is correctly and adequately locked, clean and correctly lubricated and is working in the correct sense in relation to the movement of the control by the crew.

5   Persons Authorised to Certify Duplicate Inspections

5.1   Persons authorised to make the first and second parts of the duplicate inspection of control systems in accordance with BCAR Section A Chapter A6–2 are as follows:

a) Aircraft engineers appropriately licensed in Categories A, B, C and D.

b) Members of an appropriately Approved Organisation who are considered by the Chief Inspector competent to make such inspections, in accordance with Airworthiness Notice No. 3.

c) For minor adjustments to control systems when the aircraft is away from base, the second part of the duplicate inspection may be performed by a pilot or flight engineer licensed for the type of aircraft concerned.

5.2 **Certification**

It is recommended that the certification of the duplicate inspection be in the following form:

Duplicate inspection performed in accordance with the requirements of BCAR, Section A Chapter A6–2

1st inspection .... **signature**

.... **authority**

2nd inspection .... **signature**

.... **authority**

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

6 General

6.1 JAR 5.671(b) states that, in relation to aeroplanes, each element of each control system must be designed, or distinctly and permanently marked, to minimise the probability of incorrect assembly that could result in the malfunction of the system. The interpretive material in ACJ.671(b) states that for control systems which, if incorrectly assembled would hazard the aeroplane, the design should be such that at all reasonably possible breakdown points it is mechanically impossible to assemble elements of the system to give an out-of-phase action, reversed controls or interconnection between two systems which was not intended; only in exceptional circumstances should distinctive marking be used.

6.2 Section G of BCAR, in respect of rotorcraft, specifies that the physical features of the control system elements shall be such that it is mechanically impossible to assemble any system with reversed connections or to confuse the connections between systems.

6.3 These requirements are satisfied in practice in a number of ways, e.g. by the use of end fittings having different diameter threads for different cables, by the use of different diameter pins in correspondingly different diameter holes in end fittings, by staggering the positions of breakdown points so that cross-connecting, etc., is impossible.

6.4 The above requirements do not however, minimise the necessity of thorough end-to-end inspection of each control run. Cases are on record of control cables being crossed and re-crossed so that the relative movements of the controls and the control surfaces were correct.

7 Schedule of Inspection

A schedule of all inspections and functioning checks applicable should be compiled to ensure that no part of the system is overlooked. The schedule should include as a minimum, sufficient instructions to enable the following to be completed:

a) The duplicate inspection of parts of components which will be concealed during bench assembly.

NOTE: Where such work is the subject of a sub-contract order, instructions regarding inspection and duplicate inspection should be stated on the order and incoming

release documentation should be endorsed to the effect that such inspections have been completed.

b) The duplicate inspection of the internal locking and critical assembly features the correctness of which cannot be proved during final inspection or functioning tests with the assembly installed in the aircraft.

c) The duplicate inspection of parts of the control system which may subsequently be obscured by the erection of further structure.

d) The duplicate inspection, functioning and checking for correct relative movement of the complete system.

e) The final inspection of the complete system to ensure that all covers, guards, etc., are correctly fitted.

f) The recording of control surface movements and the serial numbers of components.

NOTE: In considering the instructions to be included in a Schedule of Inspection, it should be noted that the term "control systems" includes (for the purpose of this Leaflet) all power-operated or power-assisted controls together with their attachments and operating mechanism which in any way change the flight attitude or propulsive power of the aircraft. Only when other controls, such as an engine auto-stabiliser or an automatic control unit or parts of these units are interconnected with the control system in such a way that they cannot be instantly overridden by the crew in flight, are they considered as part of the control system.

8   Powered Controls

8.1   Power-assisted Controls

In this type of control, part of the force needed to move the control surface is provided by a power system and part by the physical effort of the pilot. The pilot's 'feel' is thus provided by the control surface loads.

8.1.1   Initial movement of the pilot's controls produces (by mechanical connection) a small movement of the control surface which operates a control valve causing the control jack to follow-up, thus providing the bulk of the force to permit the movement of the control surface. As the control surface reaches the position appropriate to the position of the pilot's control, the valve is closed and the system comes to rest.

8.1.2   In the event of power failure or faults in the power system, satisfactory control can be maintained by manual means. A disconnecting mechanism is usually provided to prevent interference from the power system when it is not in use.

8.1.3   The trim control of power-assisted control systems is usually provided by conventional trailing-edge tabs, as for manually-operated flying control systems.

8.2   Power-operated Controls

In this type of system the whole of the force needed to operate the control surfaces is provided by power systems independent of each other but working in parallel.

8.2.1   Movement of the pilot's control operates a valve controlling an appropriate mechanism which operates the control surfaces until they reach the position appropriate to that of the pilot's control, when the valve is closed and the system comes to rest. It is not inherent in the system that the pilot's 'feel' should have any direct connection to the force on the control surface and this together with the self-centring of the controls, is achieved by artificial means. The two most common methods of providing feel are:

a) constant load for a given control position imposed by a spring strut, and

b) a variable loading related to airspeed and applied by a 'q' system, i.e. a force mathematically proportional to the square of the speed of the aircraft.

8.2.2   To provide for the event of power failure or faults in the power-operating mechanism, manual reversion might be provided, or there may be two or more systems, each with its own independent hydraulic system having additional pumps to safeguard against failure of their own pressure sources. In controls incorporating three power systems, where the servo unit is attached to the main structure and the jack rams move to control the aerofoil surface, a seizure of the unit selector valve could cause a hydraulic lock in the jack concerned. In this unlikely event the combined pressure of the two other jacks is designed to cause a safety relief valve in the defective unit to open, thus maintaining normal power control. The independent systems may operate one at a time, requiring manual changeover if a fault develops, or may be operating all the time in harmony, with a device to cut out (by manual selection or automatically) the system which fails to operate correctly.

8.2.3   Since power-operated controls are irreversible, it is not usual to make use of the conventional trailing-edge trim tab and trim is often obtained by adjusting the zero position of the artificial feel mechanism. However, balance tabs are sometimes fitted to assist in maintaining hinge and servo loads to within the design values.

9   Installation of Flying Controls

The flying controls must be installed in accordance with the requirements prescribed in the relevant approved drawings and documents associated with the drawings, or with the requirements of the relevant manual. All parts used in the installation (e.g. electrical, hydraulic and pneumatic parts of the system) must bear evidence of prior inspection and where applicable, duplicate inspection. It must be ensured that the highest standards of workmanship and cleanliness have been observed and that no parts have been damaged or subjected to distortion during assembly.

9.1   Pulleys and Sprockets

All pulleys and sprockets must be aligned to provide a satisfactory 'run' for the cables and chains so preventing riding on the flanges of the pulleys and sprockets and chafing against the guards and covers.

9.1.1   The pulley and sprocket bearings should be examined to ensure that they are properly lubricated, rotate freely and are free from dirt, swarf and paint spray, etc.

9.1.2   Non-metallic pulleys should be examined for freedom from embedded foreign matter and metal pulleys for freedom from roughness and sharp edges.

9.2   Guards and Covers

Pulleys and sprockets must be guarded to prevent jamming of cables and chains. The guards and covers must be so fitted and locked that they cannot foul the controls in any position and are held positively against rotation about the pulley or sprocket axis. Where a guard forms an integral part of a removable panel, adequate precautions must be taken to check the controls and the correct positioning of the guard after the panel has been replaced.

9.2.1   Glands, gaiters, etc., intended to prevent the escape of lubricant, ingress of foreign matter or loss of cabin pressure where controls pass through pressurised areas, must be undamaged and correctly and securely attached.

9.2.2   When longitudinally-split rubber seals are fitted at pressure bulkheads to seal the apertures through which control cables pass, care must be taken to ensure that the assembly is such that the seal will not be chafed as this could result in the seal being broken permitting the retaining rings to come off and ride along the control cable, possibly causing jamming of a pulley. Care must also be taken to ensure that the retaining rings are installed correctly into the groove in the seal to prevent a similar occurrence.

9.3   **Levers and Fairleads**

All levers and fairleads should be aligned to give the required run without chafing. After installation the levers should be checked for free and unrestricted movement.

9.4   **Chains**

Information on the assembly, testing and installation of chains is given in Leaflet 5–4 and should be read in conjunction with this Leaflet.

9.5   **Cables**

Information on the assembly and testing of spliced and swaged cables is given in Leaflet 2–12.

9.5.1   Before installing a cable which has an identification tag affixed other than as shown in British Standards SP53, SP54, SP105 and SP106, the tag should be removed and for future identification purposes, the particulars on it should be entered in the Aircraft Log Book.

9.5.2   Where applicable the protective treatment specified should be applied to the cables. However, where the cables pass through or over fairleads, any excess greasy substance should be removed to prevent these parts collecting abrasive dust which would wear the cables.

NOTE: In order to improve the wear and fatigue life of control cables, British Standards require a lubricant to be applied during spinning of the cable. It is important, therefore, when cleaning cables not to wash out the lubricant by saturating the cable with a grease solvent.

9.5.3   The cables should be free from broken wires or other defects, e.g. kinks and 'bird-caging', which would affect their strength.

9.5.4   It is important the cables should be correctly tensioned and this can be helped by having the control surface locks in position during tensioning to support the weight of the control surfaces. During tensioning, adjustment should be made equally on all turnbuckles, otherwise circuits which incorporate a number of pulleys and fairleads and/or where the cables have to negotiate several bends may be difficult to tension evenly.

9.5.5   Where the tension is specified in the drawing or manual, this should be checked by means of a tension meter specified for the weight of cable concerned, due allowance being made for temperature. To obtain a true reading the tension meter should be placed in the position on the cable indicated in the drawing or manual. In the absence of a position being specified it should be placed away from fairleads and pulleys.

NOTE: Where long cable runs are concerned, drawings and manuals often detail the tensions required over a range of ambient temperatures.

9.5.6   Where the tension is not specified it should be ensured that the cable run is not too slack or too taut but has a satisfactory 'feel' over the whole range of travel of the controls.

9.5.7   Turnbuckles should be locked (using wire of the gauge and specification quoted in the relevant drawing or manual) using any of the methods illustrated in Figures 1 to 3. Prior to locking, it should be ensured that the end-fittings are 'in safety' (i.e. the internal fitting extends past the inspection hole in the external fitting) by attempting to pass a hardened pin probe through the inspection hole. Locking wire must not be used more than once.

          NOTE: Some turnbuckles are designed so that they can be locked by special locking devices (e.g. spring locking clips to MS2 1256). Instructions regarding their assembly and use should be obtained from the relevant manual.

9.5.8   With the larger type of control cables (i.e. cables from 45 to 120 cwt), it has been found that tension loads tend to straighten out the helically-wound cable resulting in a torque action sufficient to break the locking wire or release lock nuts on turnbuckles or similar assemblies. To overcome this 'unlocking' action a tube fitted over the turnbuckle assembly and drilled to accommodate three bolts is often specified. This provides a positive means of preventing independent rotation of any part of the assembly.
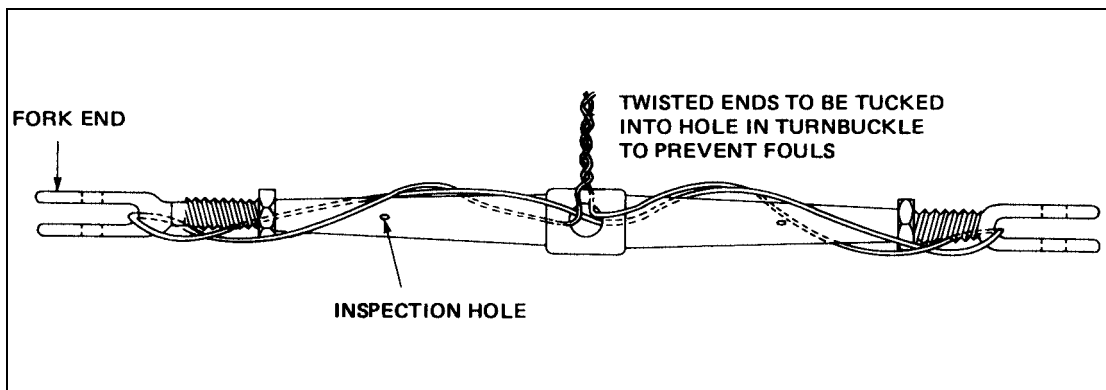

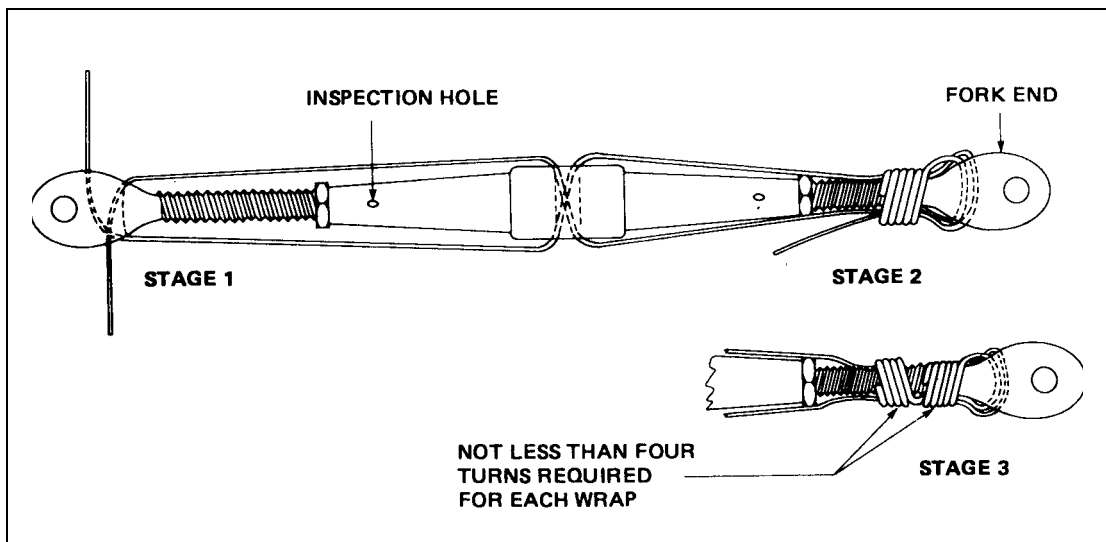**Figure 1**   Wire-locking of Turnbuckle with Fork End-fittings

Figure 2   Alternative Method of Wire-locking Turnbuckle with Fork End-fittings
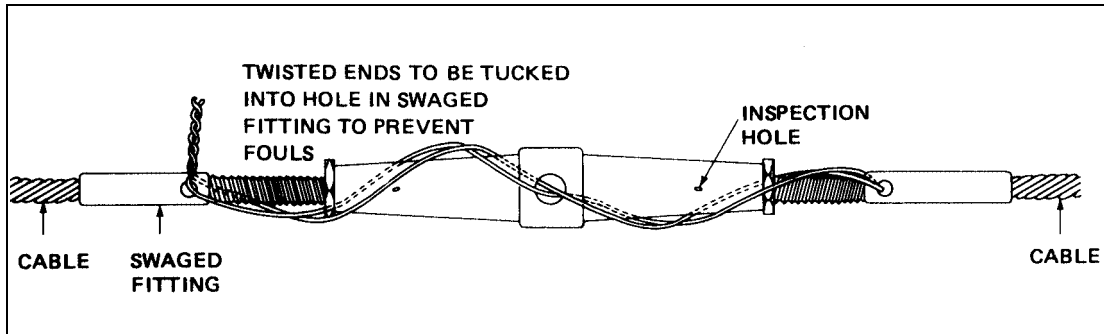
Figure 3   Wire-locking of Turnbuckle with Swaged End-fittings

9.5.9   The adjustable end-fitting shown in Figure 4 may be attached, for example, to a swaged cable, a chain or a tension rod. The threaded end must be in safety and the locknut adequately tightened. The screwed portion (A) must not abut the fitting (B) in the fork end as this would impose an additional strain on the fitting, the joint would lack flexibility and there would be no provision for further adjustment.
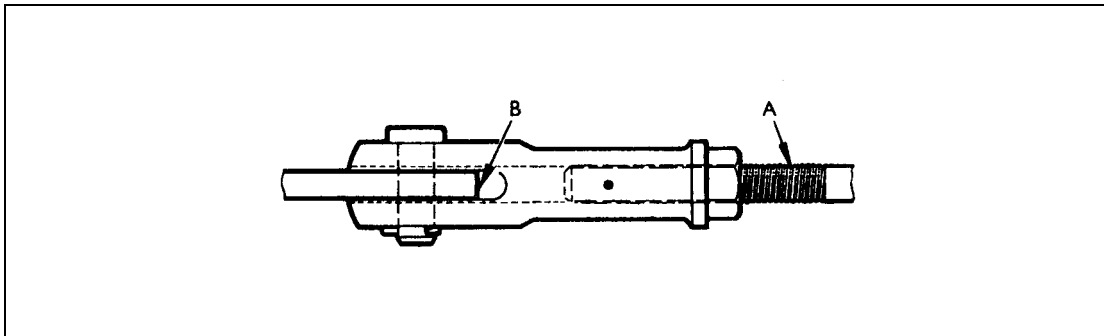

Figure 4   Adjustable Fork End-fitting

9.6   **Control Rods**

Control rods should be perfectly straight (unless designed to be otherwise) when fitted and bell-cranks, etc., to which they are attached, should be checked for freedom of movement before and after assembly of the control rods. The assembly as a whole should be checked for correct alignment.

9.6.1   Where self-aligning ball-races are fitted, free rotational movement of the rods must be obtained in all positions.

9.6.2   There have been cases of control rods with self-aligning bearings becoming disconnected because of failure of the peening retaining the ball-races in the rod end housings, thus allowing the rods to become detached from the ball-races. This can be obviated if the control rods are assembled so that the abutment flange of the rod end housing is interposed between the ball-race and the anchored (as opposed to the free) end of the attachment pin or bolt (see Figure 5). Alternatively, a washer having a larger diameter than the hole in the abutment flange may be required under the retaining nut on the end of the attachment pin.

9.7   **Gearboxes and Torque Tubes**

Where this type of equipment is installed in the system, it should be ensured that the gearboxes are correctly mounted, that the torque tubes are not bowed and run freely in their guides, that universal joints are correctly fitted and give the correct degree of

angular transmission throughout a complete rotation of the torque tube and that only the lubricant specified by the aircraft manufacturer is used in the gearbox.

9.8   **Control Surfaces, Tabs, etc.**

The method of attachment varies with each type of aircraft, but it must be ensured that the component is assembled to the aircraft without strain and that adequate clearance exists between adjacent control surfaces, or between the control surface and adjacent structure and shrouds, throughout the full range of movement. There must be no slackness in linkage which may cause collective backlash and introduce control flutter.
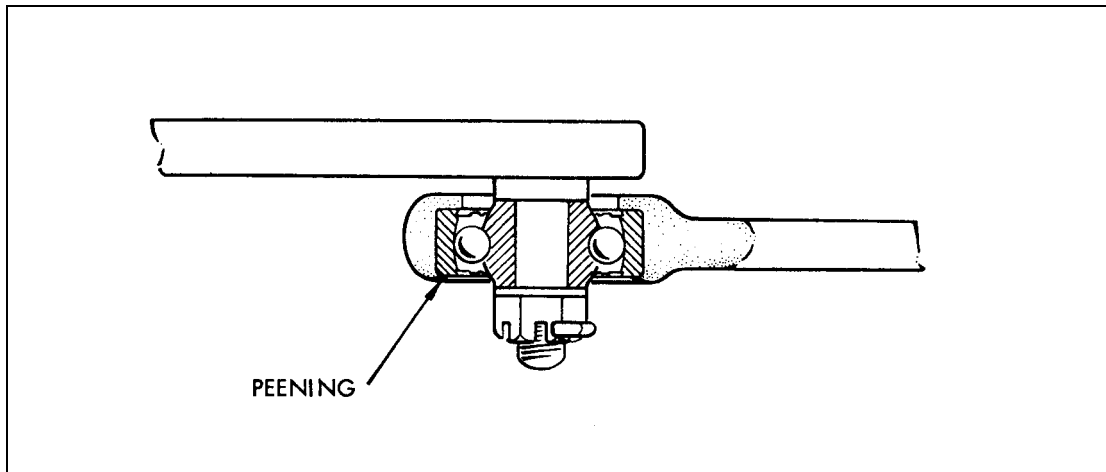

Figure 5   Self-aligning Bearing

9.9   **Rotor Blades**

Rotor blades are particularly susceptible to damage and are sensitive to the effects of damage. Particular care is necessary therefore, when handling and assembling rotor blades to prevent them becoming dented or scored. The attachment of rotor blades must be inspected in duplicate as must the re-securing of the blades after unfolding.

9.10   **Locking**

All connections of components and parts in the control system must be positively secured and locked in accordance with drawing requirements (see Leaflet 2–5).

9.11   **Lubrication**

All moving parts should be lubricated with the specified lubricant during assembly. Proprietary bearings, such as those of the oil-retaining variety, should receive lubrication only when recommended by the manufacturer.

9.12   **Placarding**

A check should be made to ensure that all placards and notices relating to the functions, direction of movement and operational positions of controls, levers, handles, etc., are clearly and correctly applied in accordance with drawing requirements and are in their specified positions.

NOTE: It is important that all placards and labels should be maintained in a clean and legible condition.

9.13   **General**

During installation, care must be taken to avoid any possibility of the controls jamming or fouling against adjacent structure, or cables rubbing together or chafing against

other fixed or moving parts throughout their range of movement. Where clearances are not stated on drawings and there is some doubt about their adequacy, the guidance of the approved Design Organisation should be sought. The system should be protected against corrosion and deterioration and should be effectively bonded (see Leaflet 9–1).

10   Control Settings

10.1   Manually operated

The manual operation of the system should be witnessed whilst the controls are operated throughout their full range. This should be carried out in quiet conditions as some mechanical defects can be detected by an unusual noise. The primary systems should be checked for static friction, using a spring balance. The CAA recommends that the forces on the control column or wheel and rudder pedals necessary to overcome static friction should not exceed the values given in Table 1. In the case of systems incorporating cables, these conditions should be met with the cables rigged at the stipulated tensions.

Table 1

Maximum Weight of Aeroplane kg(lb)	Maximum Static Force on Control N(lbf)		
	Elevator	Aileron	Rudder
5700 kg (12 500 lb) or less	17·79 N (4 lbf)	8·89 N (2 lbf)	26·68 N (6 lbf)
22 680 kg (50 000 lb) or more	44.48 N (10 lbf)	35.59 N (8 lbf)	44.48 N (10 lbf)
Linear variation should be assumed between these weights.			

10.2   The full and synchronised movement of the controls should be checked to the relevant rigging diagrams and the limit stops adjusted as necessary to the relevant rigging diagram requirements. The stops should be relocked. It is important that the pilot's controls and control surfaces contact their stops in the correct sequence.

> **NOTE:**   When checking the range of movement of the control surfaces, it is important that the controls should be operated by the pilot's controls and not by handling the control surfaces. It should be ensured that all obstructions, such as trestles, are out of the way of control surfaces.

10.3   During the checking of settings it should be ensured that collective backlash in the system does not exceed permitted limits and when controls are in the 'full-travel' position and against their respective stops, that chains, cables, etc., have not reached the limit of their travel. Where dual control facilities are provided, it should be ensured that they are correctly synchronised and function satisfactorily when operated from both positions.

10.4   Where components or control systems are interconnected, it should be ensured that they are correctly co-ordinated in accordance with drawing requirements.

10.5   Where friction devices are employed, it should be ensured that the selected degree of friction is applied to the controls throughout the range of movement.

10.6   Trim tabs and other tabs should be checked in a similar manner to the main control surfaces, it being ensured that any devices for indicating the position of the tabs

function correctly. When screw jacks are employed to actuate the tab, care must be taken to ensure that they are not out of safety when in the fully extended position.

10.7   Where spring devices are fitted in the control system, these should be checked for correct tension, cleanliness and adequate lubrication.

10.8   Guidance on control functioning checks for aeroplanes and rotorcraft is given in paragraph 11.

10.9   **Powered Controls**

The rigging of powered controls varies with each type of aircraft, therefore, it is impracticable to attempt in this Leaflet to define a procedure; it is essential to follow the manufacturer's requirements in this respect. However, reference can be made to the nature of the precautions which should be taken when rigging such systems.

10.10   It is of the utmost importance that each system should be correctly adjusted and all means of adjustment correctly locked. Where cables are used in powered control systems, it is essential that they are correctly tensioned to prevent malfunctioning of the actuating units. The tensioning requirements, the type of tension meter to be used and the positions where readings are to be taken will be prescribed in the relevant manual for the aircraft concerned. To compensate for structural flexing and changes in temperature, cable-tension compensator-units are sometimes incorporated in the control circuit; these compensators should be pre-set and the system adjusted as prescribed in the relevant manual. To simplify the adjustment, compensator units may be provided with scales or datum holes to indicate when the adjustment is correct.

10.11   It is important during initial setting that jacks do not bottom, unless the relevant manual so specifies, as this may result in over-stressing of parts of the unit which could lead to failure in service.

10.12   Pins, usually 'rigging' pins (which must have a red warning flag permanently attached), are sometimes required to simplify the setting of such parts as pulleys, levers, hydraulic control units, etc., in their neutral positions by inserting the pins in the alignment holes provided. This arrangement also simplifies the correct alignment and tensioning of the various control systems. When rigging pins are not provided, the neutral positions may be checked by means of alignment marks, by the use of special templates or by taking linear measurements; these procedures will be clearly defined in the relevant manuals.

NOTE: To prevent damage to the control system, if by error rigging pins were left in position, some rigging pins are designed to have a maximum shear value and only those designed for the system concerned should be used, but in general, the accuracy of diameter and correct fitting are the important considerations. Ground locking devices should never be used in lieu of rigging pins.

10.13   If the final alignment and adjustment of the system is correct, it should be possible to withdraw the rigging pins easily. Any undue tightness of the pins in the rigging holes indicates incorrect tensioning or malalignment of the system.

NOTE: All rigging pins or centralising devices must be removed immediately after the rigging operation is completed and before operating the power systems, otherwise damage may result. This precaution must be made part of the control system clearance procedure. Similarly, precautions should be taken to ensure that all obstructions, such as trestles, are out of the way of control surfaces.

10.14   When static friction tests are prescribed for the control circuits, these should be done with a spring balance or suitable test rig in the manner prescribed and must not exceed the limiting values permitted. In some power-assisted systems, excessive

friction could upset the feel of the system to the detriment of the handling qualities of the aircraft.

> **NOTE:** In some instances it may be necessary to disconnect the 'feel' spring struts in order that the true friction value can be obtained. It may also be necessary to check spring-strut break-out forces following the static check.

10.15 Since the hydraulic systems are independent of each other, a check should be made to ensure that the routeing of all pipelines and electrical cables does give the necessary isolation. In addition, pipelines and electrical cables should be checked for signs of chafing while the systems are functioning.

10.16 It is essential that all control functioning checks and tests are carried out strictly in accordance with the manufacturers' publications.

> **NOTE:** It must be ensured that test rigs contain the correct fluid and are provided with the same standard of filtration as is provided on the aircraft.

10.17 The correct engagement and disengagement of control locks should be checked at the same time as a check on the correct functioning of the associated warning devices.

10.18 The range of movement of the controls and control surfaces should be checked in both directions from the neutral position. If the range does not meet the rigging tolerances, the necessary adjustments should be made and the duplicate inspection completed (see paragraph 4).

10.19 Where components in control systems are interconnected, their operation should be correctly co-ordinated in accordance with drawing requirements. Where friction devices are employed, it should be ensured that the selected degree of friction is applied to the controls throughout the range of movement.

10.20 When testing the system, all hydraulic equipment and pipelines should be checked for leaks. The appropriate filters should be checked for cleanliness and freedom from damage and particular care should be taken to follow the instructions given in the relevant manual, as a broken or disintegrated filter may cause a valve to jam. Where 'tell-tale' indicators are incorporated in filters these should be checked at the periods specified. After checking for cleanliness, all air should be expelled from the systems.

10.21 **Engine Ground Run Test**

As some parts of the hydraulic systems are not tested with the hydraulic test rig, the controls should be operated during a convenient ground test run to ensure that all engine pumps operate satisfactorily over the speed range of the pumps. Where part of a hydraulic system has been disconnected, e.g. to change an engine or pump, precautions should be taken to expel any air which may have entered the system and the operation of the system should be rechecked.

11 Control Functioning

The final functioning checks on control systems is of the greatest importance and it is essential that they should be completed systematically. The checks should be carried out after thorough cleaning and only when all other work on the system has been completed.

11.1 Aeroplanes

11.1.1 The functioning checks must include verification that full, free and correct movement of the controls is obtained throughout the system relative to the movement of the crew controls.

11.1.2   A list of all controls and the salient checking points should be drawn up in a suitable sequence and in duplicate.

11.1.3   A person competent to certify a duplicate inspection should operate the controls in the cockpit, maintaining the sequence specified in the checking list. Another person competent to certify the duplicate inspection should check on the control movements in the same sequence. For the second part of the inspection the two persons should exchange positions and repeat the checks in identical sequence.

11.1.4   The relative movements of the control surfaces in relation to the pilot's controls should be carefully checked to the manufacturer's instructions.

> **NOTE:**   Where 'free operating control surfaces' are installed the relative movements of controls are affected. For example, if the control column is moved back, the elevator does not move at all, but the tab of the elevator moves downwards causing the elevator to move upwards in flight. This type of control system requires a special checking technique and the manufacturer's instructions must be closely followed.

11.1.5   The movement of wing-flaps and slats should be checked for synchronisation and a check should be made to ensure that the relevant surface position indicator accurately registers the position of the surfaces throughout their range of movement.

a)   A check should be made (where applicable) to ensure that the wing-flap or slat asymmetric control device is functioning correctly.

b)   Where wing-flaps are interconnected with leading-edge flaps or slats, the installation should be checked for correct operation during extension and retraction of the wing-flaps.

11.1.6   Where spoilers/speed brakes are interconnected with the aileron control system, their correct operation in relation to the ailerons should be checked.

11.1.7   Where an aerodynamic feel simulator is connected into the main control systems, its correct operation should be checked with the aid of a suitable pitot system test rig.

11.1.8   It should be ensured that when operational time limits are specified for certain controls, e.g. flaps, spoilers or speed brakes, these are within permitted limits.

11.2   **Rotorcraft**

11.2.1   A list of all controls affected and the salient checking points should be drawn up in a suitable sequence and used as indicated in the relevant parts of paragraph 7.

11.2.2   The nature of the functioning checks necessary will vary with the system concerned, but where applicable the following should be checked:

a)   That the direction of movement of the main and tail rotor blades or other related controls in relation to the movement of the pilot's controls is correct.

b)   That the operation of interconnected control systems (e.g. engine-throttle and collective-pitch controls) are co-ordinated in accordance with drawing requirements.

c)   That the range of movement and neutral positions of the pilot's controls (i.e. cyclic-pitch control columns, collective-pitch levers and yaw pedals) are as specified in the relevant drawings.

d)   That the maximum and minimum pitch angles of the main rotor blades, in both fore-and-aft and lateral cyclic-pitch, are within drawing requirements.

e)   That the maximum and minimum pitch angles of the main rotor blades in collective pitch are within drawing requirements.

f) That, in the case of multi-rotor aircraft, the rigging and the movement of the blades of the rotor are in correct synchronisation.

g) That the tracking of the main rotor blades is satisfactory.

h) That, when tabs are provided on main rotor blades, these are correctly set.

i) That the neutral, maximum and minimum pitch angles and coning angles of the tail rotor blades are in accordance with drawing requirements.

j) That, when dual controls are provided, these function correctly and in synchronisation when operated from both positions.

k) That, to comply with the relevant chapters of BCAR, the static operating loads of the system are not excessive and when specified, do not exceed drawing requirements.

11.2.3 Tracking Checks

When the main rotors do not 'cone' by the same amount during rotation, they are said to be 'out of track'. This may result in excessive vibration at the control column. Tracking checks should be carried out at the prescribed engine operating conditions, if possible in still air. Where it is not possible to obtain still-air conditions, the rotorcraft should be faced into a wind not exceeding 10 knots and free from gusts.

11.2.4 Tab Setting

The setting of the tabs on main rotor blades (if provided) should be checked to eliminate out-of-balance moments which will apply torque to the rotor blades. The tab setting should be checked for correctness by running the rotor at the prescribed speed and ensuring that the cyclic-pitch control column remains stationary. Out-of-balance moments impart a stirring motion to the column.

11.2.5 Checking Blade Angles

Before checking blade angles it must be ensured that the rotorcraft and where applicable, the rotorhead, is set up in the correct lateral and longitudinal position. The blades must be set in the specified position for the check. The blade angle should be checked on each blade in turn and when specified, the angles of the subsidiary blades on the main rotor must agree with those of the master blade within the prescribed limits. When it is necessary to adjust the initial blade rigging in order to obtain correct tracking or acceptable flight characteristics, the rigging should be re-checked after test flying has been completed to ensure that it is within permitted limits.

11.3 Control Locks

A check should be made on internal ground control-locking systems to ensure they are positive in action, engage fully in the 'locked' position and have adequate clearance in accordance with drawing requirements in the 'unlocked' position. There should be no possibility of interference between the locks and the controls over the full range of movement of the latter.

11.4 Inspection after Functioning

When the functioning checks have been completed, all checking equipment should be removed from the aircraft and a final inspection made to ensure that the systems are free from all foreign matter which might cause jamming (e.g. nuts, bolts and small tools). All access panels should be replaced, care being taken to make sure that securing screws are the correct length not to foul the controls and that chains and cables retaining the access panels are correctly fitted.

12 Automatic-pilot Installations

The information in this paragraph does not apply to any particular type of installation of automatic-pilot but gives general guidance on essential points which relate to the flying control system. Any moving parts of the automatic-pilot that constitute integral parts of the normal control system, whether the automatic-pilot is 'in' or 'out', should be regarded as part of the flying control system and should be inspected in accordance with the procedure given in this Leaflet.

12.1 When the automatic controls are disengaged, the normal controls should function satisfactorily, e.g. the resistance offered by the automatic-pilot motors, where applicable, should not affect the control of the aircraft.

12.2 A check should be made on the means provided for disconnecting the automatic-pilot from the normal controls to ensure it is possible to do so at all positions of the controls and that the manual override of the automatic-pilot is satisfactory.

12.3 The interconnecting mechanism between the automatic-pilot and the normal controls should give the required range of travel and should be correctly aligned and smooth and positive in operation. The clearance should be in accordance with drawing requirements.

12.4 Operating cables, where applicable, should be checked for tension in the manner applicable to the particular installation.

13 Ground Test – After Overhaul or Major Dismantling

13.1 All rigging pins or retaining devices should have been removed from the controls. Where control locks are not provided, it may be necessary to support the control surfaces until the system is functioning. The control surfaces should be checked for freedom from obstruction and the automatic-pilot should be disengaged.

13.2 If any one of the independent systems has been disturbed, a complete series of checks required to test that system should be made. Where any rectification affects more than one system or where there is any possibility of the functioning of all systems being affected, then the complete series of checks to test all systems should be made.

14 Periodic Inspections

Periodic inspections on the complete flying control systems should be carried out in accordance with the requirements of the Maintenance Schedule or manufacturer's Manual.

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Leaflet 2-14 Measurement and Calibration Systems

1   Introduction

1.1   Requirements within the relevant airworthiness codes applicable to the United Kingdom civil aviation industry such as British Civil Airworthiness Requirements (BCARs), Joint Aviation Requirements (JARs), and Air Operators Certificates (arrangements for maintenance support) prescribe that, where necessary, tools, equipment and in particular test equipment (herein after called appliances) are calibrated to standards acceptable to the CAA.

1.2   This Leaflet gives guidance on the general aspects of establishing and maintaining an effective calibration system acceptable to the CAA. It takes into account factors such as the degree of accuracy required, frequency of use and reliability of the appliance. The key factor, however, is the need to establish confidence in the accuracy of the equipment when required for use. The required calibration frequency for any particular appliance is that which will ensure it is in compliance with the standards applicable to its intended use.

1.3   In all cases, standards used are predicated upon the need for ultimate traceability to one of the following:

• The standard specified by the appliance manufacturer/design organisation.

• The appropriate national/international standard.

2   General

2.1   The appropriate standards are used to achieve consistency between measurements made in different locations possibly using alternative measuring techniques. Calibration of appliances is best achieved by operating a methodical system of control, traceable by an unbroken chain of comparisons through measurement standards of successively better accuracy up to the appropriate standard.

2.2   Where recommendations for calibration standards are not published or where the calibration or standards are not specified, calibration should be carried out in accordance with 'British Standard EN 30012–1 Quality Assurance Requirements for Measuring Equipment.'

2.3   As an alternative to operating an internal measurement and calibration system, an Approved Organisation/Licensed Engineer may enter into a sub-contracting arrangement to use the services of an appliance calibration service. This, however, does not absolve the user from implementing suitable controls and maintaining calibration records appropriate to paragraph three of this leaflet.

2.4   In all cases it is the responsibility of the user to satisfy himself that an unbroken traceability chain is in place. Organisations such as those holding suitable National Accreditation of Measurement and Sampling (NAMAS) accreditation may be considered to be acceptable to provide external calibration services.

3   Procedural Controls

3.1   Appliances requiring calibration are those items which are necessary to perform measurements or tests of an aircraft, system or component to defined limits, as specified in the Type Certificate holders technical documentation.

3.2   Procedures controlling inspection/servicing and, where appropriate, calibration of such items on a regular basis and to indicate to users that the item is within any inspection, service or calibration time-limit should be developed.

3.3   A programme should be developed to plan the periodic inspection, service or calibration within defined time limits to ensure appliances remain in calibration. The programme should consider staggering inspections, servicing or calibrations to ensure that the maximum number of appliances are available at all times. A register of such appliances is essential in order that control of the calibration system is achieved in a co-ordinated manner. Where the appliance holding does not provide a level of redundancy, contracted loan arrangements may be acceptable.

3.4   The intervals at which calibration is required to be conducted can vary with the nature of the appliance, the conditions under which it is used and the consequences of incorrect results. The inspection, service or calibration intervals should therefore be in accordance with the appliance supplier's instructions, except where the organisation can show that a different interval is warranted in a particular case. This would normally require a system of continuous analysis of calibration results to be established to support variations to manufacturers recommended intervals.

3.5   A clear system of labelling calibrated appliances is therefore necessary setting out when the next inspection, service or calibration is due and indicating the serviceability, particularly where it may not be obvious.

3.6   Any appliances whose serviceability is in doubt, should be removed from service and labelled accordingly. Such equipment shall not be returned to service until the reasons for the unserviceability have been eliminated and its continued calibration is re-validated. Where the results of calibration prior to adjustment or repair indicate that a risk of significant errors may have existed in any previous measurements made, the necessary corrective action should be taken.

3.7   Records shall be maintained in order that it can be demonstrated that the appliance is capable of functioning within the designated limits. The scope of records to be maintained is dependant on standards used and the nature of the appliance. The record system may also provide a valuable reference in cases of dispute, or warranty claims, but they are also used for assessing calibration drift and wear. Such data provides a basis for development of effective calibration intervals.

Calibration records or certificates should, as a minimum, contain the following information for each appliance calibrated:

- identification of equipment

- standard used

- results obtained

- uncertainty of measurement

- assigned calibration interval

- limits of permissible error

- the authority under which the release document was issued

- any limitation of use of the equipment

- date on which each calibration was conducted.

3.8   Where calibration services are provided by outside Organisations, it is acceptable to the CAA for the accuracy of the item to be attested by a release document in the name of the company which records the information specified in paragraph 3.7.

3.9   Any measurement is affected to some degree by the environmental conditions under which it is carried out. Appliances need to be calibrated, transported and stored under conditions compatible with the type of equipment to ensure accuracy is not impaired.

3.10   To provide valid repeatable test results, the facilities used for calibration undertakings are expected to provide controlled environmental conditions to comply with the applicable standard or original appliance supplier's specification. It will therefore be necessary to control temperature, humidity, vibration, dust, cleanliness, electromagnetic interference, lighting and any other factors that may affect calibration results to predetermined standards. In cases where appliances cannot be placed in a controlled environment for calibration, compensation corrections should be applied to the calibration standard to provide the required level of accuracy.

3.11   Although not a substitute for regular calibration, confidence that an appliance continues to measure correctly can be obtained by the use of a checking measurement standard, applied by the user. This will demonstrate that, at the value or values checked and under the conditions of the check, the appliance is still functioning correctly. The checking standard itself, which usually has to be simple and robust, will need to be calibrated in order that the results obtained by its use can, with reliance, be attributed to the instrument and not to changes in the checking measurement standard.

3.12   Any calibration system adopted would need to comply with the minimum requirements of the airworthiness code to which it has been implemented. The continued effectiveness of the calibration system and associated procedures should be periodically and systematically reviewed by company quality systems.

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