BASIC

IDENTIFICATION MARKING

BOLTS AND SCREWS OF BRITISH MANUFACTURE

1 INTRODUCTION This Leaflet gives guidance on the identification of bolts and screws complying with British Standards 'A' Series of Aircraft Materials and Components and the Society of British Aerospace Companies 'AS' series of specifications. The Leaflet does not include information on the 'AGS' series since these have been entirely superseded by other standards. Information on the manufacture and testing of bolts and screws will be found in British Standards A100 and A101, entitled "General Requirements for Bolts and Nuts of Tensile Strength not exceeding 180 000 lbf/in² (125 hbar)", and "General Requirements for Titanium Bolts", respectively.

1.1 The identification of bolts and screws located on aircraft may not always be an easy task since not all are marked to show the standard to which they conform. This Leaflet sets out to show the features from which positive identification may be made, but it should be understood that items exist, which although identical in appearance, may not be interchangeable. It is also important to understand the direction of stress in a particular bolt since a 'shear' bolt must not be used to replace a 'tension' bolt. If any doubt exists as to the identity of a particular item the appropriate Parts Catalogue should be consulted; replacement of an incorrect part may lead to failure in service.

1.2 It will be found that a number of Specifications are either obsolete or obsolescent, in some instances due to standardisation of a countersunk head of 100° included angle. The replacements are indicated in the tables.

1.3 Information on the identification of nuts of British manufacture is given in Leaflet **BL/2-6.**

1.4 A list of the abbreviations used in this Leaflet is given in paragraph 5.

2 BRITISH STANDARDS This paragraph is concerned with the identification of bolts and screws complying with the British Standards 'Aircraft' (A) series. For ease of reference the paragraph has been divided into two sections, paragraph 2.1 dealing with bolts and screws having either British Association (BA) or British Standard Fine (BSF) threads, and paragraph 2.2 dealing with bolts and screws having Unified threads.

2.1 **Bolts and Screws with BA or BSF Threads.** In this series, BSF threads are used on bolts of ¼ inch diameter and larger; smaller bolts and all screws have BA threads, except that grub screws are also supplied in ¼ inch BSF. BA sizes larger than 2 BA are not specified. Table 1 gives a list of the relevant Standards, superseding Standards and identification data appropriate to the series, and Figure 1 illustrates the types of head used. To find the Standard number of a given item proceed as follows:—
Identify the head from Figure 1, for example '(l)'. Reference to Table 1 shows that '(l)' refers to an A61 bolt. If the illustration applies to more than one specification, further information contained in the table, such as the type of finish, should enable the identification to be completed.

TABLE 1

BA AND BSF BOLTS AND SCREWS

Standard No.	*Description*	*Material*	*Finish*	*Head (Fig. 1)*	*Remarks*	*Thread*	*Normal Size Range*
A17	Hex. hd. bolt	Al Al	anodic	e or f	obsolescent	BA/BSF	6 BA to 1 in BSF
A25	Hex. hd. bolt	HTS	cad	a,b,c or d	replaces A15Y	BA/BSF	6 BA to 1 in BSF
A26	Hex. hd. bolt	CRS	nat	a	replaces A15Z	BA/BSF	6 BA to 1 in BSF
A28	Hex. hd. bolt	Al Al	anodic	g or h	obsolescent	BA/BSF	6 BA to 1 in BSF
A30	Hex. hd. c/t bolt	HTS	cad	i or j	cad h & t	BA/BSF	6 BA to 1 in BSF
A31	Cheese hd. screw	LTS	cad	o	replaces AGS 247	BA	12 BA to 2 BA
A32	Round hd. screw	LTS	cad	n	replaces AGS 245	BA	10 BA to 2 BA
A33	90° csk. hd. screw	LTS	cad	q	replaces AGS 249	BA	12 BA to 2 BA
A34	Raised csk. hd. screw	LTS	cad	p		BA	10 BA to 2 BA
A35	Cheese hd. screw	CRS	nat	o	replaces AGS 896	BA	12 BA to 2 BA
A36	Round hd. screw	CRS	nat	n	replaces AGS 967	BA	10 BA to 2 BA
A37	90° csk. hd. screw	CRS	nat	q	replaces AGS 968	BA	12 BA to 2 BA
A38	Raised csk. hd. screw	CRS	nat	p		BA	10 BA to 2 BA
A39	Cheese hd. screw	Al Al	anodic	o		BA	12 BA to 2 BA
A40	Round hd. screw	Al Al	anodic	n	replaces AGS 564	BA	10 BA to 2 BA
A41	90° csk. hd. screw	Al Al	anodic	q		BA	12 BA to 2 BA
A42	Raised csk. hd. screw	Al Al	anodic	p		BA	10 BA tp 2 BA
A43	Cheese hd. screw	Brass	tinned	o	replaces AGS 246	BA	12 BA to 2 BA
A44	Round hd. screw	Brass	tinned	n	replaces AGS 244	BA	10 BA to 2 BA
A45	90° csk. hd. screw	Brass	tinned	q	replaces AGS 248	BA	12 BA to 2 BA
A46	Raised csk. hd. screw	Brass	tinned	p		BA	10 BA to 2 BA
A55	Grub screw	FCS	cad	none		BA/BSF	6 BA to ¼ BSF
A56	Grub screw	CRS	nat	none		BA/BSF	6 BA to ¼ BSF
A57	Hex. hd. shear bolt	HTS	cad	k	cad h & t only	BSF	¼ to ¾ in BSF
A59	Hex. hd. c/t bolt	HTS	cad	i		BA/BSF	6 BA to 1 in BSF
A60	Hex. hd. shear bolt	HTS	cad	k		BSF	¼ to ¾ in BSF
A61	Hex. hd. bolt	Al Al	anodic	l or m	replaces A28	BA/BSF	6 BA to 1 in BSF

2.1.1 In some instances, e.g. A31 to A56 in Table 1, identification can only be effected from the finish applied (mechanical testing apart), or by the labelling on packages.

2.1.2 **Code Systems for Bolts.** The code system used for the identification of the bolts listed in Table 1 consists of the standard number followed by the part number of the particular bolt. The part number consists of a number indicating the nominal length of the plain portion of the shank in tenths of an inch, followed by a letter indicating the nominal diameter (Table 2). Example: The complete part reference number for a ⅜ inch A57 bolt of length L = 3·1 inch is A57 31J.

TABLE 2

DIAMETER CODE LETTERS

Code	*Size*	*Code*	*Size*
A	6 BA	P	9/16 in BSF
B	4 BA	Q	⅝ in BSF
C	2 BA	S	¾ in BSF
E	¼ in BSF	U	⅞ in BSF
G	5/16 in BSF	W	1 in BSF
J	⅜ in BSF	X	12 BA
L	7/16 in BSF	Y	10 BA
N	½ in BSF	Z	8 BA

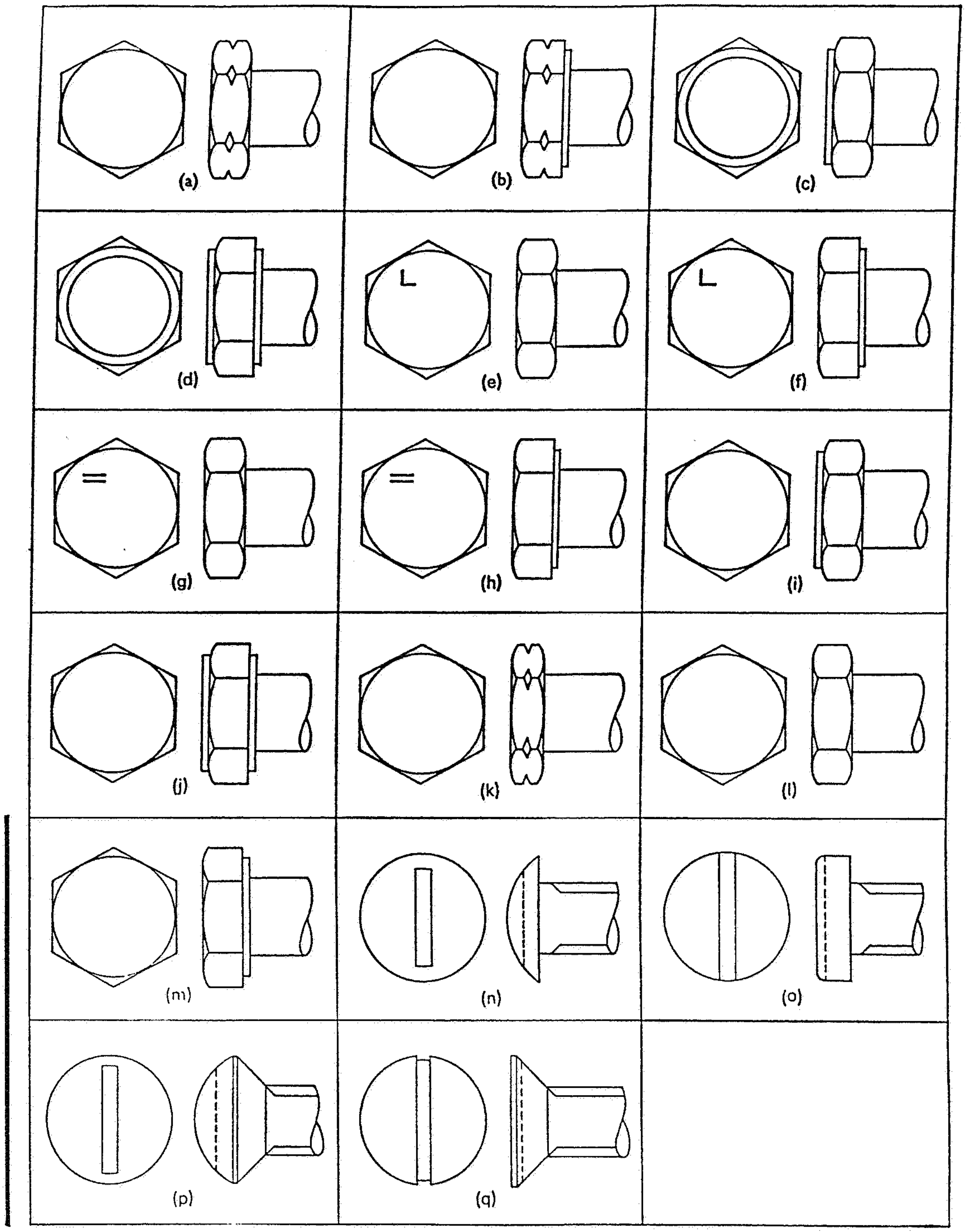


Figure 1 IDENTIFICATION OF BRITISH STANDARDS BA/BSF BOLTS AND SCREWS

(i) All bolts to British Standards A25, A26, A30, A57, A59, A60 and A61 of ¼ inch nominal diameter and over are marked with the appropriate British Standard on the upper face of the head. Additionally, bolts of $\frac{7}{16}$ inch nominal size and larger have the appropriate part number applied to the upper face of the head. Parcels of bolts have the number of the relevant British Standard and the appropriate part number clearly stated on the labels.

(ii) The positions at which the plain length is measured on hexagon bolts and the overall lengths on various types of screws are indicated in Figure 2. It should be noted that with BA and BSF bolts, the plain portion of the shank includes the thread 'run-out'. A 'washer face' (e.g. Figure 1 (b)) on the undersurface of a bolt head is not included in the plain length of the shank.

2.1.3 **Code System for Screws (A31 to A46).** The code system used for the identification of the screws listed in Table 1 consists of the British Standard number followed by the part number of the particular screw. The part number consists of a number indicating the nominal length of the screw (in thirty-seconds of an inch) when measured as described below (see also Figure 2) preceded by a letter indicating the nominal diameter (Table 2). Example: The complete part referencing number for a 2 BA A41 countersunk head aluminium alloy screw ½ inch long, is A41 C16.

(i) **Cheese and Round Heads.** The nominal length is the distance measured from the underside of the head to the extreme end of the shank, including any chamfer or radius.

(ii) **Countersunk Heads.** The nominal length is the distance measured from the upper surface of the head to the extreme end of the shank, including any chamfer or radius.

(iii) **Raised Countersunk Heads.** The nominal length is the distance measured from the upper surface of the head (excluding the raised portion) to the extreme end of the shank, including any chamfer or radius.

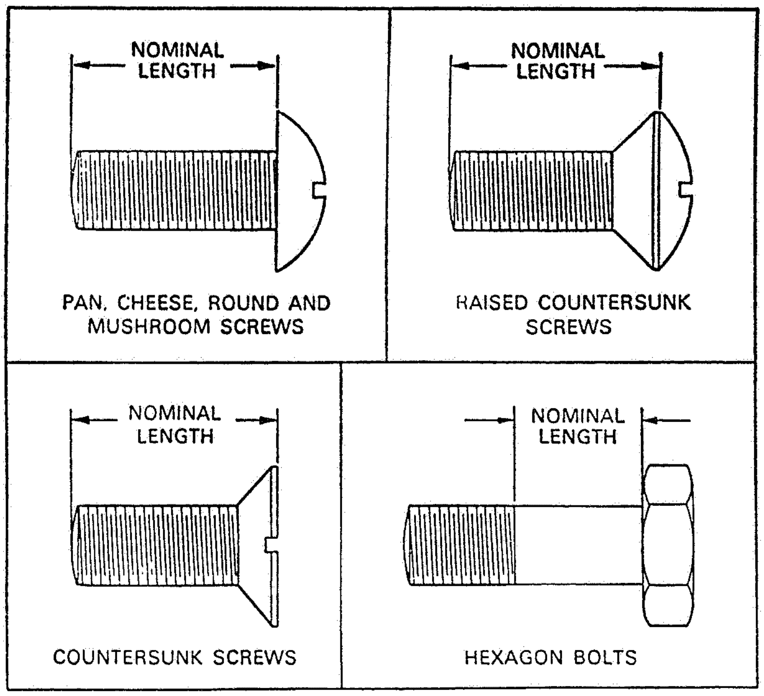


Figure 2 LENGTH OF BA/BSF BOLTS AND ALL SCREWS

2.1.4 **Code System for Grub Screws Complying with A55-A56.** The code system used for these screws consists of the British Standard number followed by the part number of the particular screw. The part number consists of a number indicating the overall length of the screw in sixteenths of an inch, preceded by a letter indicating the nominal diameter. Example: The complete part referencing number for a ¼ inch diameter A55 screw, ½ inch long, would be A55 E8.

2.2 **Bolts and Screws Having Unified Threads.** Table 3 gives a list of current and obsolescent bolts and screws in the Unified range. Figure 3 illustrates the type of head used in this range and also shows the general 'Unified' symbols, including (h) the cylindrical extension (dog point) sometimes used on parts not having hexagon shaped heads. It will be noticed that there are several shapes of hexagon head; these are alternative methods of manufacture and do not necessarily provide a means of identification, although A108 and A111 bolts, which have close tolerance shanks, have a cylindrical extension on top of the head and shear bolts always have thin heads. Bolts and screws of similar shape may be further identified by the material; aluminium alloy is dyed green, high tensile steel is cadmium plated and corrosion resistant steel or brass are normally uncoated. When the British Standard number is not marked on the bolt head, identification should be made as follows:—

Identify the head from Figure 3, for example (g). Reference to Table 3 shows that the bolt could be an A113, A114 or A170. Complete identification is possible in this example from the type of finish; in other instances it may be derived from further information, such as diameter or thread length, contained in Table 3.

2.2.1 **Code System for Unified Bolts and Screws.** The code system used for the identification of the bolts and screws listed in Table 3 consists of the Standard number followed by the part number of the particular bolt. The diameter code shown in Table 4 is used on all parts but the measurement of length varies with different Standards as follows:—

(i) All bolts from A102 to A212 inclusive, nominal length in tenths of an inch followed by the diameter, e.g. an A102, 10-32 UNF bolt with plain length of one inch = A102-10D.

NOTE: **Hexagon and mushroom head bolts are also supplied in lengths of 0·05 inch in some specifications, e.g. an A170-½D bolt has a plain length of 0·05 inch.**

(ii) All screws from A204 to A221 inclusive, diameter followed by length in thirty seconds of an inch, e.g. a 4-40 UNC A217 screw 1 inch long = A217-A32.

(iii) All bolts from A226 to A232 inclusive, diameter followed by nominal length in sixteenths of an inch, e.g. a ¼ inch UNJF A229 bolt with plain length of one inch = A229-E16.

NOTE: The position at which the nominal length of bolts is measured is shown in Figure 4; screws are measured as shown in Figure 2. It should be noted that the plain portion of the shank, on bolts with Unified threads, does not include the thread run-out.

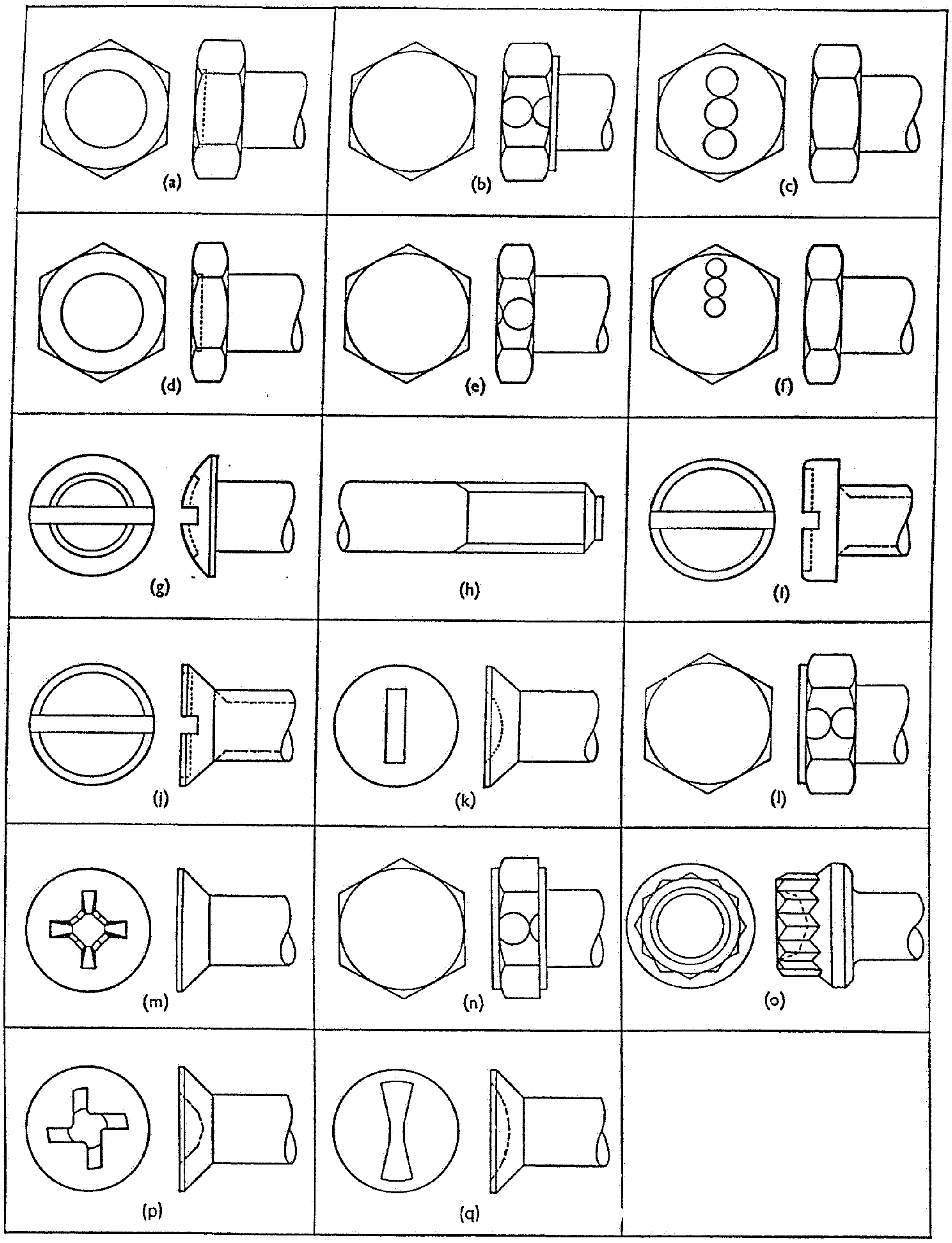


Figure 3 IDENTIFICATION OF BRITISH STANDARDS UNIFIED BOLTS AND SCREWS

TABLE 3

UNIFIED BOLTS AND SCREWS

BS No.	*Description*	*Material*	*Finish*	*Identification (Fig. 3)*	*Remarks*	*Thread and Class*	*Normal Size Range*
A102	Hex. hd. bolt	HTS	cad	a, b or c		Unified, 2A	4-40 to 1 in
A104	Hex. hd. bolt	CRS	nat	a, b or c		Unified, 2A	4-40 to 1 in
A108	Hex. hd. bolt	HTS	cad	l or n	cad hd. and	Unified, 2A	10-32 to ½ in
A109	Hex. hd. shear bolt	HTS	cad	d, e or f	thread only	Unified, 2A	¼ to ¾ in
A111	Hex. hd. c/t bolt	HTS	cad	l or n		Unified, 2A	10-32 to ½ in
A112	Hex. hd. shear bolt	HTS	cad	d, e or f		Unified, 2A	¼ to ¾ in
A113	Mush. hd. bolt	HTS	cad	g, h		Unified, 2A	6-32 to 5/16 in
A114	Mush. hd. bolt	CRS	nat	g, h		Unified, 2A	6-32 to 5/16 in
A116	Pan Hd. bolt	HTS	cad	i, h		Unified, 2A	4-40 to 5/16 in
A117	Pan hd. bolt	CRS	nat	i, h		Unified, 2A	4-40 to 5/16 in
A119	90° csk. hd. bolt	HTS	cad	j	obsolescent	Unified, 2A	¼ to ½ in
A120	90° csk. hd. bolt	CRS	nat	j	obsolescent	Unified, 2A	¼ to ½ in
A169	Hex. hd. bolt	Al Al	green	b or c	replaces A106	Unified, 2A	6-32 to ⅝ in
A170	Mush. hd. bolt	Al Al	green	g	replaces A115	Unified, 2A	6-32 to 5/16 in
A171	Pan hd. bolt	Al Al	green	i	replaces A118	Unified, 2A	4-40 to 5/16 in
A172	90° csk. hd. bolt	Al Al	green	j, h	obsolescent	Unified, 2A	¼ to ½ in
A173	100° csk. hd. bolt	HTS	cad	k			8-32 to ½ in
A174	100° csk. hd. bolt	CRS	nat	k		Unified, 2A	8-32 to ½ in
A175	100° csk. hd. bolt	Al Al	green	k	replaces A172	Unified, 2A	8-32 to ½ in
A204	100° csk. hd. screw	LTS	cad	j, h		Unified, 2A	0-80 to 10-32
A206	100° csk. hd. screw	CRS	nat	j, h		Unified, 2A	4-40 to 10-32
A208	100° csk. hd. screw	Al Al	green	j, h		Unified, 2A	4-40 to 10-32
A211	100° csk. hd. bolt	HTS	cad	m		Unified, 2A	8-32 to ½ in
A212	Hex.hd. c/t bolt	HTS	cad	b or c	special quality	Unified, 3A	10-32 to ½ in
A217	Pan hd. screw	LTS	cad	i, h	replaces A205	Unified, 2A	0-80 to 10-32
A218	Pan hd. screw	CRS	nat	i, h	replaces A207	Unified, 2A	4-40 to 10-32
A219	Pan hd. screw	Al Al	green	i, h	replaces A209	Unified, 2A	4-40 to 10-32
A220	100° csk. hd. screw	Brass	nat	j, h		Unified, 2A	0-80 to 10-32
A221	Pan hd. screw	Brass	nat	i, h		Unified, 2A	0-80 to 10-32
A226	Hex. hd. bolt	HTS	cad	a, b or c	short thread	Unified, 3A	4-40 to 10-32
A227	Pan hd. bolt	HTS	cad	i, h	short thread	Unified, 3A	4-40 to 10-32
A228	Double hex. hd. c/t bolt	HTS	cad	o		UNJF, 3A	¼ to 1 in
A229	Hex. hd. c/t bolt	HTS	cad	a, b or c		UNJF, 3A	10-32 to ½ in
A230	Csk. hd. c/t bolt	HTS	cad	q		UNJF, 3A	10-32 to ½ in
A232	Csk. hd. c/t bolt	HTS	cad	p		UNJF, 3A	10-32 to ½ in

2.2.2 **Extent of Marking.** The markings actually applied to a bolt depend on the particular specification and whether marking is practical. Adding the code 'A217-Z32' to the head of a 2-64 UNF pan head screw (head diameter 0·155 to 0·167 in), for example, would be very difficult, and having raised characters on a countersunk head bolt would, in certain circumstances, defeat the object of using that shape of head.

(i) **'Unified' Marking.** Most bolts, and screws 4-40 UNC and larger, are marked with a symbol to show that they have 'Unified' threads. The markings consist of contiguous circles (hexagon headed bolts only), a recessed head or shank dog point, and are illustrated in Figure 3.

NOTE: At some future date, to be agreed, the 'Unified' marking of screws will be discontinued and identification of these items will be solely from the label on the package.

(ii) **Code Markings.** Most hexagon head bolts 10-32 UNF and larger are marked with the full code, i.e. Standard plus size code, but pan and mushroom head bolts may only be marked with the bolt length and countersunk head bolts are not usually marked at all. The code is not applied to screws, or bolts smaller than 10-32 UNF.

TABLE 4

DIAMETER CODE LETTERS

Code	*Size*	*Code*	*Size*
Y	0-80 UNF	J	$\frac{3}{8}$ in UNF (UNJF)
Z	2-64 UNF	L	$\frac{7}{16}$ in UNF (UNJF)
A	4-40 UNC	N	$\frac{1}{2}$ in UNF (UNJF)
B	6-32 UNC	P	$\frac{9}{16}$ in UNF (UNJF)
C	8-32 UNC	Q	$\frac{5}{8}$ in UNF (UNJF)
D	10-32 UNF (UNJF)	S	$\frac{3}{4}$ in UNF (UNJF)
E	$\frac{1}{4}$ in UNF (UNJF)	U	$\frac{7}{8}$ in UNF (UNJF)
G	$\frac{5}{16}$ in UNF (UNJF)	W	1 in UNF (UNJF)

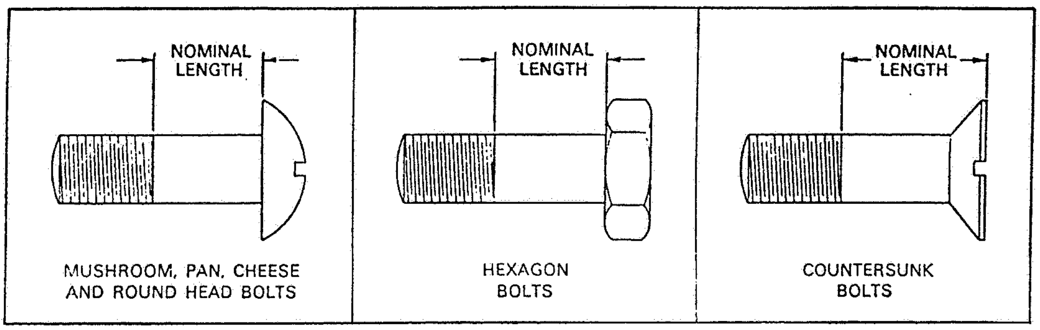


Figure 4 LENGTH OF BS UNIFIED BOLTS

3 'AS' BOLTS AND SCREWS This paragraph is concerned with the identification of bolts and screws complying with the Society of British Aerospace Companies 'AS' series of specifications. The specifications provide a range of bolts and screws in sizes and head shapes not found in British Standards specifications. Bolts manufactured from special materials (e.g. heat resistant steel) and having Unified threads are also included.

3.1 Table 5 shows the AS specifications for bolts and screws with BA/BSF threads, together with complete identification details.

TABLE 5
'AS' NUMBERS OF BA/BSF BOLTS AND SCREWS

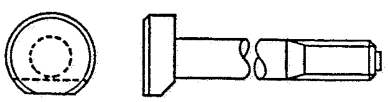
Head	Round	Mushroom	Raised Countersunk (90°)	Countersunk (90°)	Raised Countersunk (120°)	Countersunk (120°)	hexagon	*Material*	*Finish*
Bolts with screwdriver slot or hexagonal head	1247+	1249+	1245+	1243+				Al Al	Anodic
	4565	4566	4564	4563				Al Al	Blue
	1246	1248	1244+	1242			4569‡	HTS	Cad.
	2922	2923	2921	2920				SS	Nat.
							2504‡	HTS	Cad h & t
Bolts with Phillips recess	3078*+ 4597**	3079*+ 4598**	3295**	3294**	3296**	3297**		HTS	Cad.
Screws with Phillips recess	2991	2992	2994	2993	2995	2996		Mild Steel	Cad.

*1 dot on head
**2 dots on head

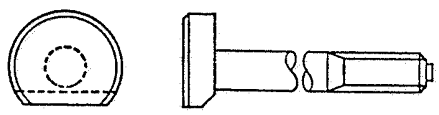
+obsolescent
‡2 BA only

3.2 Table 6 shows the AS specifications for 'round head' bolts with a locking flat and Unified threads. These bolts are manufactured from high tensile steel and are cadmium plated.

TABLE 6
'AS' NUMBERS OF ROUND HEAD BOLTS WITH FLAT (UNIFIED)



Small head

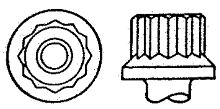
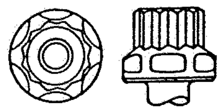


Large head

Small head				Large head			
10-32 UNF	¼ UNF	5/16 UNF	⅜ UNF	10-32 UNF	¼ UNF	5/16 UNF	⅜ UNF
6760 to 6804	6895 to 6939	7033 to 7077	7171 to 7215	6850 to 6894	6985 to 7032	7123 to 7170	7264 to 7308

3.3 Table 7 shows the AS specifications for double hexagon head bolts manufactured from heat resistant steel and having UNS or UNJF threads. Requirements for protective treatment vary between specifications, some bolts being silver plated while others have a natural finish.

TABLE 7
'AS' SPECIFICATIONS

Thread	Type	Material	HEAD SHAPE	
				
UNS Threads (10-32 to ⅜-24 UNS-3A)	Plain	DTD 5066	13000 - 13399	17000 - 17399
		DTD 5026	13400 - 13799	17400 - 17799
		DTD 5077	13800 - 14199	17800 - 18199
	Externally Relieved Body	DTD 5066	14500 - 14899	18200 - 18599
		DTD 5026	14900 - 15299	18600 - 18999
		DTD 5077	15300 - 15699	19000 - 19399
	Close Tolerance Shank	DTD 5066	19400 - 19799	
		DTD 5026	19800 - 20199	
		DTD 5077	20200 - 20599	
UNJF Threads	Plain (8-36 to ⅜-24 UNJF)	DTD 5066	20800 - 21299	
		DTD 5026	21300 - 21799	
		DTD 5077	21800 - 22299	
	Close Tolerance Shank (10-32 to ⅜-24 UNJF)	DTD 5066	22400 - 22799	
		DTD 5026	22900 - 23299	
		DTD 5077	23400 - 23799	

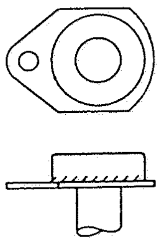
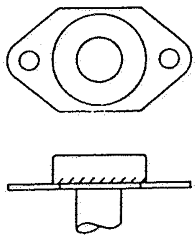
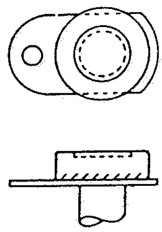
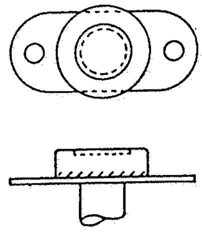
NOTE: The UNS bolts listed in the table have reduced diameter threads for use in high temperature applications and should be fitted with nuts complying with specifications AS20620 to AS 20639.

3.3.1 For purposes of standardisation a further series of heat resistant bolts with UNJF threads is being introduced to replace those with UNS threads. Details of the AS numbers allocated to these bolts are not, as yet, available, but the method of identification will be the same as described for the bolts in Table 7.

3.4 Table 8 shows the AS specifications for anchor bolts manufactured from weldable steel.

3.5 AS1 and AS2 are specifications for titanium bolts having Unified threads, with hexagon and 100° countersunk heads respectively. Both specifications are obsolescent but the bolts may be recognised by the material finish and the marking 'AS1' or 'AS2' on the head, as appropriate.

TABLE 8
'AS' NUMBERS OF ANCHOR BOLTS

BA/BSF		Unified	
			
4752	4753	6735	6736
Weldable bolt is AS 4754		Weldable bolt is AS 6737	

3.6 **Identification Marking.** AS1, AS2 and all the bolts listed in Table 7 are marked with the AS specification to which they conform. Other AS bolts are unmarked except for the 'Unified' symbol which is applied to anchor bolts (recessed head) and the round head bolts shown in Table 6 (shank dog point).

3.7 **Code System.** Although a large number of AS bolts and screws are not marked in any way, codes are necessary for ordering and storage purposes.

3.7.1 The code system used for the identification of the bolts and screws listed in Tables 5 and 8, and for AS1 and AS2 bolts, is the same as that used for British Standards bolts, i.e. AS number followed by a number indicating length in tenths of an inch and a letter indicating diameter (Tables 2 or 4 as appropriate). The length is measured in the same way as for British Standard parts.

NOTE: AS 2504 and 4569 bolts are only manufactured in 2 BA; the diameter code is therefore not required.

3.7.2 Reference to Table 6 shows that a batch of AS numbers is allocated to each diameter of bolt in this series. A separate number within each batch is reserved for a particular length of bolt so that a code system is unnecessary; any particular AS number in this series applies only to a bolt of specified length and diameter. The plain length is graduated in steps of 0·05 inch from 0·05 inch to 0·9 inch, and steps of 0·1 inch thereafter up to 3·4 inch. A 10-32 UNF bolt 1·2 inch long and having a small head will therefore be AS6780

3.7.3 The bolts shown in Table 7 also have a batch of AS numbers allocated to each diameter but in this case the range of available lengths varies between specifications. The length of the bolt is taken as the whole length of the shank, including the thread in sixteenths of an inch up to 2 inches long, and eighths thereafter, each particular size having a unique reference number. It should be noted that this series of bolts has a threaded length greater than that normally found on aircraft fasteners. A minimum length of plain portion is also maintained, so that the thread length in the shorter bolts is reduced below the normal for the particular diameter.

4 FUTURE TRENDS Because of the importance of reducing weight in the construction of an aircraft, designers are constantly seeking means of using higher strength or lighter alloys for structural purposes. This trend applies particularly to fasteners and it is apparent that the use of smaller diameter bolts and miniature anchor nuts will become more widespread. It will be accompanied by the use of threads of UNJF form.

4.1 In the field of light alloys, specifications for titanium bolts are being prepared and will probably be drawn up in accordance with existing American practice, within the framework of British Standard A 101, entitled "General Requirements for Titanium Bolts".

4.2 Because of the vast experience gained, particularly in America, in the use of both standard and miniature components, it has been internationally agreed to use Unified inch threads on fasteners. However, with the introduction of metric dimensions in other fields, it is probable that a metric thread series will eventually be accepted.

4.3 As far as identification features are concerned it appears likely that the system used for recent specifications will continue; bolts in the AS series will be marked with a number which will be unique for a particular diameter and length, and bolts in the BS series will use the code at present applied to bolts with UNJ threads.

NOTE: There is no symbol used to differentiate between threads of standard unified or UNJ form.

5 ABBREVIATIONS The following is an alphabetical list of abbreviations used in this Leaflet:—

AGS	Aircraft General Standards
AS	Aircraft Standards
Al Al	Aluminium alloy
BA	British Association
blue	dyed blue over anodic film
BSF	British Standard Fine
cad.	cadmium plated all over
cad. h & t	cadmium plated head and thread only
csk.	countersunk
c/t	close tolerance
CRS	corrosion resisting steel
FCS	free-cutting steel
green	dyed green over anodic film
hd.	head
hex.	hexagon
HTS	high tensile steel
LTS	low tensile steel
mush.	mushrocm
nat.	natural finish
SS	stainless steel
UNC	Unified coarse thread
UNF	Unified fine thread
UNS	Unified special thread
UNJF	Unified fatigue-resistant fine thread

BL/2-4

Issue 2.

December, 1979.

BASIC

IDENTIFICATION MARKING

IDENTIFICATION MARKINGS ON METALLIC MATERIALS

1 INTRODUCTION This Leaflet gives guidance on the determination of type and positioning of markings on metallic materials, for the purpose of identification during manufacture. This Leaflet should be read in conjunction with CAIP Leaflet **BL/2-2**, which gives information on standard colour schemes and **BL/2-1** which gives information on the processes for identification marking of aircraft parts.

1.1 Chapter **A6—6** of British Civil Airworthiness Requirements specifies that materials used in parts affected by airworthiness requirements shall comply with one of the following specifications:—

(a) British Standard Aerospace Series Specifications.

(b) DTD Specifications.

(c) Specifications approved by the CAA.

(d) Specifications prepared for a material in accordance with BCAR, Chapter **D4—1** for large aeroplanes*, by an Organisation approved for design where the material is to be used in a part designed within the terms of the design approval.

1.2 British Standards Aerospace Series and DTD Specifications make provision for the identification of materials by requiring the mark of the inspector and such other markings as may be necessary to ensure full identification. Manufacturers' Specifications (as in paragraph 1.1 (d)) normally refer to the inspectional clauses of the relevant BS or DTD Specifications and, consequently, similar provision for identification is made.

1.3 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 METHOD OF MARKING Materials should be identified as early as possible in their manufacture.

2.1 The markings most appropriate for materials such as sheet, bar and castings are—

(a) metallic stamp markings,

(b) markings produced by the die or mould used in shaping the material, and

(c) marking by rubber stamp, hand roller or printing machine.

Whichever method of marking is employed, damage to the material must be avoided and particular care should be taken when marking stressed parts of materials.

*Chapters **K4-1** for light aeroplanes, **G4-1** for rotorcraft, **C2-2** for engines.

2.2 The markings most appropriate for parts and semi-finished materials are—

(a) acid etching,

(b) electro-chemical methods,

(c) vibratory percussion,

(d) grit blasting, and

(e) deposition of iron-copper selenite.

2.3 Incised markings are not recommended for—

(a) stressed parts where the impressions may act as stress raisers and originate cracks,

(b) materials and parts of thin section,

(c) materials or parts of such hardness, surface condition or shape that it is impracticable to apply a well defined marking, and

(d) material ordered to exact sizes where no provision is made for the subsequent removal of the portion containing the incised markings.

NOTE: Electro-engraving of parts is prohibited and metallic stamp and vibratory percussion methods must not be used at highly stressed locations. If it is necessary to mark a part in a stressed region, etching or electro-chemical methods should be employed.

2.4 When metallic stamp marking is used, and this method is preferred for stock or random sizes of material, the marks have to be confined to a minimum area in a suitable position.

2.5 When marking with ink, enamel or paint is permitted, the marking medium has to meet the following criteria:—

(a) It has to be permanent, except for 'non-immersion' markings used with some aluminium-based materials, where the marking is designed to disappear during solution treatment.

(b) It has to have no corrosive or adverse effect on the material and be compatible with any material or substance with which it may subsequently be in contact.

NOTE: For stainless steels, the marking medium has to be free from organic compounds to obviate the possibility of carbon 'pick-up'.

(c) It has to remain legible when any protective process is applied to the material.

2.6 Where material is ordered to sizes which do not permit the identification markings being removed during production of a part, the purchaser may state expressly in his order that the material is to be used in the size as delivered and must not bear any incised markings. In such circumstances the material may be identified by—

(a) the pieces of material being bundled or parcelled and the marks required being stamped on a metal label securely attached to each bundle or parcel,

(b) marking with paint, enamel or ink (see paragraph 2.5), or

(c) one of the etching or electrochemical methods.

3 IDENTIFICATION OF METALLIC MATERIALS TO APPROVED SPECIFICATIONS

The Procedure Specifications in the British Standards Aerospace Series, i.e. HC.100, HR.100, L.100, L.500, S.100, S.500, T.100 and TA.100, contain identification marking clauses which are applicable to all BS Aerospace Series and DTD Specifications for iron, nickel, copper and refractory base alloy castings, wrought heat resisting alloys, wrought aluminium and aluminium alloys, aluminium base and magnesium base ingots and castings, wrought magnesium alloys, wrought steels and wrought titanium and titanium alloys. New issues of approved specifications will include references to the identification clauses of the relevant specification.

3.1 The identification marking of metallic materials other than those covered in paragraph 3 is governed by the individual Approved Specification.

3.2 The identification markings should consist of the specification reference, the inspection stamp (except as indicated in paragraph 4) and such other markings as are necessary to enable the following details to be established:—

(a) Manufacturer.

(b) Cast number (where cast or cast/heat treatment batching is required by the Specification).

(c) Batch number.

(d) Test report number.

3.3 The identification mark of the inspector and the manufacturer's trade or identification mark may be combined in one symbol. Correlation between the relevant approved certificate and test report may conveniently be secured by marking the material with the test report number.

3.4 Additional markings such as those agreed by the supplier and purchaser and stated on the order or drawing may also be applied.

4 IDENTIFICATION OF MATERIAL FORMS The identification markings which are generally applicable to various forms of material, ingots, castings, bars, sheets, etc., are given in this paragraph.

4.1 **Ingots.** Each ingot should be stamped with the marks indicated in paragraph 3.2, except that the inspection stamp may be omitted if the manufacturer's name or trade mark is cast on each ingot and the relevant inspection records are signed by the inspector accepting the ingots.

4.2 **Castings, Forgings and Stampings.** Each casting, forging and stamping which is large enough to be individually marked should bear the marks described in paragraph 3.2 and such other markings as may be stated on the order.

4.2.1 Marks, such as the part number and the manufacturer's name, may be incorporated in the die or mould used in shaping the part. Marks not so applied should be added by means of stamps unless some other method of marking is specified. All stamp markings must be placed where they have the least detrimental effect on the part; such position usually being indicated on the drawing.

4.2.2 Where forgings, stampings and precision castings approximate closely to the finished parts, the method of identification should follow the requirements for the marking of the finished parts, as shown on the drawing. Wherever practicable, compressor and turbine blade forgings should be individually identified, and this is of particular importance where the blade forgings are of similar shape and size and made from closely associated alloys, e.g. the alloys of the Nimonic series. Segregation and identification of stock, 'uses' and forgings for blades throughout the various production and heat treatment stages is necessary.

4.3 **Billets and Bars.** Each billet and bar, the diameter or width across flats of which is greater than 19 mm (0·75 in), should be stamped at one end with the markings detailed in paragraph 3.2.

4.4 **Sheets and Strips.** Each sheet and each coil or strip wider than 19 mm (0·75 in) should be stamped with the markings detailed in paragraph 3.2.

4.5 **Sections.** Each extruded and rolled section, the major sectional dimension of which exceeds 19 mm (0·75 in), should be stamped at one extreme end with the markings detailed in paragraph 3.2.

4.6 **Wire.** Each coil or bundle of wire should bear a metal label stamped with the markings detailed in paragraph 3.2 and such additional markings as may be required by the relevant specification (which may also require colour identification).

4.7 **Tubes.** Each tube, the diameter of which exceeds 25 mm (1 in), or in the case of light alloy and steel tubes exceeds 19 mm (0·75 in), should be stamped at one end with the markings detailed in paragraph 3.2 and with any additional markings required by the relevant specification.

4.8 **Items not Requiring Individual Identification.** As an alternative to individual identification, and provided that the material is from the same cast or batch:

(a) ingots, small castings, forgings, stampings and bars, the diameter or width across flats of which does not exceed 6·5 mm (0·25 in);

(b) sheet and flat strips, the width of which does not exceed 19 mm (0·75 in);

(c) sections, the major sectional dimensions of which do not exceed 19 mm (0·75 in);

(d) tubes, the diameter of which does not exceed 25 mm (1 in), or in the case of light alloy and steel tubes does not exceed 19 mm (0·75 in)

should be either wired together or packed in parcels, as appropriate, and a metal label, stamped with the markings detailed in paragraph 3.2, should be attached to each bundle or parcel.

5 ALUMINIUM-BASED MATERIALS The identification marking requirements for aluminium-based materials are prescribed in British Standards L.100 and L.101, and castings, extruded bars, sections and sections rolled from strip, wire and tubes should, unless otherwise specified, be so identified.

5.1 **Ingots.** Ingots which have a sufficiently clean and smooth face to enable full legibility to be secured, may, at the discretion of the appropriately authorised person, be rubber stamped with the specification reference, preferably at each end of the ingot. The letters and figures should be not less than 13 mm (0·5 in) high and the ink used should comply with paragraph 2.5.

5.2 **Sheet and Strip in Coil Form.** In addition to the identification markings detailed in paragraph 3.2, sheet and strip may be required to be 'all-over' marked by the specification. Where strip is identified by ink markings, marking the material with the Specification reference may be omitted. 'All-over' marking should be carried out in accordance with the relevant clauses of BS L.100 and as detailed in paragraphs 5.2.1 to 5.2.4, unless otherwise agreed between the manufacturer and the purchaser and stated on the order.

5.2.1 Each sheet and each strip in coil form, the width of which is 152 mm (6 in) or greater, should be marked in green ink with the Specification reference and the manufacturer's symbol in figures and letters 13 mm (0·5 in) high. The lines of markings should be at a pitch of 100 mm (4 in). The markings should be arranged in accordance with (a) or (b).

(a) The specification reference and the manufacturer's symbol should appear alternately and should be repeated at intervals of approximately 100 mm (4 in) along each line of marking; the marks being so disposed that the Specification reference in one line is above the manufacturer's symbol in the line immediately below it.

(b) The specification reference and manufacturer's symbol should appear on alternate lines, the marks in each line being repeated with a gap of approximately 25 mm (1 in) between them.

5.2.2 Each sheet and each strip in coil form, the width of which does not exceed 152 mm (6 in) (but not less than 50 mm (2 in) wide), should be marked as in 5.2.1 (a) or (b) at intervals of 100 mm (4 in) approximately along the centre line.

5.2.3 At the option of the manufacturer, each sheet and strip in coil form, the width of which does not exceed 50 mm (2 in) wide, can be 'all-over' marked, individually identified as detailed in paragraph 3.2, or, if from the same batch, bundled together with the required marks stamped on a metal label attached to each bundle.

5.2.4 Sheet and strip in coil form of material 26 s.w.g. and thinner, in the heat treatment condition stipulated by the specification and wide enough to be 'all-over' marked, may be hand marked in green ink along two lines only.

5.3 **Plate and Extrusions.** Plate, not included in the current issue of BS L.100, should, unless otherwise specified, be marked in accordance with the relevant DTD Specification.

5.3.1 For plate fabrication and machining it is advantageous to know both the direction of rolling (not readily apparent with pieces cut to size) and the results of non-destructive testing. The user may require appropriate indications to be marked on each plate; such additional markings should be agreed between the purchaser and manufacturer and stated on the drawing or order.

5.3.2 Extrusions and plate which have been stretched in accordance with the specification or other conditions should be marked with the letters CS in a circle. Bars and sections should be marked at one end and plate should be marked alongside the specification reference. The marks should be made either by rubber stamp (blue or black ink) or by metal stamps, at the discretion of the material manufacturer.

NOTE: See also paragraph 5.5 when the contents of that paragraph are applicable.

5.4 **Forgings.** Forgings should, unless otherwise specified, be finally marked as required by BS L.100. Where individual markings are required, L.100 specifies that the drawing for the forgings should state the position at which the identification marks are to be applied; this is particularly important for forgings in high strength alloys.

NOTE: The method of applying the identification markings should be confirmed where it is not indicated on the drawing.

5.5 **Annealed, Not Aged, and as-Rolled Material.** Material released in other than the heat treatment condition stipulated by the specification should be marked in red by means of a transfer, paint or ink markings with the appropriate term to denote its condition and Approved Certificates covering such material should be clearly annotated "annealed", "not aged", etc., as appropriate.

5.5.1 For sheet and strip in coil form, the red markings in letters 13 mm (0·5 in) high should be repeated at intervals of approximately 101 mm (4 in) in lines midway between the lines of markings detailed in paragraph 5.2.1 to 5.2.3.

5.5.2 For extruded bars, sections and tubing, the red marking should be applied near one end of each length but, where lengths greater than 5 m (15 ft) are supplied, the markings should be applied at each end of each length.

5.5.3 For plate, the red marking should be placed near the specification reference or, where 'all-over' marking is required by the order, repeated at intervals midway between the lines of 'all-over' marking.

5.5.4 Material which is to be bundled and labelled should bear the appropriate wording stamped on the attached label.

5.5.5 The following terms are to be used, as appropriate:—

(a) AS ROLLED. To denote 'as-rolled' material.

(b) ANNEALED. To denote material in the softened condition.

(c) NOT AGED. To denote material solution treated but which requires precipitation treatment.

5.5.6 The method of applying the red markings is left to the discretion of the manufacturer but the medium used should comply with paragraph 2.5.

6 MAGNESIUM-BASED MATERIALS Cast products should, unless otherwise specified, be identified in accordance with the requirements of BS L.101. Wrought products should be identified as required to BS L.500, the contents of paragraph 3.2 being taken into consideration. In general, the guidance given in previous paragraphs is applicable and the markings should be applied before chromate treatment.

7 TITANIUM-BASED MATERIALS Titanium-based materials should be finally marked in accordance with BS TA.100 and order requirements, the contents of paragragh 3.2 being taken into consideration. It is preferable not to use metallic stamping unless otherwise indicated on the order; billets, bars, sheet, etc., may be identified by rubber stamp markings. Where the cross-section is insufficient to enable full legibility to be secured, bars, rods, etc., from the same cast or batch and of the same nominal size may be wired together and the marks required may be stamped on a metal label attached to each bundle.

8 FERROUS MATERIALS Steel ingots and wrought products should, unless otherwise specified, be identified in accordance with the relevant procedure specifications, i.e. BS S.100, S.500 and T.100; the identification marking requirements for steel castings are given in the relevant specifications.

NOTE: Leaded steels should be identified with a distinguishing mark "L", "LED" or "LEADED" and the associated Approved Certificate should be appropriately endorsed.

9 IDENTIFICATION OF METALLIC MATERIALS TO OTHER THAN APPROVED SPECIFICATIONS Parts for general supplies (i.e. uncontrolled items as specified in Section A, Chapter A3-3 of British Civil Airworthiness Requirements) may be made from materials for which identification marking requirements are not specified. In such cases the appropriate person employed by the materials manufacturer should be guided by the terms of the order, but it is preferable that some form of marking be carried out by the manufacturer to correlate the material with its accompanying release documentation. It is essential, however, that the material is rendered identifiable after delivery to prevent any possible confusion with other material held by the purchaser.

BASIC

IDENTIFICATION MARKING

NUTS OF BRITISH MANUFACTURE

1 INTRODUCTION This Leaflet gives guidance on the identification of nuts complying with British Standards 'A' Series of Aircraft Materials and Components, with AGS Specifications and with certain specifications in the Society of British Aerospace Companies 'AS' Series.

1.1 Failure of a fastener through the use of an incorrect nut could cause malfunction and, in certain circumstances, lead to the jamming of controls. It is most important, therefore, that engineers and inspectors should be acquainted with the features by which any particular type of nut may be identified. A nut may have the correct type of thread but it may be unsuitable for some other reasons such as material, temperature classification or length of thread; it is also possible to fit a nut of incorrect size, e.g. a 10-32 UNF nut may fit an 8-32 UNC screw. These dangers may be minimised by constant vigilance during servicing operations.

1.2 For the benefit of engineers engaged on the maintenance of older types of aircraft, information on obsolescent Standards is also included in this Leaflet, together with details of replacement Standards.

1.3 Information on the identification of bolts and screws of British manufacture is given in Leaflet **BL/2-3.**

1.4 A list of abbreviations and terms used in this Leaflet is given in paragraph 7.

2 BRITISH STANDARDS NUTS HAVING BA OR BSF THREADS Table 1 gives a list of relevant Standards and superseding Standards. Identification details are included in the table and the different nuts included in this range are illustrated in Figure 1.

2.1 **Identification.** Identification of a particular nut may be effected from its shape and anti-corrosive treatment; in addition, all nuts larger than $\frac{3}{8}$ inch BSF are marked with the British Standard number, and parcels of nuts are labelled with the complete part number.

2.2 **Code System for Nuts.** The code system used for the identification of the nuts listed in Table 1 (with the exception of A14) consists of the Standard number followed by a letter indicating the size of the thread (Table 2), followed by a letter indicating the type of nut, i.e. P (ordinary nut), S (slotted nut), C (castle nut), and T (thin nut). These type letters are not, however, applied to the nuts. For example, the complete part referencing number used on the drawing, or when ordering $\frac{7}{16}$ inch ordinary A27 nuts is A27LP, but the corresponding marking of the nuts will be A27L.

2.2.1 Where nuts have a left-hand thread the letter 'L' is added to the part number, thus the above example with a left-hand thread would have the part number A27LPL. The letter 'L' is marked on one of the hexagonal surfaces of the nut.

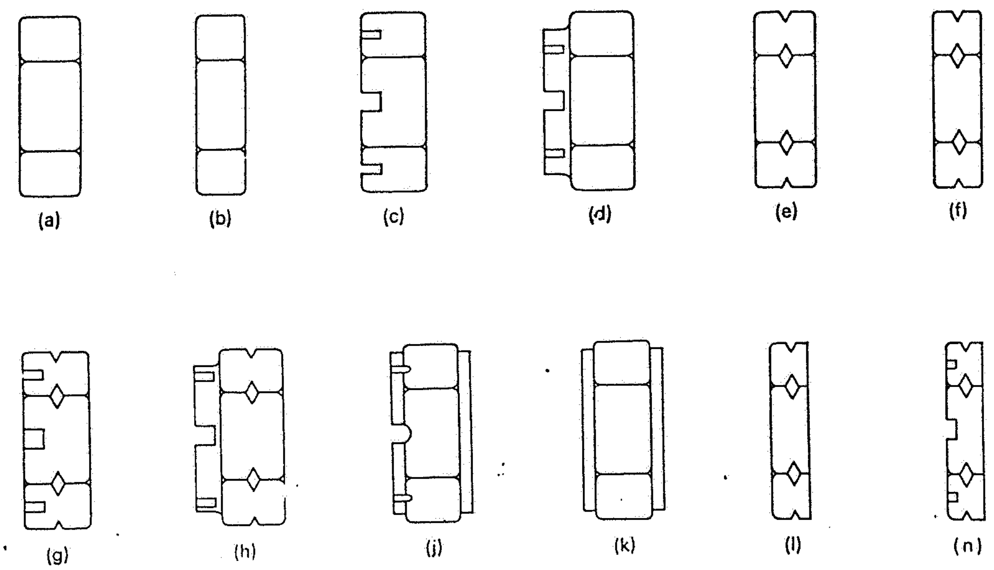
TABLE 1

BA AND BSF HEXAGON NUTS

BS No.	*Types (para. 2.2)*	*Material*	*Finish*	*Remarks*	*Identification (Fig. 1)**	*Size Range*
A14	P and T	Brass	cad or natural	obsolescent	a or b	(i) 10 BA to 0 BA (ii) 4 BA to 1¼ BSF
A24	P, T, S and C	HTSS	natural	replaces A16 Z	e, f, g or h	6 BA to 1 in BSF
A27	P, T, S and C	HTS	cadmium	replaces A16 Y	e, f, g or h**	6 BA to 1 in BSF
A29	P and S	Al Al	anodic	replaces A18	j or k	6 BA to 1 in BSF
A47	P	LTS	cadmium }	order as A27 in 2, 4 and 6 BA	a	12 BA to 2 BA
A48	T	LTS	cadmium }		b	8 BA to 2 BA
A49	P	SS	natural		a	12 BA to 2 BA
A50	T	SS	natural		b	8 BA to 2 BA
A51	P	Al Al	anodic		a	12 BA to 2 BA
A52	T	Al Al	anodic		b	8 BA to 2 BA
A53	P	Brass	tinned	replaces A14 P	a	12 BA to 2 BA
A54	T	Brass	tinned	replaces A14 T, 2 and 4 BA	b	8 BA to 2 BA
A58	T or TS	HTS	cadmium	shear nut	l or n	¼ to ¾ in BSF

* The BS number is marked on all nuts larger than ⅜ inch BSF.

** a, b, c or d in sizes below ¼ inch BSF.



NOTE: Shear nuts (l) and (n) are 0·2 in thick in all sizes.

Figure 1 IDENTIFICATION FEATURES BA/BSF NUTS

TABLE 2

DIAMETER CODE LETTERS

Code	*Size*	*Code*	*Size*
A	6 BA	P	$\frac{9}{16}$ in BSF
B	4 BA	Q	$\frac{5}{8}$ in BSF
C	2 BA	S	$\frac{3}{4}$ in BSF
E	$\frac{1}{4}$ in BSF	U	$\frac{7}{8}$ in BSF
G	$\frac{5}{16}$ in BSF	W	1 in BSF
J	$\frac{3}{8}$ in BSF	X	12 BA
L	$\frac{7}{16}$ in BSF	Y	10 BA
N	$\frac{1}{2}$ in BSF	Z	8 BA

2.2.2 **Code System for BS A14 Brass Nuts.** In the obsolescent British Standard A14 two ranges of nuts are covered, viz. 0 BA to 10 BA plain and 4 BA to $1\frac{1}{4}$ inch BSF thin.

(i) In the former (which is superseded by A53) the diameter is indicated by the BA number, and the part number consists of the Standard number followed by the diameter number and the letter 'B'. For example, the complete part reference number used on the drawing or when ordering 4 BA plain nuts, is A14 4B.

(ii) In the second range the 4 and 2 BA nuts are superseded by British Standard A54, but the coding system is similar to that in Table 3, with the exceptions that 'X' and 'Y' are used to denote $1\frac{1}{8}$ inch BSF and $1\frac{1}{4}$ inch BSF nuts respectively, and the letter 'B' is substituted for the usual letter 'T'. For example, a $\frac{1}{4}$ inch thin nut has a reference number A14 EB.

(iii) Both ranges include nuts with left-hand threads and the information contained in para. 2.2.1 applies also to this series.

TABLE 3

UNIFIED HEXAGON NUTS

BS No.	*Type (para. 3.2)*	*Material*	*Finish*	*Remarks*	*Identification (Fig. 2)**	*Size Range*
A103	P, T, S or C	HTS	cad		a, b, c or d	4-40 UNC to 1 in UNF
A105	P, T, S, or C	CRS	natural	marked with 'Z'	a, b, c or d	4-40 UNC to 1 in UNF
A107	P or S	Al Al	green		a or c	4-40 UNC to 1 in UNF
A110	T or TS	HTS	cad	shear nut	e or f	$\frac{1}{4}$ to $\frac{3}{4}$ in UNF
A222	P	LTS	cad		a	0-80 and 2-64 UNF
A223	T	LTS	cad		b	0-80 and 2-64 UNF
A224	P	Brass	tinned		a	0-80 and 2-64 UNF
A225	T	Brass	tinned		b	0-80 and 2-64 UNF

* The BS number is marked on all nuts larger than $\frac{3}{8}$ inch UNF.

3 BRITISH STANDARDS NUTS HAVING UNIFIED THREADS Table 3 gives a list of the relevant Standards and superseding Standards for ordinary hexagon nuts and Table 4 gives the Standards applicable to stiffnuts of various types. The nuts are illustrated in Figures 2 and 3 respectively.

TABLE 4
UNIFIED STIFFNUTS

Basic Type		*Attachment plate material*	*Temperature Classification, Nut Material and Coating*				
			—75°C to +125°C		—75°C to +200°C		—75°C to + 425°C
			Al Al†	*Brass* or *Bronze*††	*Steel**	*CRS***	
			Anodised	*Tinned*	*Cad plated*		*Silver Plated*
Hexagon	ordinary thin cap		A129 A130 A214	A131 A132 —	A125 A126 A213	A127 A128 —	A180 A181 —
Clinch			A124	A123	A122	—	—
Single lug fixed anchor	ordinary thin		A161 A162	A163 A164	A157 A158	A159 A160	A200 A201
Double lug fixed anchor	ordinary thin cap		A140 A141 A216	A142 A143 —	A136 A137 A215	A138 A139 —	A186 A187 —
Double lug floating anchor	ordinary thin	Al Al	A153 A154	— —	A151 A152	— —	— —
	ordinary thin	Brass	— —	A155 A156	— —	— —	— —
	ordinary thin	Steel	— —	— —	A147 A148	— —	— —
	ordinary thin	CRS	— —	— —	— —	A149 A150	A192 A193
Strip	ordinary thin		A167 A168	— —	A165 A166	— —	— —

* Nut body is made from S 92, S 112, S 113, S 114 or S 117 depending on the size of the nut. Base plate is made from S 510 or S 511 and attachment plate from S 511 or L 72.

** Nut body is made from S 80, base plate and attachment plate from S 521.

† Nut body is made from L 65, base plate and attachment plate from L 72.

†† Nut body is made from B 11, BS 249, BS 250, BS 251 or BS 369. Base plate and attachment plate are made from BS 267 or BS 409.

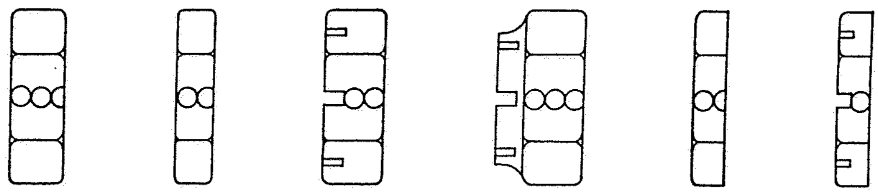
3.1 **Identification.** Nuts with Unified threads may be identified by their shape, type of finish and thread size. Additionally, all nuts other than anchor nuts, 8-32 UNC and larger, are marked with the 'Unified' symbol of contiguous circles. The identification of smaller nuts may be more difficult, for example, an A222, 2-64 UNF nut is similar to an A47, 8 BA nut, and it may be necessary to try the nut on a bolt of known thread to achieve positive identification.

3.1.1 Nuts listed in Table 3, larger than $\frac{3}{8}$ inch diameter, are marked with the British Standard number.

3.1.2 Stiffnuts $\frac{1}{4}$ inch UNF and larger which are manufactured from corrosion resisting steel, are marked with the letter 'Z', either on one flat or on the base plate; when the nut is also silver plated, the letter 'X' is added to or replaces the 'Z'.

3.1.3 Brass anchor nuts are marked with the letter 'B' and all hexagon brass stiffnuts have a washer face (Figure 3).

NOTE: The shape of the friction element on a stiffnut should not be taken as an identification feature. These are usually patented devices and depend on the design favoured by the particular manufacturer. Nut specifications normally only quote the maximum dimensions of the friction element and the frictional unscrewing torque required.



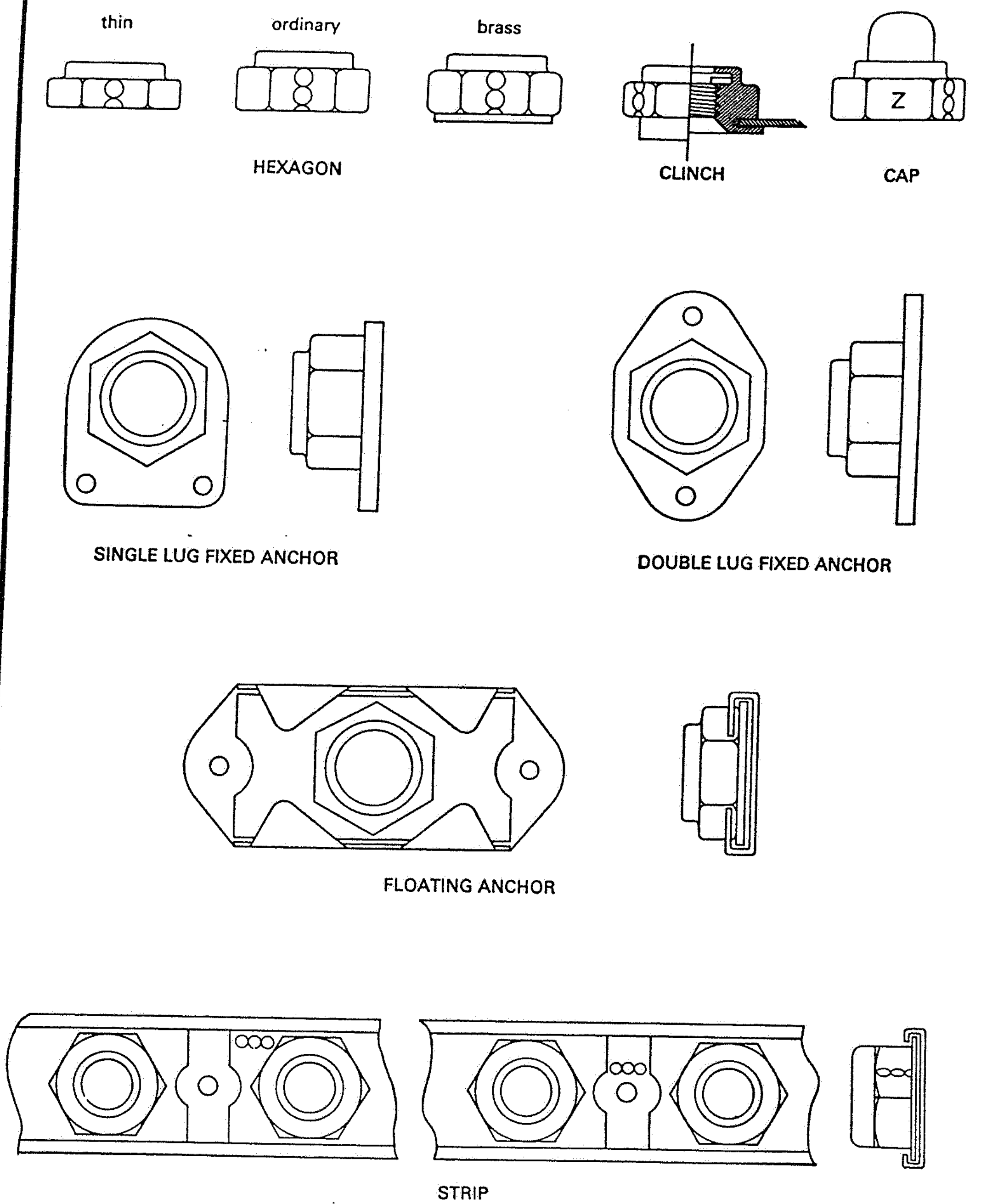
NOTE: Shear nuts (e) and (f) are 0·2 in thick in all sizes.

Figure 2 UNIFIED NUTS

3.2 **Code System.** The code system used for the identification of nuts having Unified threads consists of the British Standard number followed by a letter indicating the size of thread (Table 5), followed, when appropriate, by a letter indicating the type of nut, i.e. P (ordinary nut), S (slotted nut), C (castellated nut) and T (thin nut). These letters are not, however, applied to the nut. For example, the complete part number used on drawings or when ordering a $\frac{7}{16}$ inch UNF ordinary A107 nut is A107 LP but the nut is only marked 'A107'. Where stiffnuts are concerned the part number is not marked on nuts of any size, but over $\frac{3}{8}$ inch diameter a letter indicating thread size is applied.

3.2.1 **Clinch Nuts, A122 to A124.** A similar coding system to that described in paragraph 3.2 is used, followed by a number indicating the length of spigot required. A choice of three spigot lengths is specified for each size of nut, depending on the thickness of material through which the nut is to be clinched.

3.3 **Stiffnuts.** As mentioned in paragraph 3.1, hexagon, clinch and strip stiffnuts are marked with a 'Unified' symbol to show the type of thread used. Anchor nuts (fixed or floating) are not so marked as the shape of the base plates is considered to be adequate for recognition purposes; these are much smaller and less angular than those fitted to similar stiffnuts with BA or BSF threads in the AGS range of specifications. In the Unified stiffnuts the base plate is integral with the nut body, but the nut portion of an AGS stiffnut is retained inside a cage.



NOTE: The nut body of any anchor stiffnut may be either hexagonal or round

Figure 3 IDENTIFICATION FEATURES, UNIFIED STIFFNUTS

3.3.1 When it is necessary to differentiate on the drawing or order between metallic and non-metallic friction element stiffnuts in the steel and corrosion-resisting steel (—75°C to +200°C) ranges, the suffix '/66' or '/77' respectively is added to the part reference. For example, the complete part reference for a ¼ inch UNF steel nut with a metallic friction element is A125 E/66, and for a nut of the same size with a non-metallic friction element A125 E/77. A part reference without such a suffix indicates that either type of nut may be used.

3.3.2 Stiffnuts complying with British Standards A180, A181, A186, A187, A192, A193, A200 and A201 may be supplied unplated for use in that condition, or for subsequent plating by the user for applications where plating other than silver is required. When ordering such nuts, '/UP' should be added to the reference number. For example, a 5/16 inch UNF corrosion-resisting steel, thin, double-lug, floating anchor nut unplated, is A193 G/UP.

3.4 **Left-Hand Threads.** Left-hand threads in nuts are indicated by the use of the suffix letter 'L'. Thus the reference number for a 4-40 UNC ordinary brass nut complying with BS A210 would be A210 APL, i.e. the Standard number + the diameter letter + the nut type + left-hand thread. The letter 'L' is also applied to one of the hexagon faces of the nut. There is no provision made for left-hand threads in the specifications relating to stiffnuts.

TABLE 5

DIAMETER CODE LETTERS
UNIFIED THREADS

Code	*Size*	*Code*	*Size*
Y	0-80 UNF	J	⅜ in UNF
Z	2-64 UNF	L	7/16 in UNF
A	4-40 UNC	N	½ in UNF
B	6-32 UNC	P	9/16 in UNF
C	8-32 UNC	Q	⅝ in UNF
D	10-32 UNF	S	¾ in UNF
E	¼ in UNF	U	⅞ in UNF
G	5/16 in UNF	W	1 in UNF

4 'AS' NUTS

4.1 **Double Hexagon Stiffnuts.** A range of double-hexagon stiffnuts manufactured from heat resistant steel and having UNJF threads, is provided in the SBAC, AS series 20623 to 20630, representing thread sizes 8-36 UNJF to 9/16–18 UNJF. These nuts are specified for use on the AS series of heat resistant bolts with UNJF threads, and may be identified from the AS number marked on the extended washer portion of the nut. They are illustrated in Figure 4.

4.2 **Ordinary and Anchor Stiffnuts.** A series of AS specifications for lightweight hexagon and anchor stiffnuts has been produced in the range AS 8600 to 8661 (see Table 6). These nuts are manufactured from high tensile steel and are considerably lighter than conventional nuts; all are now manufactured with UNJ threads.

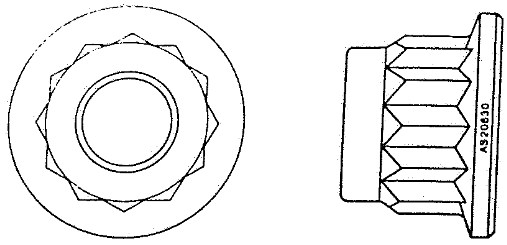


Figure 4 'AS' DOUBLE HEXAGON STIFFNUTS

4.2.1 No markings are applied to the nuts but they are quite different from either the BS or AGS stiffnuts and may be identified purely from their shape (see Figure 5). For storage and ordering purposes the nuts are identified by the AS number, followed by a size code letter as shown in Table 5. A further code is necessary for ordering strip nuts, and this consists of a number representing the distance between nut centres in eighths of an inch, followed by an additional number representing the number of nuts required in a strip. A 10-32 UNF strip nut with 0.75 inch nut spacing and having 10 nuts would therefore be, AS 8612/D/6/10.

4.2.2 As with the BS and AGS stiffnuts, the shape of the friction device is optional, the specification merely stating the maximum or minimum limits as appropriate. A further stipulation with this series of nuts is the maximum permissible weight per 100 units (and weight per inch for strip nut channels).

TABLE 6

'AS' LIGHTWEIGHT STIFFNUTS

	AS Numbers		
Material	*HTS*	*CRS*	*CRS*
Max. rated temperatures	250°C	450°C	250°C
Finish	*Cad.*	*Silver*	*Natural*
Hexagon, flange type	8600	8623	8650
Hexagon	8601	8624	8651
Double lug anchor	8602	8625	8652
Miniature double lug anchor	8603	8626	8653
Single long lug anchor	8604	8627	8654
Miniature single long lug anchor	8605	8628	8655
Miniature single short lug anchor	8606	8629	8656
Corner anchor	8607	8630	8657
Miniature corner anchor	8608	8631	8658
Double lug floating anchor	8609	8632	8659
Miniature double lug floating anchor	8610	8633	8660
Single large lug floating anchor	8611	8634	8661
Strip	8612		

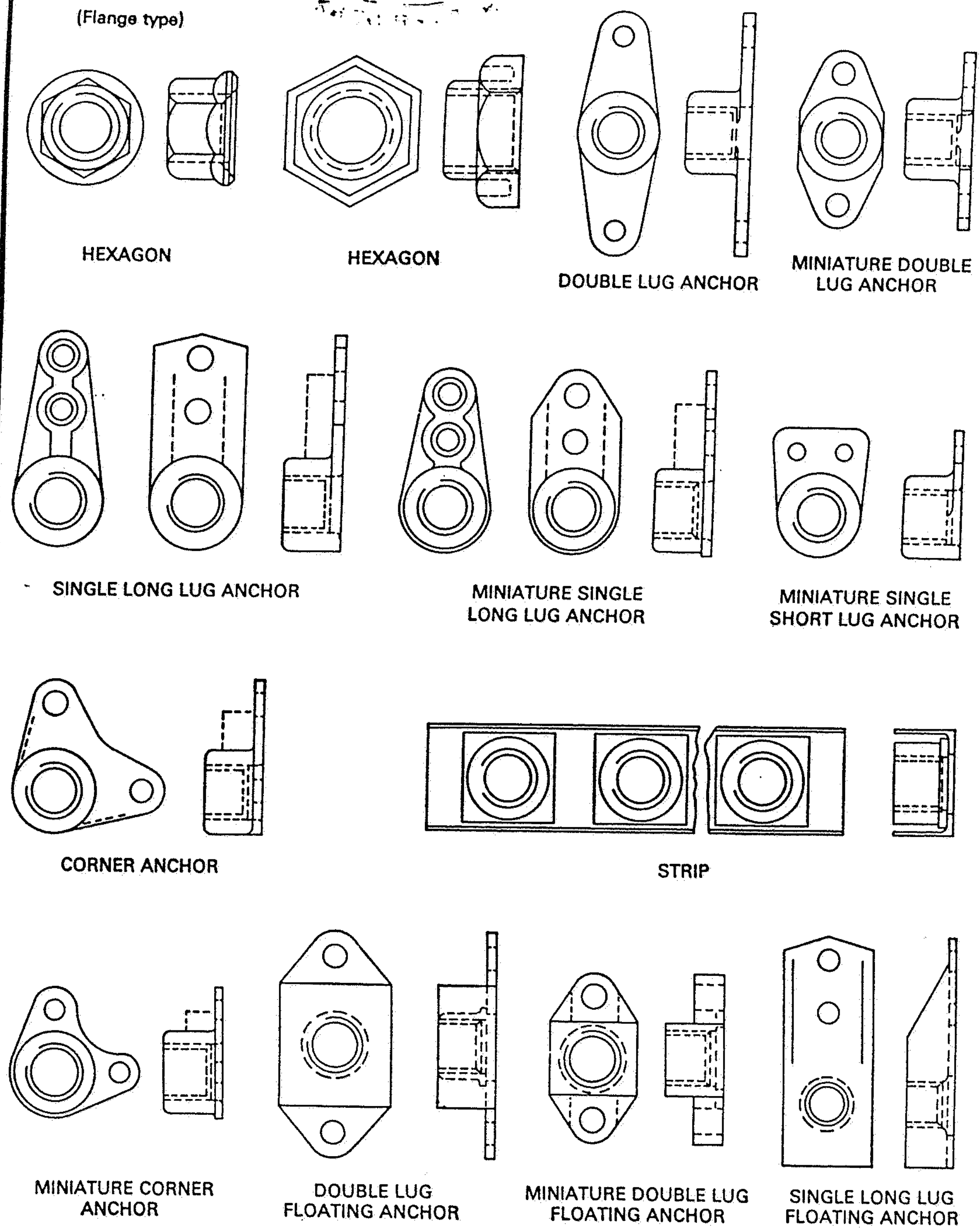


Figure 5 TYPICAL 'AS' LIGHTWEIGHT STIFFNUTS

5 AGS NUTS

5.1 **Stiffnuts.** Table 7 gives a list of the relevant AGS numbers for the various types of stiffnuts in this series; the nuts are illustrated in Figure 6 to show the differences from British Standards stiffnuts AGS stiffnuts have BA or BSF threads

TABLE 7
AGS STIFFNUTS

Type	*AGS Number*				
	Standard	*Thin*	*Csk*	*Cap*	*Csk cap*
Hexagon ..	2001	2002	2003	2021	2024
Single anchor, single fixing	2004*	2005*	2006*		
Single anchor, double fixing	2018	2019	2020		
Double anchor	2007	2008	2009	2023	
Floating	2012	2013	2014		
Strip	2015	2016	2017		
Clinch	2011				

* obsolescent.

5.1.1 **Code Systems.** The part referencing system consists of the AGS number, followed by a letter indicating the thread size, followed by a number indicating the material Floating anchor nuts are referenced with two material numbers, the first for the attachment plate and the second for the nut. The complete part number for a $\frac{5}{16}$ inch BSF countersunk floating anchor nut with mild steel base plate and light alloy nut would be, AGS 2014/G/13. The diameter code letters are the same as those shown in Table 2 and the material code is as follows:—

1 Mild steel, cad. plated
2 CRS or monel, cad. plated
3. Light Alloy, anodised and dyed blue
4 Brass or bronze, electro-tinned.

TABLE 8
WING NUTS

Code	*Size*	*Code*	*Size*
A	6 BA (AGS 113 only)	D	$\frac{11}{32}$ in BSF (AGS 120 only)
B	4 BA (AGS 113 only)	E	$\frac{3}{8}$ in BSF (AGS 120 only)
C	2 BA (AGS 113 only)	F	$\frac{13}{32}$ in BSF (AGS 120 only)
A	$\frac{1}{4}$ in BSF (AGS 120 only)	G	$\frac{7}{16}$ in BSF (AGS 120 only)
B	$\frac{9}{32}$ in BSF (AGS 120 only)	H	$\frac{1}{2}$ in BSF (AGS 120 only)
C	$\frac{5}{16}$ in BSF (AGS 120 only)		

5.2 **AGS Nuts—Various**

5.2.1 **Wing Nuts AGS 113 and AGS 120 (Brass Cadmium Coated).** AGS 113 relates only to BA sizes, whilst AGS 120 relates only to BSF sizes. The coding system for these nuts consists of the AGS number followed by a letter indicating the size of thread (Table 8). **Example: A ¼ inch BSF brass wing nut would be AGS 120/A.**

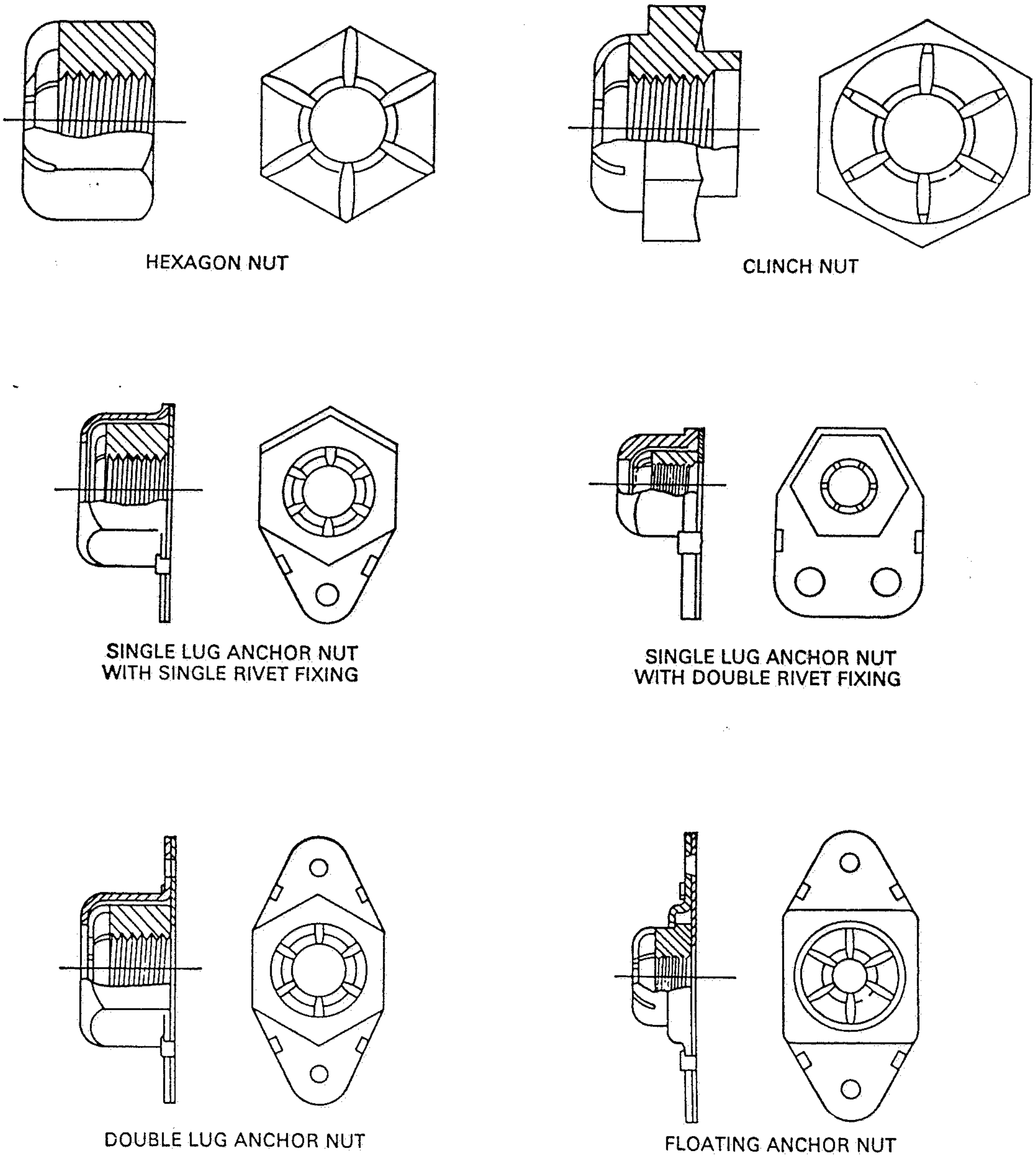


Figure 6 TYPICAL AGS STIFFNUTS

5.2.2 **Wing Nuts AGS 3413.** These are cadmium coated brass wing nuts with Unified threads in the sizes 4-40 UNC to $\frac{1}{2}$ inch UNF. The coding system consists of the AGS number followed by a letter indicating the thread size (Table 5).

5.2.3 **BSP Union Lock Nuts, AGS 207 (Mild Steel, cad. plated), AGS 224 (Brass, cad. plated) and AGS 957 (Al Al anodised).** The coding system used for these nuts consists of the AGS number (which indicates the type of material), followed by a letter indicating the thread size. The letters A to E are used, representing the sizes $\frac{1}{8}$ inch BSP to $\frac{5}{8}$ inch BSP in steps of $\frac{1}{8}$ inch. A $\frac{1}{2}$ inch BSP brass lock nut would therefore be AGS 224/D.

5.2.4 **Thin Nuts BSP and Whitworth Form, AGS 1148 (Al Al anodised).** The coding system used for these nuts consists of the AGS number, followed by a letter indicating the thread size (Table 9). Example: A $\frac{1}{2}$ inch BSP nut would be AGS 1148/D.

TABLE 9

THIN NUTS

Code	*Size*	*Code*	*Size*
A	$\frac{1}{8}$ in BSP	F	$\frac{3}{4}$ in BSP
B	$\frac{1}{4}$ in BSP	G	$\frac{7}{8}$ in BSP
BB	19 t.p.i. Whit. Form 0.60 o/d	H	1·0 in BSP
C	$\frac{3}{8}$ in BSP	J	$1\frac{1}{4}$ in BSP
CC	14 t.p.i. Whit. Form 0.75 o/d	K	$1\frac{1}{2}$ in BSP
D	$\frac{1}{2}$ in BSP	L	$1\frac{3}{4}$ in BSP
E	$\frac{5}{8}$ in BSP	M	2·0 in BSP

5.2.5 **Union Nuts AGS 1187 (Al Al Anodised), AGS 1216 (Mild Steel, Cadmium treated) and AGS 1217 (Brass, Cadmium treated).** The coding system used for these nuts consists of the AGS number, followed by a letter indicating the thread size (Table 9). Example: A $\frac{1}{4}$ inch BSP union nut made of brass would be AGS 1217/B.

5.2.6 **L.T. Union Lock Nut, AGS 1710 (Brass, tinned).** This nut is made in one size only, i.e. $\frac{1}{2}$ inch x 26 t.p.i. Whitworth form.

6 FUTURE TRENDS

6.1 The need for saving weight on aircraft structures has led to the widespread use of lightweight fasteners of all types, particularly of self-locking nuts and anchor nuts. The use of lightweight and miniature stiffnuts was pioneered in the United States and although these nuts are readily available in this country, very few of British design are, as yet, manufactured in Great Britain.

6.2 Aircraft manufacturers are tending to make greater use of the UNJ thread form because of its high resistance to fatigue. All future specifications for aircraft fasteners are expected to stipulate this thread and some existing specifications for nuts contain a clause requiring the thread to be of UNJ form after a specified date. Nuts with UNJ threads are fully interchangeable with nuts having standard Unified threads of the same class, the only difference being a slight increase in the minor diameter to accommodate the increased root radius of the external thread.

6.3 In view of the general acceptance of metric dimensions in other fields, it seems likely that the metric thread of UNJ form will eventually be used internationally and result in further specifications for nuts in both the AS and BS series. It is expected that fasteners having metric threads will be identified by marking with the letter 'M'.

7 ABBREVIATIONS AND TERMS USED

AGS	Aircraft General Standards.
Al Al	Aluminium Alloy.
AS	Aircraft Standards of the SBAC.
Attachment Plate	The formed sheet metal plate of a floating anchor nut which is riveted to the structure. It retains the nut body and base plate, allowing a specified amount of movement in relation to the structure.
BA	British Association.
Base Plate	The plate, normal to the axis of the nut, which forms the riveting lugs of a fixed anchor nut. In a floating anchor nut it retains the nut body in the attachment plate.
BS	British Standard.
BSF	British Standard Fine.
BSP	British Standard Pipe.
Cap Nut	A stiffnut, the threaded bore of which is sealed by a metal cap to prevent the leakage of fluids.
Clinch Nut	A self-retaining stiffnut having a spigot at the bearing face which is spread to hold the nut in position.

CRS	Corrosion resisting steel.
Fixed Anchor Nut	A stiffnut which is rigidly attached to the structure.
Floating Anchor Nut	A stiffnut which has a limited amount of movement in a plane normal to the axis of the nut for purposes of alignment.
Friction Element	The portion of a stiffnut, above the nut body, designed to impose friction between the nut and the thread on which it is mounted. The shape of the friction element varies with different designs but must be contained within the maximum plan form and height quoted in the appropriate specification.
HTS	High Tensile Steel. Normally implying a tensile strength in excess of 50 tonf/in^2, but in some specifications the smaller fasteners may be manufactured from material with a lower tensile strength.
HTSS	High Tensile Stainless Steel.
LTS	Low Tensile Steel. Steel with a tensile strength of up to approximately 25 tonf/in^2.
MTS	Medium Tensile Steel. Steel with a tensile strength between that of LTS and HTS.
Nut Body	The portion of a stiffnut containing the screw thread.
SS	Stainless Steel.
Stiffnut	A nut body surmounted by a device which imposes friction between the nut and the thread on which it is mounted so that no other form of locking is required.
Strip Nuts	A row of stiffnuts mounted on a common attachment plate in the form of a continuous strip.
t.p.i.	Threads per inch.
UNC	Unified Coarse Thread.
UNF	Unified Fine Thread.

UNJ	Unified thread with increased root radius for added fatigue resistance. Ranges of fine threads (UNJF) and coarse threads are provided in this series.
UNS	Threads of basically Unified form but differing slightly from the standard Unified series.
Whit.	Whitworth.

BL/2-7

Issue 1.

3rd December, 1976.

BASIC

IDENTIFICATION MARKING

STANDARD FASTENERS OF AMERICAN MANUFACTURE

1 INTRODUCTION This Leaflet gives guidance on the identification and coding of bolts, nuts, screws and washers which are manufactured to American National Standards and are used for general aircraft assembly. Many other types of American fasteners are used on aircraft, particularly in the field of light-weight, self-locking nuts and bolts, and these are approved for use by the relevant manufacturer or Airworthiness Authority; these fasteners will not necessarily be marked or identified in accordance with the national standards, but will comply with information published by the particular manufacturer.

2 SPECIFICATIONS Standard aircraft fasteners in America are manufactured in accordance with Government, Military and Civil Specifications. The following series of specifications cover the materials, processes, and component drawings for all standard fasteners:—

Federal Specifications
Society of Automotive Engineers Specifications (SAE)
Aeronautical Materials Division of SAE Specifications (AMS)
Air Force/Navy Specifications (AN)
Military Standards (MIL and MS)
National Aerospace Standards (NAS)

2.1 These specifications provide for a range of fasteners with Unified threads in the UNC, UNF and UNJF series (see Leaflet **BL/3-2** for full details of Unified threads). However, whereas for British aircraft, fasteners are manufactured in a selected range of Unified threads, American fasteners are, in some instances, supplied with both UNC and UNF threads. Extreme care is necessary when matching up nuts with screws or bolts in these series. If not properly identified, then thread gauges must be used to check the thread. Visual comparison of small threads is not recommended.

2.2 The various standards are dealt with separately in this Leaflet, and it should be noted that the AN series has to a large extent been replaced by MS and NAS components.

3 AN FASTENERS These specifications are in two series. The early series has numbers from 3 to 9000, with the fasteners occupying a range from 3 to 1000; these fasteners are of comparatively low strength, and are manufactured in steel or aluminium alloy. The steel parts are generally manufactured from low-alloy steel, and if non-corrosion-resistant, are cadmium plated, whilst the aluminium parts are anodised. The later series parts have six figure numbers commencing with 100000, are of more recent design and are generally manufactured from higher-strength materials.

3.1 **Early Series AN Bolts.** Table 1 gives a list of the early series AN Bolts, and Fig. 1 shows the types of heads and the identification marking used to indicate the material from which the parts are made.

TABLE 1 EARLY SERIES AN BOLTS

AN Number	Type	Material	Process	Nominal Range of Thread Sizes **	Thread
3 – 20	Bolt, hexagon head	Steel	Cad. plated	No.10 to 1¼ in	UNF
		CRS *	Nil		
		Al. alloy	Anodised		
21 – 36	Bolt, clevis	Steel	Cad. plated	No.6 to 1 in	UNF
42 – 49	Bolt, eye	Steel	Cad. plated	No.10 to $\frac{9}{16}$ in	UNF
73 – 81	Bolt, hexagon, drilled head	Steel	Cad. plated	No.10 to ¾ in	UNF or UNC
173 – 186	Bolt, close-tolerance	Steel	Cad. plated thread and head	No.10 to 1 in	UNF
		CRS *	Nil		
		Al. alloy	Anodised		

* CRS = Corrosion-resistant steel. ** See Leaflet BL/3–2 for details of thread designations.

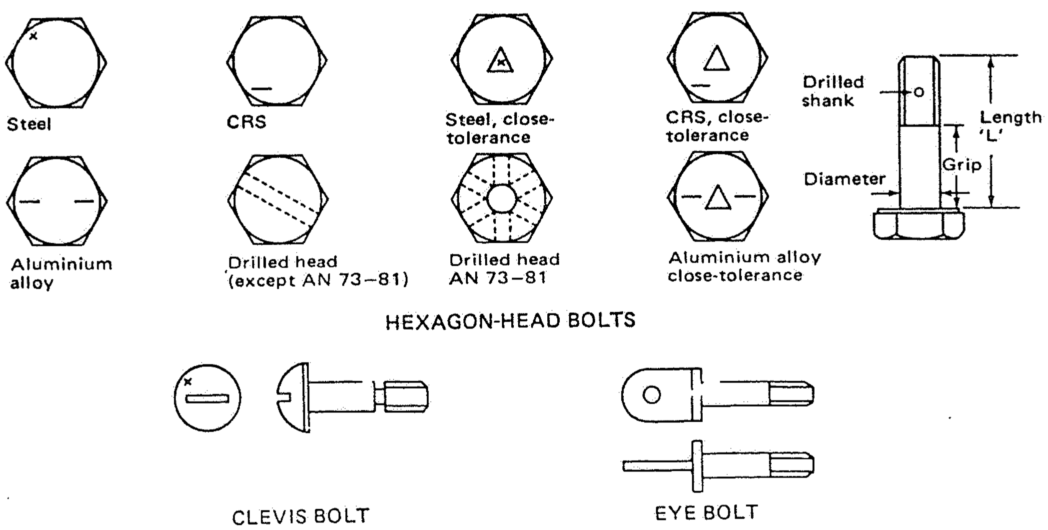


Figure 1 EARLY SERIES AN BOLTS

3.1.1 All of the bolts listed in Table 1 may be identified as to type by reference to the head marking or position of the locking wire holes. Diameter may be identified by experience, or by measurement and reference to the specification. Other dimensions such as grip length, head size and thread length, must be obtained from the specification.

3.1.2 **Coding.** For identification purposes the AN number is used to indicate the type of bolt and its diameter, and a code is used to indicate the material, length and thread (where these vary) and the position of the locking wire or cotter pin (split pin) hole.

(a) **Diameter.** The last figure or last two figures of the AN number indicate the diameter of the thread. 1 = No.6, 2 = No.8, 3 = No.10, and 4 = $\frac{1}{4}$ in, and subsequent numbers indicate the diameter in $\frac{1}{16}$ in increments; above $\frac{5}{8}$ in the available sizes are in $\frac{1}{8}$ in steps, but are still coded in sixteenths. Thus an AN 4 is a hexagon head bolt with $\frac{1}{4}$ in thread, an AN 14 is a hexagon head bolt with a $\frac{7}{8}$ in ($\frac{14}{16}$) thread and an AN 182 is a close-tolerance bolt with a $\frac{3}{4}$ in ($\frac{12}{16}$) thread (the numbering in this case starting at 173). An exception to this is the eye bolt, where different diameter pin holes affect the coding; AN 42 is No.10, AN 43 is $\frac{1}{4}$ in, AN 44 is $\frac{5}{16}$ in with a $\frac{1}{4}$ in diameter pin hole, and AN 45 is $\frac{5}{16}$ in with a $\frac{5}{16}$ in diameter pin hole.

(b) **Length.** The length of a bolt as quoted in the specifications, is the overall length from under the head to the end of the shank (L in Fig. 1), but the length is generally regarded as from under the head to the first full thread (excluding the chamfer) and is quoted in $\frac{1}{8}$ in increments as a 'dash' number. The last figure of the dash number represents eighths of an inch, and the first figure of the dash number represents inches. Thus an AN 4–12 is a $\frac{1}{4}$ in hexagon-head bolt $1\frac{1}{4}$ in (i.e. $1\frac{2}{8}$) long, and an AN 12–24 is a $\frac{3}{4}$ in hexagon-head bolt $2\frac{1}{2}$ in long. The total lengths quoted in the specifications for these bolts, is actually $1\frac{9}{32}$ in and $2\frac{21}{32}$ in, respectively. Clevis bolts (AN 21 to 36) do not follow this coding, but the length is indicated in $\frac{1}{16}$ in increments by the dash number; thus an AN 29–9 is $\frac{9}{16}$ in long.

(c) **Position of Drilled Hole.** Bolts are normally supplied with a hole drilled in the threaded part of the shank, but different arrangements may be obtained by use of the following code:—

Drilled shank = normal coding, e.g. AN 24–15.

Undrilled shank = A added after dash number, e.g. AN 24–15A.

Drilled head only = H added before dash number (replacing the dash sign) and A added after dash number, e.g. AN 6H10A.

Drilled head and shank = H added before dash number, e.g. AN 6H10.

(d) **Material.** The standard coding applies to a non-corrosion-resistant, cadmium-plated steel bolt. Where the bolt is supplied in other materials, letters are placed after the AN number as follows:—

C = corrosion-resistant steel (CRS)

DD = aluminium alloy, e.g. AN 6DD10.

(e) **Thread.** Where the bolt is supplied with either UNF or UNC threads, a UNC thread is indicated by placing an 'A' in place of the dash, e.g. AN 74A6.

TABLE 2 EARLY SERIES AN MACHINE SCREWS

AN Number	Type	Material	Process	Head Marking *	Nominal Range of Thread Sizes	Thread
500	Screw, fillister head	Steel	Cad. plated		No.2 to $\frac{3}{8}$ in	UNC
		CRS	Nil			
		Brass	Nil			
501	Screw, fillister head	Steel	Cad. plated		No.0 to $\frac{3}{8}$ in	UNF
		CRS	Nil			
		Brass	Nil			
502	Screw, fillister head (drilled)	Steel	Cad. plated	XX	No.10 to $\frac{5}{16}$ in	UNF
503	Screw, fillister head (drilled)	Steel	Cad. plated	XX	No.6 to $\frac{5}{16}$ in	UNC
505	Screw, flat 82°	Steel	Cad. plated	— —	No.2 to $\frac{3}{8}$ in	UNC
		CRS	Nil			
		Brass	Nil			
		Al. alloy	Anodised			
507	Screw, flat 100°	Steel	Cad. plated		No.6 to ¼ in	UNC and UNF
		CRS	Nil	— —		
		Brass	Black oxide			
		Brass	Nil			
		Al. alloy	Anodised			
509	Screw, flat 100° structural	Steel	Cad. plated	XX	No.8 to $\frac{5}{16}$ in	UNF
		Al. alloy	Anodised			
		Bronze	Cad. plated	= =		
		Bronze	Nil	= =		
510	Screw, flat 82°	Steel	Cad. plated		No.5 to ¼ in	UNF
		CRS	Nil	— —		
		Brass	Nil			
		Al. alloy	Anodised			
515	Screw, round head	Steel	Cad. plated		No.5 to $\frac{3}{8}$ in	UNC
		CRS	Nil	— —		
		Brass	Nil			
		Al. alloy	Anodised			
520	Screw, round head	Steel	Cad. plated		No.5 to ¼ in	UNF
		CRS	Nil	— —		
		Brass	Nil			
		Al. alloy	Anodised			
525	Screw, washer head	Steel	Cad. plated		No.8 to ¼ in	No.8 UNC & UNF No.10 UNF ¼ in UNF
526	Screw, truss head	Steel	Cad. plated		No.6 to ¼ in	UNF and UNC
		CRS	Nil	— —		
		Al. alloy	Anodised			

*Only one symbol may be found on some screw heads

3.2 **Early Series AN Machine Screws.** Screws differ from bolts in being made from a lower strength material, having a looser fit (class 2A thread instead of class 3A) and having a slotted or a cruciform-recessed head, for rotation by a suitably-shaped screwdriver. The thread is usually continued up to the head, but the shank of 'structural' screws (i.e. AN 509 and 525) has a plain portion and may be used in locations where shear loading is present. Some screw heads are marked to indicate the material from which they are made, and these markings are listed in Table 2. The markings, head shape and material will enable identification of a particular screw to be made. Table 2 lists the AN machine screws, and Fig. 2 illustrates the various head shapes. It should be noted that some of these screws are obsolescent, and may not be available in the full range of sizes.

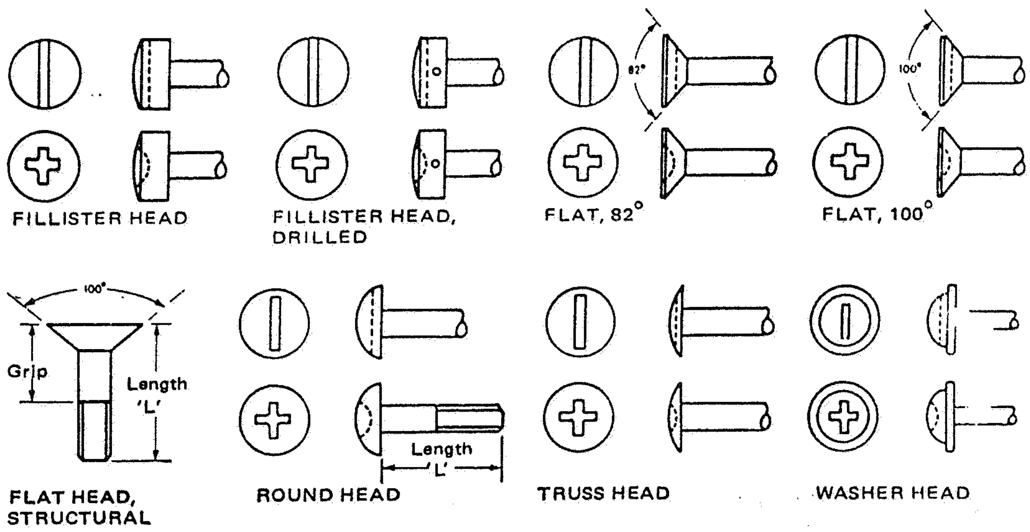


Figure 2 EARLY SERIES AN SCREWS

3.2.1 **Coding.** Screws are coded by the AN number, to indicate the type (e.g. round head), letters to indicate material (and in some cases the shape of the screwdriver recess), and two dash numbers indicating diameter and length. In addition, some are coded to indicate whether the head is drilled or not.

(a) **Diameter.** The coding for the diameter depends on whether the screw is available with only fine or coarse threads, or with either type of thread. Diameter is indicated by the first dash number.

(i) Screws available with only one type of thread are coded by the thread number or diameter in sixteenths of an inch. For example, No.4 (UNC or UNF) = —4, No.10 (UNC or UNF) = —10, $\frac{1}{4}$ in (UNC or UNF) = —416, $\frac{5}{16}$ in (UNC or UNF) = —516, etc.

(ii) Screws available with both coarse and fine threads (AN 507, AN 525 and AN 526) are coded by the thread number or diameter in sixteenths of an inch, followed by the number of threads per inch. For example, No.6–32 (UNC) = —632, No.8–36 (UNF) = —836, $\frac{1}{4}$–20 (UNC) = —420, $\frac{1}{4}$–28 (UNF) = —428, etc.

(iii) AN 525 screws are available in only one coarse thread size (No.8) and this is coded —832. The remaining sizes are coded in accordance with (i).

(b) **Length.** The second dash number indicates the length (L in Fig. 2) of a screw in sixteenths of an inch. AN 509 screws are an exception to this rule, the actual length of the screw being $\frac{1}{32}$ in longer than the size indicated by the code.

(c) **Material.** Material is indicated by a letter (or letters) placed after the AN number as follows:—

Steel = no letter
CRS = C
Brass (unplated), AN 507 = UB, and other screws = B
Brass (black oxide), AN 507 = B
Aluminium alloy, AN 507, 509 and 526 = DD, and other screws = D
Bronze (cad. plated), AN 509 = P
Bronze (unplated), AN 509 = Z

(d) **Head Recess.** Where a screwdriver slot is required the basic code only is used. Where a cruciform recess is required, 'R' is added instead of the second dash.

(e) **Drilled Head.** AN 500 and 501 screws are provided with plain or drilled heads. The letter A before the first dash number indicates a screw with a drilled head.

(f) **Examples of Coding**

(i) An AN 500A6–32 is a fillister head screw with a locking wire hole. It is made of cadmium-plated steel, has a No.6 (UNC) thread, has a slotted head and is 2 in long.

(ii) An AN 507C832R8 is a 100° flat head screw in corrosion-resistant steel. It has a No.8–32 (UNC) thread, has a cruciform recessed head and is $\frac{1}{2}$ in long.

(iii) An AN 509DD416–20 is a 100° flat head, structural screw in aluminium alloy. It has a $\frac{1}{4}$ in (UNF) thread, has a slotted head and is $1\frac{3}{32}$ in long.

3.3 **Early Series AN Nuts.** These nuts are made in a variety of different materials, and should normally be used with early series AN bolts and AN screws. Some nuts are designed specifically for use in engines, and should not be used in airframe locations; they are thicker than standard airframe nuts. Early series AN nuts are not marked for identification purposes, but can be recognized from their shape and surface finish. Table 3 gives a list of these nuts, and Fig. 3 illustrates the various types. As with the AN screws, some nuts may be obsolescent, and not available in the full range of sizes.

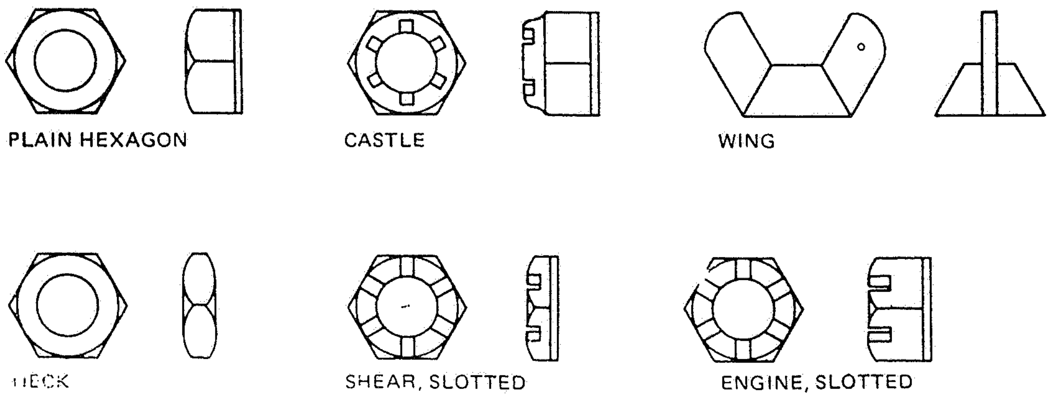


Figure 3 EARLY SERIES AN NUTS

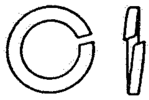
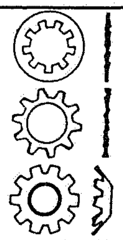
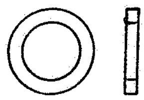
3.3.1 **Coding.** The nuts listed in Table 3 are coded according to the type and size of thread, by a dash number placed after the AN number. Those nuts which are intended for use with AN bolts have the same code as the bolts, i.e. a number indicating thread diameter in sixteenths of an inch, and No.6, No.8 and No.10 threads being —1, —2 and —3, respectively. Those nuts intended for use with machine screws (AN 340 and 345) are coded according to the code for screws. The code represents the thread number (—0 to —10) or the diameter in sixteenths of an inch (—416, —516, etc.) as detailed in paragraph 3.2.1 (a)(i). Wing nuts (AN 350) are coded by the thread designation (—640, —832, etc.) or thread diameter in the fraction sizes (—4 = $\frac{1}{4}$ in, —5 = $\frac{5}{16}$ in, etc.). Material is indicated by a letter placed in the code instead of the dash; C = corrosion-resistant steel, DD = aluminium alloy, machine-screw nuts, D = other aluminium alloy nuts, B = brass, and the absence of a letter indicates a non-corrosion-resistant steel nut. With AN 315 and 316 nuts, 'L' or 'R' is added after the code to indicate left- or right-hand threads. Examples of this coding are: AN 350B4 is a brass wing nut to fit a $\frac{1}{4}$ in bolt, and AN 316–6L is a steel check nut to fit a $\frac{3}{8}$ in bolt with a left-hand thread.

TABLE 3 EARLY SERIES AN NUTS

AN Number	Type	Material	Process	Nominal Range of Thread Sizes	Thread
310	Nut, castle	Steel CRS Al. alloy	Cad. plated Nil Anodised	No.10 to 1¼ in	UNF
315	Nut, plain	Steel CRS Al. alloy	Cad. plated Nil Anodised	No.6 to 1¼ in (also left-hand thread)	UNF
316	Nut, check	Steel	Cad. plated	¼ to 1 in (also left-hand thread)	UNF
320	Nut, castle, shear	Steel CRS Al. alloy	Cad. plated Nil Anodised	No.6 to 1¼ in	UNF
340	Nut, machine screw, hexagon	Steel CRS Brass Al. alloy	Cad. plated Nil Nil Anodised	No.2 to ¼ in No.2 to ¼ in No.2 to No.6 No.6 to $\frac{3}{8}$ in	UNC
345	Nut, machine screw, hexagon	Steel CRS Brass Al. alloy	Cad. plated Nil Nil Anodised	No.0 to ¼ in No.0 to ¼ in No.0 to No.10 No.10 to ¼ in	UNF
350	Nut, wing	Steel Brass	Cad. plated Nil	No.6 to ½ in	UNF
355	Nut, engine, slotted	Steel	Cad. plated	No.10 to ¾ in	UNF
360	Nut, engine, plain	Steel	Cad. plated	No.10 to ¾ in	UNF

3.4 **Early Series AN Washers.** AN Standards include three types of washers, and, although these have been replaced in later aircraft designs by MS washers, they may still be found on some older types of aircraft and are included for reference. These washers are listed and illustrated in Table 4.

TABLE 4 EARLY SERIES AN WASHERS

AN Number	Type	Shape	Material	Process	Material Code
935	Washer, lock, spring		Steel Bronze CRS	Cadmium plated Nil	Nil B C
936	Washer, shake-proof	A B C 	Steel Bronze	Cadmium plated Tinned	Nil B
960	Washer, plain		Steel CRS Brass Al. alloy Al. alloy	Cadmium plated Nil Nil Nil Anodised	Nil C B D PD

3.4.1 **Coding.** Washers are identified by the AN number, a dash number to indicate size, and letters to indicate material and finish.

(a) **Size.** The size of a washer is related to the size of bolt it is designed to fit, and the dash number is in accordance with the code outlined in paragraph 3.2.1 (a) (i).

(b) **Material.** Material is indicated in the code by adding the letters shown in Table 4.

(c) **Thickness.** AN 935 and 960 washers may be available in light or regular thickness, the light washer being indicated by an 'L' at the end of the code. Actual thicknesses should be obtained from the AN Standard.

(d) **Examples**

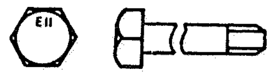
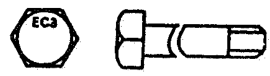
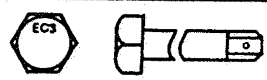
(i) AN 936A416B is a style A regular shakeproof washer designed to fit a ¼ in bolt and is made of bronze.

(ii) AN 960 C–616L is a light plain washer in corrosion-resistant steel, for a ⅜ in bolt.

3.5 **Late Series AN Fasteners.** These fasteners are all marked to show the material from which they are made. When ordering a particular fastener, the part number should be taken from the tables in the appropriate specification, since the size cannot be determined from a standard coding. Tables 5, 6 and 7 list the various bolts, screws and nuts which are currently available in this series of specifications, and give the range of numbers allocated to each type.

3.5.1 Late series AN bolts are listed in Table 5 and are available in sizes 10–32, ¼–28, 5/16–24, ⅜–24, 7/16–20, ½–20, 9/16–18, ⅝–18 and ¾–16.

TABLE 5 LATE SERIES AN BOLTS

AN Number	Type	Material	Identification
101001–101900	Bolt, hexagon head	Alloy steel (AMS 6322) cadmium plated	
101901–102800	Bolt, hexagon head, drilled shank		
102801–103700	Bolt, hexagon head, drilled head (1 hole)		
103701–104600	Bolt, hexagon head, drilled head (6 holes)		
104601–105500	Bolt, hexagon head	Corrosion-resistant steel (AMS 7472)	
105501–106400	Bolt, hexagon head, drilled shank		
106401–107300	Bolt, hexagon head, drilled head (1 hole)		
107301–108200	Bolt, hexagon head, drilled head (6 holes)		

3.5.2 Late series AN screws are listed in Table 6, and are available in the sizes shown.

3.5.3 Late series AN nuts are listed in Table 7 and are available in the sizes shown.

3.5.4 A plain washer is also available in the late series AN specifications. This is a plain steel washer of cadmium plated steel (AMS 6350), made to fit bolts in sizes No.10 to 1 in, and given a number in the range 122576 to 122600. The washers are rubber stamped with the mark 'E 23'.

4 MS FASTENERS A wide variety of fasteners is available in the MS range. All of these fasteners are marked to show the material from which they are made or the MS specification to which they conform; in addition, most fasteners are marked with the manufacturer's identification. Bolts and screws are marked on their heads, and nuts are marked either on the flat (hexagon nuts) or on the top face (other types). To assist in identification, Fig. 4 illustrates the various types of bolt and screw heads in this series, and these are referred to in the appropriate Tables. Nuts are similar to those illustrated in Table 7.

TABLE 6 LATE SERIES AN SCREWS

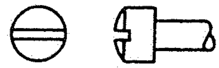
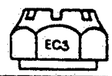
AN Number	Type	Material	Sizes	Identification
116901–116912	Screw, oval fillister	Carbon steel (AMS 5061) cadmium plated	4–40	
116913–116924	Screw, oval fillister, drilled		4–40	
116925–116960	Screw, oval fillister		6–32	
116961–117000	Screw, oval fillister, drilled		6–32	
117001–117040	Screw, oval fillister		8–32	
117041–117080	Screw, oval fillister, drilled		8–32	
115401–115600	Screw, flat fillister	Alloy steel (AMS 6322) cadmium plated	UNF No. 10 to $\frac{3}{8}$ in	
115601–115800	Screw, flat fillister, drilled shank			
115801–116150	Screw, flat fillister, drilled head		No. 10 UNF ¼ to $\frac{3}{8}$ in UNF ¼ to $\frac{3}{8}$ in UNC	

TABLE 7 LATE SERIES AN NUTS

AN Number	Type	Material	Sizes	Identification
121501–121525	Nut, hexagon, plain	Alloy steel (AMS 6322) cadmium plated	No. 10 to 1 in UNF	
121551–121575	Nut, hexagon, castle			
121526–121550	Nut, hexagon, plain	Corrosion-resistant steel (AMS 7472)		
121576–121600	Nut, hexagon, castle			
150401–150425	Nut, hexagon, check	Alloy steel (AMS 6320) cadmium plated	No. 10 to ¾ in UNF	
150426–150450	Nut, hexagon, shear, slotted			

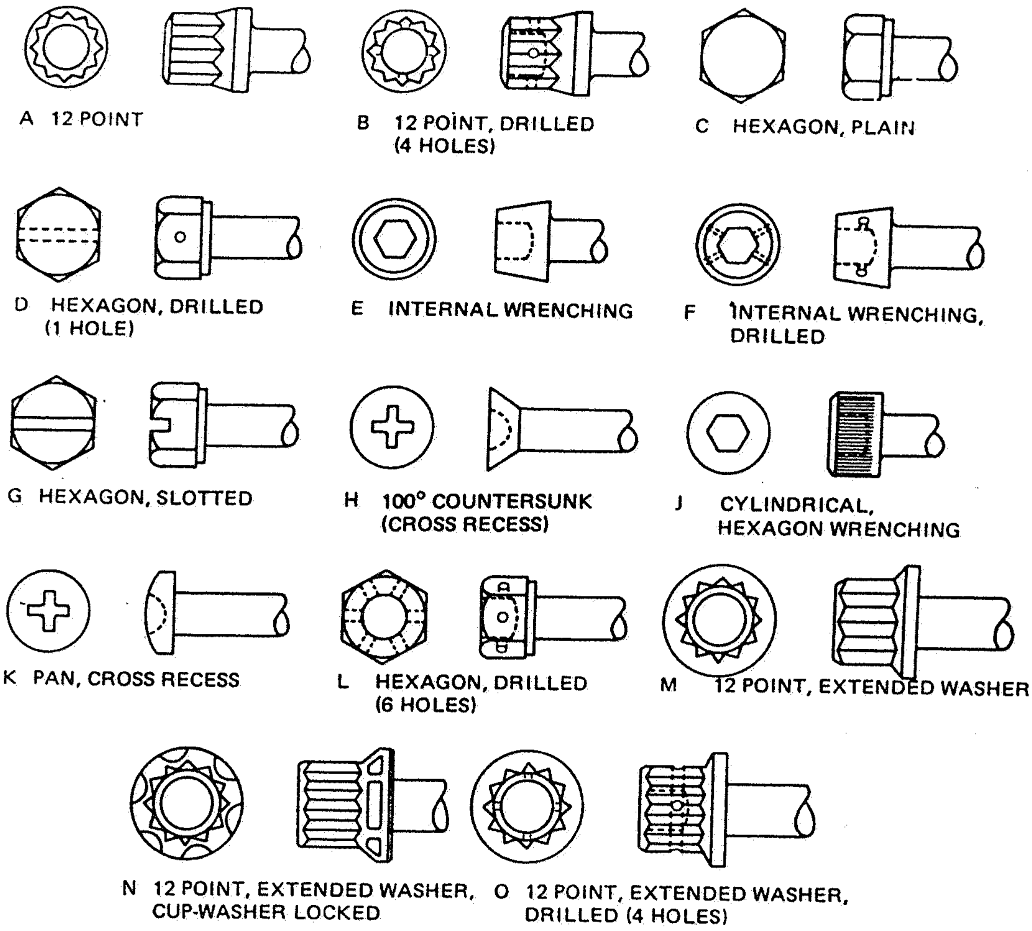


Figure 4 MS BOLTS AND SCREWS

4.1 **MS Bolts.** Table 8 lists a wide range of bolts and screws in the MS series. It should be noted, however, that the term 'bolt' is applied to the whole range of sizes in which a particular item is supplied. In the specifications, an item with a No. 8 or smaller thread is generally termed a 'screw', regardless of the fact that it is identical in shape and material to a larger item, which is termed a 'bolt'. However, in some cases the term 'bolt' is also applied to an item with a No. 8 thread.

4.1.1 **Coding.** For most of the items listed in Table 8, the MS number relates to an item of a particular diameter, and a table provided in the specification details the range of lengths available in that size. Length is indicated by a dash number, but the length indicated by a particular dash number varies with the diameter, so that the complete part number of a particular item can only be determined by reference to the specifications.

TABLE 8 MS BOLTS AND SCREWS

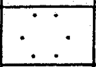
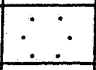
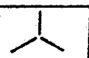
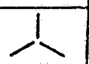
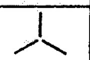
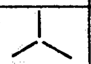
MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material*	Plating
9033–9038	Bolt, 12 point, heat resistant	A	EH 19	UNF	No.10 – ½ in	AMS 5735	Nil
9060–9066	Bolt, 12 point, drilled, extended washer head	O	EH 19	UNF	No.10 – ½ in	AMS 5735	Nil
9088–9094	Bolt, 12 point, drilled head	B	E 11	UNF	No.10 – 9/16 in	AMS 6322	Cad.
9110–9113	Bolt, 12 point, extended washer head	M	MS No.	UNF	No.10 – 3/8 in	AMS 5731	Nil
9146–9152	Bolt, 12 point	A	E 11	UNF	No.10 – 9/16 in	AMS 6322	Cad.
9157–9163	Bolt, 12 point	A	E 11	UNF	No.10 – 9/16 in	AMS 6322	Black oxide
9169–9175	Bolt, 12 point, drilled head	B	E 11	UNF	No.10 – 9/16 in	AMS 6322	Black oxide
9177 and 9178	Screw, 12 point, extended washer head	N	EH 19	UNF	No.6 & No.8	AMS 5735	Nil
9183 and 9184	Screw, 12 point, drilled head	B	E 11	UNF	No.6 & No.8	AMS 6322	Cad.
9185 and 9186	Screw, 12 point	A	E 11	UNF	No.6 & No.8	AMS 6322	Cad.
9189 and 9190	Screw, 12 point	A	E 11	UNF	No.6 & No.8	AMS 6322	Black oxide
9191 and 9192	Screw, 12 point, drilled head	B	E 11	UNF	No.6 & No.8	AMS 6322	Black oxide
9206–9214	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No.6 – 9/16 in	AMS 6304	Diffused nickel cadmium
9215–9222	Bolt, 12 point, extended washer, drilled head	O	MS No.	UNJF	No.6 – ½ in	AMS 6304	Diffused nickel cadmium
9224	Bolt, 12 point, heat resistant	A	EH 19	UNF	9/16 in	AMS 5735	Nil
9281–9291	Bolt, hexagon head	C	MS No.	UNF	No.4 – ¾ in	AMS 6322	Black oxide
9292–9302	Bolt, hexagon head, drilled	D	MS No.	UNF	No.4 – ¾ in	AMS 6322	Black oxide
9438–9448	Bolt, hexagon head, drilled	D	MS No.	UNJF	No.6 – ¾ in	AMS 6304	Diffused nickel cadmium
9449–9459	Bolt, hexagon head	C	MS No.	UNJF	No.6 – ¾ in	AMS 6304	Diffused nickel cadmium
9487–9497	Bolt, hexagon head	C	MS No.	UNJF	No.8 – ¾ in	AMS 5731	Nil
9498–9508	Bolt, hexagon head, drilled	D	MS No.	UNJF	No.6 – ¾ in	AMS 5731	Nil
9516–9526	Screw, hexagon head	C	MS No.	UNJF	No.4 – ¾ in	AMS 6322	Cad.
9527–9537	Screw, hexagon head, drilled	D	MS No.	UNJF	No.4 – ¾ in	AMS 6322	Cad.
9554–9562	Bolt, 12 point, extended washer head, PD shank	M	MS No.	UNJF	No.6 – 9/16 in	AMS 5731	Nil
9563–9571	Bolt, 12 point, ext. washer, drilled head, PD shank	O	MS No.	UNJF	No.6 – 9/16 in	AMS 5731	Nil
9572–9580	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No.6 – 9/16 in	AMS 5731	Silver plated
9583–9591	Bolt, hexagon head, drilled	L	MS No.	UNJF	No.10 – ¾ in	AMS 5731	Nil

TABLE 8 (continued)

MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material*	Plating
9676–9679	Bolt, 12 point, extended washer head, cupwasher locked	N	MS No.	UNJF	No.10 – ¼ in	AMS 5731	Nil
9680–9683	Bolt, 12 point, extended washer head, cupwasher locked	N	MS No.	UNJF	No.10 – ⅜ in	AMS 6322	Cad.
9694–9702	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No.4 – 9/16 in	AMS 5708	Nil
9712–9720	Bolt, 12 point, extended washer, drilled	O	MS No.	UNJF	No.4 – 9/16 in	AMS 5708	Silver plated
9730–9738	Bolt, 12 point, extended washer, PD shank	M	MS No.	UNJF	No.4 – 9/16 in	AMS 5643	Nil
9739–9747	Bolt, 12 point, extended washer, drilled, PD shank	O	MS No.	UNJF	No.4 – 9/16 in	AMS 5643	Nil
9748–9756	Bolt, 12 point, extended washer head, PD shank	M	MS No.	UNJF	No.4 – 9/16 in	Titanium	Nil
9757–9765	Bolt, 12 point, extended washer, drilled head, PD shank	O	MS No.	UNJF	No.4 – 9/16 in	Titanium	Nil
9883–9891	Bolt, 12 point, extended washer head	M	MS No.	UNJF	No.4 – 9/16 in	AMS 5616	Nil
20004–20024	Bolt, internal wrenching	E or F	MS No.	UNF	¼ – 1½ in	Alloy steel	Cad.
20033–20046	Bolt, hexagon head, 1200°F	C	1200	UNF	No.10 – 1 in	Corrosion- and heat-resisting steel	Nil
20073 & 20074	Bolt, hexagon head, drilled	D	X	–73 = UNF –74 = UNC	No.10 – ¾ in	Alloy steel	Cad.
21095	Bolt, self-locking, 250°F, hexagon head	C	–	UNF	No.10 – 1¼ in	CRS	Nil
21096	Bolt, self-locking, 250°F, pan head + recess	K	Nil	4,6,8 = UNC, larger = UNF	No.4 – ½ in	Alloy steel	Cad.
21097	Bolt, self-locking, 250°F, pan head + recess	K	Nil	4,6,8 = UNC, larger = UNF	No.4 – ½ in	CRS	Nil
21250	Bolt, 12 point, 180 000 lbf/in², drilled or plain	A or B	MS No.	UNF	¼ – 1½ in	Alloy steel	Cad.
21277–21285	Bolt, 12 point, extended washer head	M	MS No.	MIL–S–8879	No.4 – 9/16 in	AMS 5735	Nil
21286–21294	Bolt, 12 point, extended washer, drilled	O	MS No.	MIL–S–8879	No.4 – 9/16 in	AMS 5735	Nil

* AMS 6304 and AMS 6322 are low alloy steels.
All other AMS specifications in the Table are corrosion- and heat-resisting alloys.

TABLE 9 MS SCREWS

MS Number	Type	Head Shape (Fig. 4)	Head Marking	Thread	Thread Size Range	Material	Plating
9122 and 9123	Screw, hex. head, slotted	G	E 11	UNF	No. 10 and $\frac{1}{4}$ in	AMS 6322	Cadmium
21262	Screw, cyl. head, 160 KSI int. wren. 250°F	J		4,6,8 - UNC Larger - UNF	No. 4 – $\frac{5}{8}$ in	Alloy steel	Cadmium
21295	Screw, cyl. head, 160 KSI int. wren. 250°F	J		4,6,8 - UNC Larger - UNF	No. 4 – $\frac{5}{8}$ in	CRS	Nil
24693	Screw, flat 100°, + recess	H	—	UNC 2A UNF 2A	No. 6 – $\frac{3}{8}$in	CRS	Nil
24694	Screw, flat 100°, + recess	H	—	UNC 3A UNF 3A	No. 6 – $\frac{9}{16}$ in	CRS	Nil
27039	Screw, pan head, + recess, structural	K	B C	8 - UNC Larger - UNF	No. 8 – $\frac{1}{2}$ in	Bronze Alloy steel CRS	Nil Cadmium Nil
35297	Screw, cap, hex. head	C		UNC 2A	$\frac{1}{4} - 1\frac{1}{4}$ in	Carbon steel	Cad. or zinc
35299	Screw, cap, hex. head	C		UNC 2A	$\frac{1}{4} - 1\frac{1}{4}$ in	Carbon steel	Phosphate
35307	Screw, cap, hex. head	C		UNC 2A	$\frac{1}{4} - 1\frac{1}{4}$ in	CRS	Nil
35308	Screw, cap, hex. head	C		UNF 2A	$\frac{1}{4} - 1\frac{1}{4}$ in	CRS	Nil
51095	Screw, cap, hex. head, drilled	D		UNC 2A	$\frac{1}{4} - 1$ in	Carbon steel	Cadmium
51096	Screw, cap, hex. head, drilled	D		UNF 2A	$\frac{1}{4} - 1$ in	Carbon steel	Cadmium
51099	Screw, cap, hex. head, drilled	D		UNC 2A	$\frac{1}{4} - 1$ in	CRS	Nil
51100	Screw, cap, hex. head, drilled	D		UNF 2A	$\frac{1}{4} - 1$ in	CRS	Nil
51105	Screw, cap, hex. head, drilled	D		UNC 2A	$\frac{1}{4} - 1$ in	Carbon steel	Cadmium
51106	Screw, cap, hex. head, drilled	D		UNF 2A	$\frac{1}{4} - 1$ in	Carbon steel	Cadmium
51107	Screw, cap, hex. head, drilled shank	C		UNC 2A	$\frac{1}{4} - 1$ in	Alloy steel	Phosphate
51108	Screw, cap, hex. head, drilled shank	C		UNF 2A	$\frac{1}{4} - 1$ in	Alloy steel	Phosphate
51109	Screw, cap, hex. head, drilled shank	C		UNC 2A	$\frac{1}{4} - 1$ in	CRS	Nil
51110	Screw, cap, hex. head, drilled shank	C		UNF 2A	$\frac{1}{4} - 1$ in	CRS	Nil
90726	Screw, cap, hex. head	C		UNF 2A	$\frac{1}{4} - 1\frac{1}{2}$ in	Carbon steel	Cadmium
90727	Screw, cap, hex. head	C		UNF 2A	$\frac{1}{4} - 1\frac{1}{2}$ in	Alloy steel	Cadmium
90728	Screw, cap, hex. head	C		UNC 2A	$\frac{1}{4} - 1\frac{1}{2}$ in	Alloy steel	Cadmium

4.1.2 With bolts in the ranges MS 20004 to 20024 and MS 20033 to 20046, the thread size is indicated by the part number as outlined in paragraph 3.1.2 (a), and the length is indicated by a dash number, which represents grip length in sixteenths of an inch.

4.1.3 With bolts in the MS 21250 series, the dash number indicates both diameter and length. The first two figures indicate diameter in sixteenths of an inch, and the last two figures indicate grip length in sixteenths of an inch.

4.1.4 With the MS 20004 to 20024, and MS 21250, bolts, an H in place of the dash indicates a drilled-head bolt.

4.2 **MS Screws.** Table 9 lists a variety of the screws covered by MS specifications, and shows the features by which these screws may be partially identified.

4.2.1 Because the individual specifications vary, the screws listed in Table 9 should be fully identified by reference to the particular specification.

4.3 **MS Nuts.** The non-self-locking nuts to MS specifications are listed in Table 10. These nuts are similar in appearance to those shown in Table 7, but all are marked with the appropriate MS part number for identification purposes.

TABLE 10 MS NON-SELF-LOCKING NUTS

MS Number	Type	Thread	Size Range	Material	Plating
9356	Nut, plain, hexagon	No.4, 6 and 8 nuts have UNC thread. Larger size nuts have UNF thread.	No.4 – 1 in	AMS 5735	Nil
9357	Nut, plain, hexagon		No.4 – 1 in		Silver
9358	Nut, castle		No.10 – 1 in		Nil
9359	Nut, castle		No.10 – 1 in		Silver
9360	Nut, plain, hexagon, drilled		No.10 – 1 in		Silver
9361	Nut, plain, hexagon, check		No.10 – 1 in		Nil
9362	Nut, plain, hexagon, check		No.10 – 1 in		Silver
9363	Nut, hexagon, slotted, shear		No.10 – 1 in		Nil
9364	Nut, hexagon, slotted, shear		No.10 – 1 in		Silver

4.3.1 **Coding.** Nuts are coded by the MS number plus a dash number indicating thread size —04 is No. 4, —06 is No. 6, —08 is No. 8, —09 is No. 10, —10 is $\frac{1}{4}$ in, —11 is $\frac{5}{16}$ in, —12 is $\frac{3}{8}$ in, —13 is $\frac{7}{16}$ in, —14 is $\frac{1}{2}$ in, —15 is $\frac{9}{16}$ in, —16 is $\frac{5}{8}$ in, —17 is $\frac{3}{4}$ in, —18 is $\frac{7}{8}$ in and —19 is 1 in.

4.4 **MS Washers.** Two ranges of washers are covered in the MS series. MS 35338 is a cadmium-plated, steel, spring washer, and replaces the AN 935 regular spring washer. MS 35333 and 35335 are lock washers in cadmium-plated steel and bronze, which replace the AN 936 style A and style B shakeproof washers, respectively. All of these washers are ordered by the MS number, followed by a dash number indicating the size of bolt the washer is designed to fit. The dash number applicable to a particular washer should be obtained from the tables provided in the specification.

5 NAS FASTENERS NAS Specifications provide a wide range of fasteners, with a variety of head shapes and wrenching recesses (Fig. 5). The range of bolts and screws includes both self-locking and non-locking versions, and many varieties are also available with oversize shanks for repair work. A few washers and nuts are also included in the NAS specifications, but these items are generally supplied under manufacturers' specifications and are not included in this Leaflet.

5.1 All NAS bolts and screws are marked for identification purposes, but the extent of the marking depends on the size of the head and on the requirements of the particular specification. Many components are marked in accordance with NAS 1347, which provides for four types of identification. Type I is the material code and is the same as that shown in Fig. 1 for AN bolts; Type II is the basic part number, i.e. the NAS number; Type III is the basic part number and a material code letter; Type IV is the complete part number, including basic part number, material code, figures for diameter and length, and a letter for type of finish. These markings are shown in Table 11, and explained in paragraphs 5.2 and 5.3. It should be noted, however, that in the smaller sizes a shortened version of the code may be permitted by the specification. On fasteners with a Tri-Wing recess the marking also includes a figure, inside a circle, which indicates the size of the recess in accordance with NAS 4000. Oversize bolts are also marked with an 'X' or 'Y'.

NOTE: Provision is also made for including the manufacturer's identification mark on the head.

5.2 **Coding.** The bolts and screws listed in Table 11 are coded according to their type, diameter, length, type of plating and material. Where a component is made in more than one material, an alloy steel part is given the basic part number; similarly, where applicable, the basic part number implies that the part is not drilled for locking purposes.

5.2.1 **Diameter.** Most bolts and screws are coded according to thread size in a similar way to AN and MS parts; however, there are some exceptions.

(a) NAS 1261 to 1265 and NAS 1266 to 1270 are available in sizes $\frac{9}{16}$—18, $\frac{5}{8}$—18, $\frac{3}{4}$—16, $\frac{7}{8}$—14, and 1—12; they are coded in numerical order and indicated by an 'A' in Table 11.

(b) For bolts and screws which are given a range of numbers (except as detailed in (d)), the last figure or two figures indicates the size as follows:—

NAS xxx0 = 4—40, xxx1 = 6—32, xxx2 = 8—32, xxx3 = 10—32, xxx4 = $\frac{1}{4}$—28, xxx5 = $\frac{5}{16}$—24, xxx6 = $\frac{3}{8}$—24, xxx7 = $\frac{7}{16}$—20, xxx8 = $\frac{1}{2}$—20, xxx9 = $\frac{9}{16}$—18, xx10 = $\frac{5}{8}$—18, xx12 = $\frac{3}{4}$—16, xx14 = $\frac{7}{8}$—14, xx16 = 1—12, xx18 = $1\frac{1}{8}$—12, and xx20 = $1\frac{1}{4}$—12.

The threads are usually UNC, UNF, UNJC or UNJF, but some bolts and screws are also available with American National threads, and these are coded separately. Those parts which comply with the Unified standard are indicated by a 'B' in Table 11.

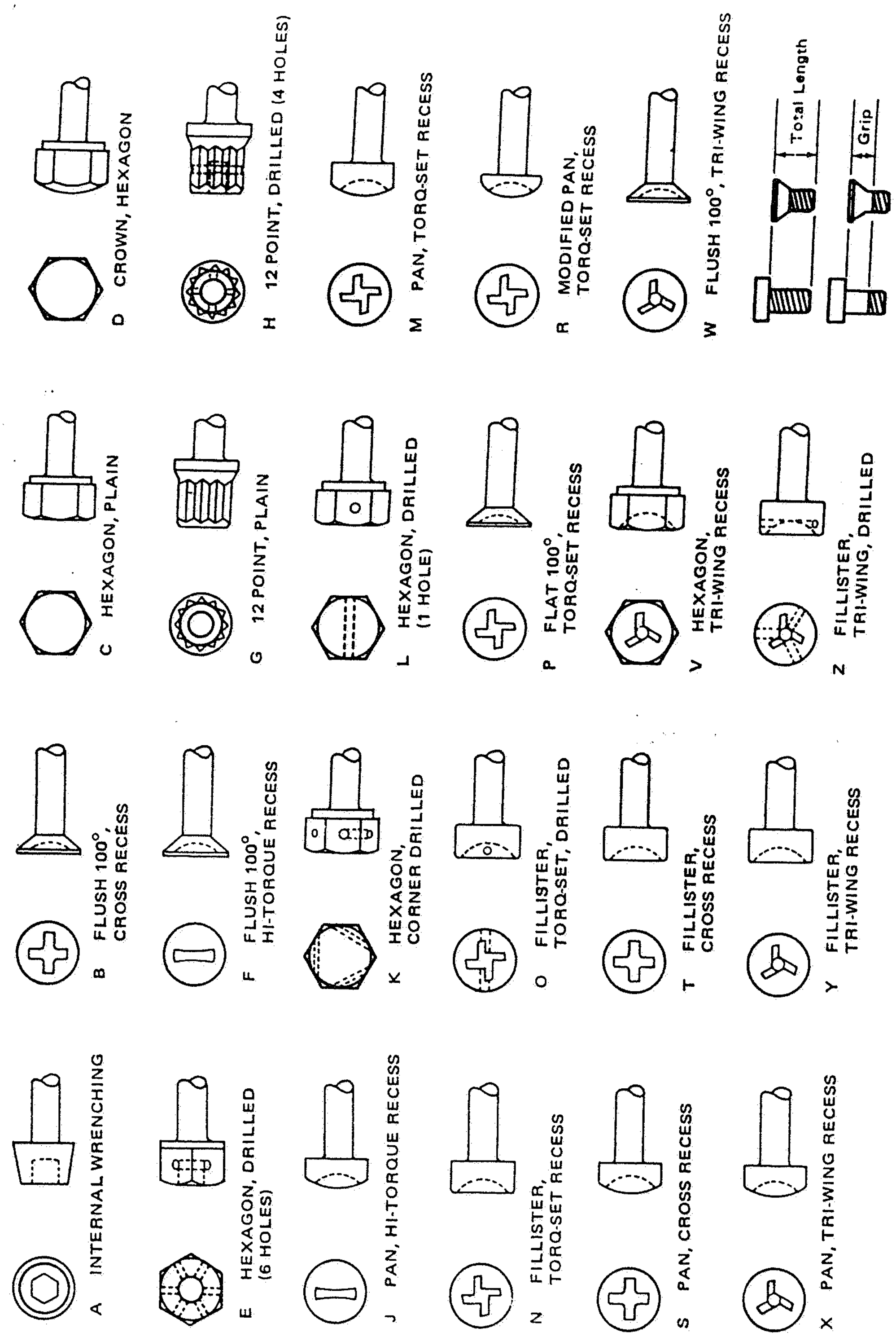


Figure 5 NAS BOLTS AND SCREWS

(c) For bolts and screws which are given a single NAS number, the diameter is given by the first dash number as follows:—

NAS xxxx—02 = 2—56, xxxx—04 = 4—40, xxxx—06 = 6—32, xxxx—08 = 8—32, xxxx—3 = 10—32, xxxx—4 = ¼ — 28, and so on, in steps of $\frac{1}{16}$ in, following the sizes given in (b). Parts following this code are marked 'C' in Table 11.

(d) NAS 1271 to 1280 are available in sizes from ¼ to 1 in, and are coded in numerical order.

5.2.2 **Length.** The length is indicated by the second dash number for parts with the 'C' diameter code, or the first dash number for all other parts. The length dash-number indicates the total length of a part with a full thread or the grip length of a part with a shorter thread (see Fig. 5), in sixteenths of an inch; exceptions are NAS 563 to 572, for which the length dash number represents thirty-seconds of an inch, and NAS 428, for which the dash number represents eighths of an inch as detailed in paragraph 3.1.2(b) for AN parts.

5.2.3 **Plating.** Alloy-steel bolts and screws are normally cadmium plated in accordance with QQ–P–416 Type II Class 3. If a different plating is used, or if CRS or titanium parts are plated, the following code may be used:—
W = QQ–P–416 Type I Class 3 plating.
B = Blackened Type II plating.
H = CRS with Type II plating.
P = CRS or titanium with Type II plating.
U = Unplated.
A = Aluminium coating to NAS 4006.

5.2.4 **Type of Locking.** Unless otherwise noted in Table 11, the type of locking is indicated as follows:—
D = Drilled shank.
H = Drilled head.
L = Nylon strip locking element.
N = Nylon button or pellet locking element.
LK = KEL–F strip locking element.
NK = KEL–F pellet locking element.
K = KEL–F locking element, type optional.

NOTE: The lack of a letter for a self-locking bolt indicates that the type of locking element is unimportant.

5.2.5 **Type of Recess.** Where a choice of wrenching recesses is available, the following code is used to indicate the type required:—
T = Torq–Set.
H = Hi–Torque.
P or R = Phillips (cruciform).

NOTE: The type of recess indicated by the lack of a code letter is shown in Table 11.

5.2.6 **Type of Material.** The NAS fasteners listed in Table 11 are manufactured from alloy steel, corrosion-resistant steel (CRS), corrosion-and heat-resistant (C and HR) steel, and titanium alloy. Except in the case of titanium alloy, which is sometimes indicated by a 'V' (see Table 11), the type of material is not specified unless the fastener is made in more than one material. The basic code applies to alloy steel, and the following code indicates other materials:—
CR = corrosion-resistant steel, 125,000 lbf/in².
C = corrosion-resistant steel, 140,000 lbf/in².
E = corrosion-resistant steel, 160,000 lbf/in².
V = titanium alloy.

TABLE 11 NAS BOLTS AND SCREWS

NAS No.	Ty‿e	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
144–158	Bolt, internal wrenching	A	No.1 – 1¼ in	Alloy steel	B	A = drilled shank DH = drilled head Nil = undrilled			NAS No.
333–340	Bolt, flush 100°, close-tolerance	B	No.10 – ⅝ in	Alloy steel	B	A = undrilled shank P = Phillips recess Nil = hex. socket C = cad. plated shank	–	See Specification for Length Code	NAS No. + △
428	Bolt, crown hex. head	D	No.10 – ¾ in	Alloy steel	C	H = drilled head K = slotted shank	–	–	NAS 1347 Type IV
464	Bc'lt, shear, close-tolerance	C	No.10 – 1 in	Alloy steel	C	P = cad. shank	A = undrilled shank		NAS No. + △
501	Bolt, hex. head, non-magnetic	C	No.10 – 1¼ in	CRS	C	A = undrilled shank H = drilled head	–	–	NAS No. + –
560	Screw, 100°, non-magnetic, structural	B	No.8 – ⁹⁄₁₆ in	CRS	C	C = low strength H = high temp. X = high strength	K = Phillips recess P = cad. plated	–	NAS No. + C, H or X
563–572	Bolt, full threaded, fully identified	E	No.10 – ¾ in	Alloy steel	B	–	–	–	NAS No. + dash no.
583–590	Bolt, 100°, close-tolerance, 160,000 lbf/in², Hi-Torque	F	No.10 – ⅝ in	Alloy steel	B	–	–	–	NAS 1347 Type IV
624–644	Bolt, 12 point, 180,000 lbf/in²	G or H	¼ – 1½ in	Alloy steel	B	H = drilled head	–	–	NAS No.
653–658	Bo‿, hex. head, short thread, close-tolerance	C	No.10 – ½ in	Titanium	B	V = titanium	–	D = drilled shank	NAS No. + dash no. + material
663–668	Bolt, 100°, close-tolerance, long thread	F	No.10 – ½ in	Titanium	B	V = titanium	–	HT = Hi-Torque	NAS 1347 Type IV
673–678	Bolt, hex. head, close-tolerance	C or K	No.10 – ½ in	Titanium	B	V = titanium	–	D = drilled shank H = drilled head	NAS No. + dash no. + material
1003–1020	Bolt, hex. head, non-magnetic, heat-resistant	C or L	No.10 – 1¼ in	CRS	B	–	–	A = undrilled H = drilled head Nil = drilled shank	NAS No. + dash no.
1083–1088	Bolt, 100°, close-tolerance, short thread	F	No.10 – ½ in	Titanium	B	V = 6AL–4V alloy T = 4AL–4MN alloy		Nil = Phillips HT = Hi-Torque	NAS 1347 Type IV

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1100	Screw, pan head, full thread, Torq-Set	M	No.0 – ⅜ in	Alloy steel Titanium CRS	C	C = CRS 140 000 psi E = CRS 160 000 psi V = titanium,	–	B = black plating P = type II plating W = type I plating	NAS No. + dash no. + material
1101	Screw, flat fillister, full thread, Torq-Set	N or O	No.0 – ⅜ in	As 1100	C	As 1100	H = drilled head	As 1100	NAS No. + dash no. + material
1102	Screw, 100°, full thread, Torq-Set	P	No.2 – ⅜ in	As 1100	C	As 1100	–	As 1100	NAS No. + dash no. + material
1103–1120	Bolt, shear, hex. head modified short thread	C	No.10 – 1¼ in	Alloy steel	C	As 1100	–	As 1100 D = drilled	NAS No. + dash no. + material
1121–1128	Screw, flat fillister, close-tolerance, short thread	N or O	No.6 – ½ in	As 1100	B	As 1100	–	H = drilled head P and W as 1100	NAS No. + dash no. + material
1131–1138	Screw, pan head, close-tolerance, short thread	M	No.6 – ½ in	As 1100	B	C = CRS V and T as 1083	–	P and W as 1100	NAS No. + dash no. + material
1141–1148	Screw, pan head (mod), close-tolerance, short thread	R	No.6 – ½ in	As 1100	B	As 1100	–	P and W as 1100	NAS No. + dash no. + material
1151–1158	Screw, 100°, close-tolerance, short thread	P	No.6 – ½ in	As 1100	B	As 1131	–	D = Drilled shank P and W as 1100	NAS No. + dash no. + material
1161–1168	Screw, 100°, shear, self-locking	P	No.6 – ½ in	Alloy steel CRS	B	E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots
1171–1178	Screw, pan, shear, self-locking	M	No.6 – ½ in	Alloy steel CRS	B	E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots
1181–1188	Screw, flat fillister, shear, self-locking	N	No.6 – ½ in	Alloy steel CRS	B	C and E as 1100	–	P and W as 1100 + locking code	NAS No. + dash no. + material + circle of dots

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding: Dia.	Coding: Replacing Dash or First Dash	Coding: Replacing Second Dash	Coding: At End	Head Marking
1189	Screw, 100°, full thread, self-locking, 250°F	B or P	No.2 – $\frac{3}{8}$ in	Alloy steel CRS	C	C as 1100	P = Phillips recess T = Torq-Set recess	W as 1100 + locking code	NAS No. + dash no. + circle of dots
1190	Screw, pan head, full thread, self-locking	M or S	No.2 – $\frac{3}{8}$ in	Alloy steel CRS	C	C and E as 1100	P = Phillips recess T = Torq-Set recess	H = type II plating W = type I plating + locking code	NAS No. + dash no. + circle of dots
1191	Screw, flat fillister, full thread, self-locking, 250°F	N or T	No.2 – $\frac{3}{8}$ in	Alloy steel CRS	C	C and E as 1100	P = Phillips recess T = Torq-Set recess	H and W as 1190 + locking code	NAS No. + dash no. + circle of dots
1202–1210	Bolt, 100°, close-tolerance, 160,000 lbf/in², short thread	B	No.8 – $\frac{5}{8}$ in	Alloy steel	B		–	D = drilled shank W as 1190	NAS 1347 Type IV
1216	Bolt, pan head, full thread, Hi-Torque	J	No.4 – $\frac{3}{8}$ in	Alloy steel CRS	C	–	CR = CRS 125,000 lbf/in² C = CRS 140,000 lbf/in²	B = black plating P = type II plating	NAS 1347 Type IV
1217	Bolt, pan head, short thread, Hi-Torque	J	No.8 – $\frac{3}{8}$ in	Alloy steel CRS	C	–	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1218	Bolt, pan head, long thread, Hi-Torque	J	No.4 – $\frac{3}{8}$ in	Alloy steel CRS	C	–	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1219	Bolt, 100°, full thread, Hi-Torque	F	No.4 – $\frac{3}{8}$ in	Alloy steel CRS	C	–	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1220	Bolt, 100°, short thread, Hi-Torque	F	No.8 – $\frac{5}{8}$ in	Alloy steel CRS	C	–	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1221	Bolt, 100°, long thread, Hi-Torque	F	No.4 – $\frac{3}{8}$ in	Alloy steel CRS	C	–	C and CR as 1216	B and P as 1216	NAS 1347 Type IV
1223–1235	Bolt, hex. head, close-tolerance, self-locking	C	No.10 – 1¼ in	Alloy steel CRS	B	C = CRS	–	W as 1190 + locking code	NAS 1347 Type IV + circle of dots
1243–1250	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 0·0156 in oversize, 160,000 lbf/in² (a)	F	No.10 – $\frac{5}{8}$ in	Alloy steel	B	–	–	–	NAS 1347 Type IV
1253–1260	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 0·0312 in oversize, 160,000 lbf/in² (a)	F	No.10 – $\frac{5}{8}$ in	Alloy steel	B	–	–	–	NAS 1347 Type IV

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding: Dia.	Coding: Replacing Dash or First Dash	Coding: Replacing Second Dash	Coding: At End	Head Marking
1261–1265	Bolt, hex. head, close-tolerance, short thread	C	9/16 – 1 in	Titanium	A	–	–	D = drilled shank	NAS 1347 Type IV
1266–1270	Bolt, hex. head, close-tolerance	C	9/16 – 1 in	Titanium	A	–	–	D = drilled shank	NAS 1347 Type IV
1271–1280	Bolt, 12 point	G or H	¼ – 1 in	Titanium	D	H = drilled head	–		NAS 1347 Type IV
1303–1320	Bolt, hex. head, close-tolerance, 160,000 lbf/in^2	C or K	No.10 – 1¼ in	Alloy steel	B	–	–	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
1503–1510	Bolt, 100°, close-tolerance, short thread, Hi-Torque, 160,000 lbf/in^2	F	No.10 – ⅜ in	Alloy steel	B	–	–	W = type I plating	NAS No. + dash no.
1578	Bolt, pan head, shear, 1200°F	J or M	No.10 – ½ in	C and HR steel (U–212)	C	–	T = Torq-Set recess H = Hi-Torque recess	–	NAS 1347 Type II
1579	Bolt, pan head, full thread, 1200°F	J or M	No.10 – ¾ in	C and HR steel (U–212)	C	–	T and H as 1578	–	NAS 1347 Type II
1580	Bolt, ension, 100°, 1200°F	F or P	No.10 – ⅝ in	C and HR steel (U–212)	C	–	T and H as 1578	–	NAS 1347 Type II
1581	Bolt, shear, 100° reduced, 1200°F	F or P	No.10 – ⅝ in	C and HR steel (U–212)	C	–	T and H as 1578	–	NAS 1347 Type II
1582	Bolt, 100°, full thread, 1200°F	F or P	No.10 – ¾ in	C and HR steel (U–212)	C	–	T and H as 1578	–	NAS 1347 Type II
1586	Bolt, tension, 12 point, 1200°F, external wrenching	G or H	¼ – 1½ in	C and HR steel (U–212)	C	–	H = drilled head	–	NAS 1347 Type II
1588	Bolt, shear, hex, head, 1200°F	C	No.10 – 1 in	C and HR steel (U–212)	C	–	–	–	NAS 1347 Type II

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
1603–1610	Bolt, 100°, close-tolerance, 0·0312 in oversize, 160,000 lbf/in² (b)	F or P	No.10 – ⅝ in	Alloy steel	B	—	—	R = Phillips recess Nil = Hi-Torque	NAS 1347 Type IV
1620–1628	Screw, 100°, short thread, Torq-Set recess	P	No.4 – ½ in	Alloy steel CRS Titanium	B	C, E and V as 1100	—	D = drilled shank P = type II plating	NAS 1347 Type IV
1630–1634	Screw, pan head, short thread, Torq-Set	M	No.4 – ¼ in	Alloy steel CRS Titanium	B	C, E and V as 1100	—	D = drilled shank P = type II plating	NAS 1347 Type IV
1703–1710	Bolt, 100°, close-tolerance, 0·156 in oversize, 160,000 lbf/in² (b)	B or F	No.10 – ⅝ in	Alloy steel	B	—	—	R = Phillips recess Nil = Hi-Torque	NAS 1347 Type IV
2803–2810	Bolt, 100°, close-tolerance, 180,000 lbf/in², Torq-Set	P	No.10 – ⅝ in	Alloy steel	B	—	—	—	NAS No. + dash no.
2903–2920	Bolt, shear, hex. head, 0·0156 in oversize (b)	C or K	No.10 – 1¼ in	Alloy steel	B	E = short thread	—	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
3003–3020	Bolt, shear, hex. head, long or short thread, 0·0312 in oversize (b)	C or K	No.10 – 1¼ in	Alloy steel	B	E = short thread	—	D = drilled shank H = drilled head W = type I plating	NAS No. + dash no.
4104–4116	Bolt, 100°, close-tolerance, long thread, Tri-wing recess, self-locking and non-locking	W	¼ – 1 in	Alloy steel	B	B = black plating D, L or P see (g)	—	X = 0·0156 in oversize Y = 0·0312 in oversize	NAS No. + dash no. (e) (f) (g)
4204–4216	Bolt, 100°, close-tolerance, long thread, Tri-wing recess, self-locking and non-locking	W	¼ – 1 in	CRS (c)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
4304–4316	Bolt, 100°, long thread, Tri-wing recess, self-locking and non-locking	W	¼ – 1 in	Titanium (d)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
4400–4416	Bolt, 100°, short thread, Tri-wing recess, self-locking and non-locking	W	No.4 – 1 in	Alloy steel	B	B = black plating D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
4500 – 4516	Bolt, 100°, close-tolerance, short thread, Tri-wing recess, self locking or non-locking	W	No.4 – 1 in	CRS (c)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f) (g)
4600 – 4616	Bolt, 100°, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	W	No.4 – 1 in	Titanium (d)	B	U = unplated D, L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f) (g)
4703 – 4716	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 – 1 in	Alloy steel	B	D = drilled shank Nil = undrilled	—	X and Y as 4104	NAS No. + dash no. (e) (f)
4803 – 4816	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 – 1 in	CRS (c)	B	D = drilled shank U = unplated	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f)
4903 – 4916	Bolt, 100°, close-tolerance, short thread, reduced head, non-locking, Tri-wing recess	W	No.10 – 1 in	Titanium (d)	B	D = drilled shank U = unplated	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f)
5000 – 5006	Bolt, pan head, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	X	No.4 – 3/8 in	Alloy steel	B	B = black plating L or P see (g)	—	X and Y as 4104	NAS No. + dash no. (e) (f) (g)
5100 – 5106	Bolt, pan head, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	X	No.4 – 3/8 in	CRS (c)	B	U = unplated L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + C for CRS (e) (f) (g)
5200 – 5206	Bolt, pan head, close-tolerance, short thread, Tri-wing recess, self-locking and non-locking	X	No.4 – 3/8 in	Titanium (d)	B	U = unplated L or P see (g)	—	X and Y as 4104	NAS No. + dash no. + V for titanium (e) (f) (g)
5300 – 5360	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 – 3/8 in	Alloy steel	B	H = drilled head B = black plating L or P see (g)	—	—	NAS No. + dash no. (f) (g)

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
5400–5406	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 – $\frac{3}{8}$ in	CRS (c)	B	H = drilled head U = unplated L or P see (g)	–	–	NAS No. + dash no. + C for CRS (f) (g)
5500–5506	Screw, flat fillister head, full thread, Tri-wing recess, self-locking and non-locking	Y or Z	No.4 – $\frac{3}{8}$ in	Titanium (d)	B	H = drilled head U = unplated L or P see (g)	–	–	NAS No. + dash no. + V for titanium (f) (g)
5600–5606	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 – $\frac{3}{8}$ in	Alloy steel	B	B = black plating L or P see (g)	–	–	NAS No. + dash no. (f) (g)
5700–5706	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 – $\frac{3}{8}$ in	CRS (c)	B	B = black plating U = unplated L or P see (g)	–	–	NAS No. + dash no. + C for CRS (f) (g)
5800–5806	Screw, 100°, full thread, Tri-wing recess, self-locking and non-locking	W	No.4 – $\frac{3}{8}$ in	Titanium (d)	B	U = unplated L or P see (g)	–	–	NAS No. + dash no. + V for titanium (f) (g)
6000 - 6003	Screw, hex. head, full thread, Tri-wing recess	V	No.4 to No.10	CRS (c)	B	U = unplated	–	–	NAS No. + dash no. + C for CRS (f)
6100 - 6103	Screw, hex. head, full thread, Tri-wing recess	V	No.4 to No.10	Titanium (d)	B	U = unplated	–	–	NAS No. + dash no. + V for titanium
6203–6220	Bolt, hex. head, short thread, close-tolerance, self-locking and non-locking	C or K	No.10 – 1¼ in	Alloy steel	B	D, L or P see (g)	–	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)
6303–6320	Bolt, hex. head, short thread, close-tolerance, self-locking or non-locking	C or K	No.10 – 1¼ in	CRS (c)	B	U = unplated L or P see (g)	–	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)
6403–6420	Bolt, hex. head, short thread, close-tolerance, self-locking and non locking	C or K	No.10 – 1¼ in	Titanium (d)	B	U = unplated L or P see (g)	–	X or Y as 4104 D = drilled shank H = drilled head	NAS No. + dash no. (e) (g)

TABLE 11—*continued*

NAS No.	Type	Head (Fig. 5)	Size Range	Material	Coding				Head Marking
					Dia.	Replacing Dash or First Dash	Replacing Second Dash	At End	
6604 6620	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	¼ – 1¼ in	Alloy steel	B	D = drilled shank H = drilled head L or P see (g)	–	X or Y as 4104	NAS No. + dash no. (e) (g)
6704–6720	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	¼ – 1¼ in	CRS (c)	B	D = drilled shank H = drilled head U = unplated L or P see (g)	–	X or Y as 4104	NAS No. + dash no. (e) (g)
6804–6820	Bolt, hex. head, long thread, close-tolerance, self-locking and non-locking	C or K	¼ – 1¼ in	Titanium (d)	B	D = drilled shank H = drilled head U = unplated L or P see (g)	–	X or Y as 4104	NAS No. + dash no. (e) (g)

NOTES:

(a) For repair work only, replacing NAS 1503 to 1510.

(b) For repair work only.

(c) Cadmium plated CRS bolts have green dye or paint on the end of the shank.

(d) Cadmium plated titanium bolts have red dye or paint on the end of the shank.

(e) Oversize bolts are marked with 'X' or 'Y' (see code).

(f) Heads are also marked with an encircled number, to indicate the size of the Tri-wing recess, in accordance with NAS 4000.

(g) Method of locking, included in code and marked on head, is as follows:
D = drilled shank. L = locking element is optional. P = patch type locking element.

5.3 **Examples of Coding**

(a) NAS 564–15 is a full-threaded bolt in cadmium-plated alloy steel, with $\frac{1}{4}$–28 thread, and length of $\frac{15}{32}$ in.

(b) NAS 1146E12P is a screw with a modified pan head, close-tolerance shank and Torq-Set recess, made from CRS (160,000 lbf/in^2), with Type II plating. It has a $\frac{3}{8}$–24 thread and a $\frac{3}{4}$ in grip length.

(c) NAS 1189–3T8L is a self-locking screw with a 100° countersunk head and full thread. It has a 10–32 thread, is $\frac{1}{2}$ in long, and is in alloy steel with Type II plating. It has a strip-type nylon locking element and a Torq-Set recess.

(d) NAS 6804D10X is a hexagon head, close-tolerance bolt in titanium alloy, with a long thread. It has a $\frac{1}{4}$–28 thread and $\frac{5}{8}$ in grip length, and a drilled shank which is 0·0156 in oversize.

COLOURS	SPECIFICATIONS
Red, blue, brown, yellow	BS970-060-A86 (as rolled or forged), BS3601-S-320.
Red, blue, green, red	
Red, blue, green, white	BS970-080-A86 (as rolled or forged), BS3601-S-360.
Red, blue, green, yellow	BS970-060-A96 (PART 1 - as rolled or forged), BS1449-HR8B, BS1449-HRP8B.
Red, blue, red, green	BS970-832-M13 (as rolled or forged and bright bars).
Red, blue, red, white	
Red, blue, red, yellow	
Red, blue, white, red	TA14, TA15.
Red, blue, white, yellow	BS970-060-A99 (as rolled or forged), BS1449-HS17C.
Red, blue, yellow, red	BS970-120-M19 (as rolled or forged).
Red, blue, yellow, white	BS970-150-M19-P.
Red, brown, black, white	BS970-120-M28 (as rolled or forged), BS3839-H.
Red, brown, black, yellow	BS970-150-M28-S.
Red, brown, blue, red	BS1554-En 58G (softened).
Red, brown, blue, white	BS970-120-M36 (normalised), BS1449-HR8C, BS1449-HRP8C, BS1554-En 58H (softened).
Red, brown, blue, yellow	BS970-120-M19 (cold drawn from hot rolled), BS1449-HS90, BS1554-En 58J (softened).
Red, brown, green, red	DTD5222.
Red, brown, green, white	BS970-150-M36 (normalised).
Red, brown, green, yellow	TA29, TA32, TA35.
Red, brown, red, black	BS970-659-M15 (as rolled or forged).
Red, brown, red, blue	BS970-835-M15 (as rolled or forged).
Red, brown, red, green	BS1449-En 42F (cold rolled and annealed).
Red, brown, red, white	BS1449-En 42F (hardened and tempered).
Red, brown, red, yellow	BS970-897-M39 (suitable for nitriding-85 tonf/in^2), BS1449-En 2A/1.
Red, brown, white, red	S202, BS1449-HS23C.
Red, brown, white, yellow	HR1 (forging stock), BS1449-NHR25.
Red, brown, yellow, red	BS970-120-M28 (normalised).
Red, brown, yellow, white	
Red, green, black, red	BS1554-En 56D (softened).
Red, green, black, white	BS1554-En 57 (softened).
Red, green, black, yellow	BS970-216-M28 (as rolled or forged), BS1554-En 58A (softened), BS1824-NS107 (temper 3).
Red, green, blue, white	BS970-216-M28-P.
Red, green, blue, yellow	BS970-212-M36-P.
Red, green, brown, white	BS1824-NS107 (temper 2).
Red, green, brown, yellow	BS970-216-M36-Q.
Red, green, red, black	BS970-905-M31-R.
Red, green, red, blue	BS970-905-M39-R.
Red, green, red, brown	BS970-070-A72 (PART 5 - as rolled or forged), BS1449-En 2C/1.
Red, green, red, white	BS1449-En 2C/2.
Red, green, red, yellow	BS1471-NT8-0.
Red, green, white, red	S203, BS1449-NHR15.
Red, green, white, yellow	TA45.
Red, green, yellow, red	BS970-225-M36 (as rolled or forged).
Red, green, yellow, white	BS970-212-M44 (as rolled or forged), BS1449-HR5C, BS1449-HRP5C, BS1449-HR16C, BS1449-HRP16C.
Red, white, black, red	BS1554-En 58B (softened).
Red, white, black, white	
Red, white, black, yellow	BS1824-NS107 (temper 1 - extra hard), BS1554-En 58C (softened).
Red, white, blue, white	BS1824-NS107 (temper 4).
Red, white, blue, yellow	BS970-216-M28-Q.
Red, white, brown, white	
Red, white, brown, yellow	TA46, BS970-216-M36-P, BS1449-NHR24.
Red, white, green, white	
Red, white, green, yellow	BS1824-NS107 (temper 5 - soft), BS4360-43C.

COLOURS	SPECIFICATIONS
Red, white, red, blue	BS1449-En 2D/1.
Red, white, red, white	BS970-040-A22 (as rolled or forged), BS1449-En 21A.
Red, white, red, yellow	BS1449-En 43G (cold rolled and annealed).
Red, white, yellow, red	BS970-225-M36-Q, BS1449-HR5A, BS1449-HRP5A, BS1449-HR16A, BS1449-HRP16A.
Red, white, yellow, white	
Red, yellow, black, red	BS1554-En 58D (softened).
Red, yellow, black, white	TA49.
Red, yellow, black, yellow	
Red, yellow, blue, white	BS970-216-M28 (cold drawn from hot rolled).
Red, yellow, blue, yellow	
Red, yellow, brown, white	TA52, TA53.
Red, yellow, brown, yellow	BS1449-HR5B, BS1449-HRP5B, BS1449-HR16B, BS1449-HRP16B, BS1471-NT8-H2.
Red, yellow, green, white	BS970-120-M19-P, BS1449-HR16/1, BS1449-HRP16/1.
Red, yellow, green, yellow	BS1449-En 2C/B.
Red, yellow, red, black	BS970-080-A52 (PART 5 - as rolled or forged).
Red, yellow, red, blue	BS1449-En 43G (hardened and tempered).
Red, yellow, red, brown	BS1449-En 43J (cold rolled and annealed).
Red, yellow, red, green	BS970-080-M50 (normalised), BS1449-En 43J (hardened and tempered).
Red, yellow, red, white	BS970-080-M50-R, BS1449-En 42E (cold rolled and annealed), BS1449-HR7C, BS1449-HRP7C.
Red, yellow, red, yellow	BS970-040-A10 (as rolled or forged), BS1449-En 42E (hardened and tempered).
Red, yellow, white, yellow	
White, black, blue, white	TA38
White, black, blue, yellow	TA39
White, black, brown, white	BS970-150-M36-T.
White, black, brown, yellow	BS1554-En 58C (drawn).
White, black, green, white	
White, black, green, yellow	BS970-120-M19 (normalised).
White, black, red, white	TA54
White, black, red, yellow	BS970-120-M28-Q.
White, black, white, yellow	
White, black, yellow, white	BS970-212-M44-Q.
White, blue, black, white	BS1554-En 56A (hardened and tempered).
White, blue, black, yellow	HR1 (solution treated bar and section for machining), BS1449-CS22A, BS1554-En 56B (hardened and tempered).
White, blue, brown, white	
White, blue, brown, yellow	BS970-225-M44 (as rolled or forged), BS1554-En 58D (drawn).
White, blue, green, white	
White, blue, green, yellow	
White, blue, red, white	
White, blue, red, yellow	BS1449-HS70.
White, blue, white, blue	BS1449-En 42G (cold rolled and annealed).
White, blue, white, brown	BS1449-En 42G (hardened and tempered).
White, blue, white, green	BS1449-En 42J (cold rolled and annealed).
White, blue, white, red	BS970-060-A96 (PART 5 - as rolled or forged), BS1449-En 42J (hardened and tempered).
White, blue, white, yellow	BS1449-En 44D (cold rolled and annealed).
White, blue, yellow, white	BS970-225-M36 (cold drawn from hot rolled), DTD5152.
White, brown, black, yellow	
White, brown, blue, white	BS1554-En 56C (hardened and tempered).
White, brown, blue, yellow	BS970-212-M44-R, BS1554-En 56D (hardened and tempered).
White, brown, green, white	DTD5056 (rod).
White, brown, green, yellow	BS1449-NHR22.
White, brown, red, white	BS970-225-M44-R.
White, brown, red, yellow	TA40.
White, brown, white, blue	BS1449-En 44D (hardened and tempered).

COLOURS	SPECIFICATIONS
White, brown, white, brown	BS1449-En 44E (cold rolled and annealed).
White, brown, white, green	BS1449-En 44E (hardened and tempered).
White, brown, white, red	BS970-250-A53 (as rolled or forged), BS1449-En 56A (softened), BS2056-En 56A (softened).
White, brown, white, yellow	BS970-250-A58 (as rolled or forged), BS1449-En 56A (hardened and tempered).
White, brown, yellow, white	BS1400-LB5.
White, green, black, yellow	BS970-216-M36 (cold drawn from hot rolled).
White, green, blue, white	BS1554-En 57 (hardened and tempered).
White, green, blue, yellow	TA26.
White, green, brown, white	BS1554-En 58E (drawn).
White, green, brown, yellow	BS1554-En 58F (drawn).
White, green, red, white	BS1449-HS30.
White, green, red, yellow	BS970-225-M36-R, BS1449-NHR21.
White, green, white, blue	BS1449-En 56B (softened), BS2056-En 56B (softened).
White, green, white, brown	BS1449-En 56B (hardened and tempered).
White, green, white, green	BS1449-En 56C (softened), BS2056-En 56C (softened).
White, green, white, red	BS1449-En 56C (hardened and tempered).
White, green, white, yellow	BS1400-LB4, BS1449-En 56D (softened), BS2056-En 56D (softened).
White, green, yellow, white	BS970-120-M36 (cold drawn from hot rolled), BS1449-CS22B.
White, red, black, yellow	HR2 (solution treated bar and section for machining).
White, red, blue, white	BS1554-En 57 (drawn).
White, red, blue, yellow	BS970-120-M19-Q, BS1554-En 58A (drawn).
White, red, brown, white	BS1554-En 58G (drawn).
White, red, brown, yellow	BS970-212-M44-S, BS1554-En 58H (drawn).
White, red, green, yellow	BS970-120-M28-R.
White, red, white, blue	BS1449-En 56D (hardened and tempered).
White, red, white, brown	BS1449-En 57 (softened), BS2056-En 57 (softened).
White, red, white, green	BS1449-En 57 (hardened and tempered).
White, red, white, yellow	BS1449-En 58A (cold rolled).
White, red, yellow, white	HR504.
White, yellow, black, yellow	
White, yellow, blue, white	BS1554-En 58B (drawn).
White, yellow, blue, yellow	
White, yellow, brown, white	BS1554-En 58J (drawn).
White, yellow, brown, yellow	DTD5086 (wire-cold drawn).
White, yellow, green, yellow	BS1449-HS50
White, yellow, red, yellow	BS1449-CS22C.
White, yellow, white, blue	BS1449-En 58B (softened).
White, yellow, white, brown	BS1449-En 58B (cold rolled).
White, yellow, white, green	BS1449-En 58C (softened).
White, yellow, white, red	BS1449-En 58C (cold rolled).
White, yellow, white, yellow	BS970-080-M30 (normalised), BS1449-En 58D (softened).
Yellow, black, blue, yellow	BS1470-SIC-M, DTD5086 (rod-solution annealed), DTD5142.
Yellow, black, brown, yellow	S204, BS1824-NS104 (temper 2).
Yellow, black, green, yellow	BS1824-NS104 (temper 3), DTD5076 (annealed cold reduced and solution treated).
Yellow, black, red, yellow	BS1824-NS104 (temper 4), DTD5076 (annealed cold reduced and finally heat treated).
Yellow, black, white, yellow	L113 (annealed), HR54 (heat treated bars for machining), BS1824-NS104 (temper 5 - soft).
Yellow, blue, brown, yellow	DTD5076 (annealed and cold reduced).
Yellow, blue, green, yellow	HR54 (forging stock), BS1449-HS60.
Yellow, blue, red, yellow	
Yellow, blue, white, yellow	S111D.
Yellow, blue, yellow, red	BS970-431-S29 (hardened and tempered, and T condition), BS1449-En 56R.

COLOURS	SPECIFICATIONS
Yellow, brown, green, yellow	TA50.
Yellow, brown, red, yellow	TA41.
Yellow, brown, white, yellow	
Yellow, brown, yellow, black	BS1449-En 56T.
Yellow, brown, yellow, green	BS1449-En 56V.
Yellow, green, red, yellow	TA43.
Yellow, green, white, yellow	
Yellow, red, white, yellow	TA47.
Yellow, red, yellow, brown	BS970-945-M38-R.
Yellow, white, yellow, green	BS970-816-M40-S.
Yellow, white, yellow, red	BS970-640-M40-R.
Black, blue, black, blue, black	BS970-321-S12 (as rolled).
Black, blue, brown, blue, black	BS970-606-M36-S.
Black, blue, green, blue, black	BS970-321-S12 (softened).
Black, blue, red, blue, black	BS970-321-S12 (cold drawn).
Black, blue, white, blue, black	BS970-503-H37 (as rolled).
Black, blue, yellow, blue, black	BS970-606-M36-T.
Black, brown, black, brown, black	BS970-503-H37 (heat treated).
Black, brown, blue, brown, black	BS970-503-H42 (as rolled).
Black, brown, green, brown, black	BS970-503-H42 (heat treated).
Black, brown, red, brown, black	BS970-530-H30 (as rolled).
Black, brown, white, brown, black	BS970-530-H32 (as rolled).
Black, brown, yellow, brown, black	BS970-530-H30 (heat treated).
Black, green, black, green, black	BS970-530-H32 (heat treated).
Black, green, blue, green, black	BS970-530-H36 (as rolled).
Black, green, brown, green, black	BS970-530-H36 (heat treated).
Black, green, red, green, black	
Black, green, white, green, black	BS970-321-S20 (as rolled).
Black, green, yellow, green, black	BS970-530-H40 (as rolled).
Black, red, black, red, black	BS970-321-S20 (softened).
Black, red, blue, red, black	BS970-530-H40 (heat treated).
Black, red, brown, red, black	BS970-523-M15 (as rolled or forged and bright bars).
Black, red, green, red, black	BS970-527-M20 (as rolled or forged and bright bars).
Black, red, white, red, black	BS970-635-H15 (as rolled or forged and bright bars).
Black, red, yellow, red, black	BS970-635-A14 (as rolled or forged and bright bars).
Black, white, black, white, black	BS970-655-H13 (as rolled or forged and bright bars).
Black, white, blue, white, black	BS970-655-M13 (as rolled or forged and bright bars).
Black, white, brown, white, black	BS970-659-A15 (as rolled or forged and bright bars).
Black, white, green, white, black	BS970-659-H15 (as rolled or forged and bright bars).
Black, white, red, white, black	BS970-665-A17 (as rolled or forged and bright bars).
Black, white, yellow, white, black	BS970-665-H17 (as rolled or forged and bright bars).
Black, yellow, black, yellow, black	BS970-321-S20 (cold drawn).
Black, yellow, blue, yellow, black	BS970-070-M20 (cold drawn from hot rolled).
Black, yellow, brown, yellow, black	
Black, yellow, green, yellow, black	BS970-637-A16 (as rolled or forged and bright bars).
Black, yellow, red, yellow, black	BS970-637-H17 (as rolled or forged and bright bars).
Black, yellow, white, yellow, black	BS970-655-A12 (as rolled or forged and bright bars).
Blue, black, blue, black, blue	S150 (bars and billets for forging - softened).
Blue, black, brown, black, blue	BS970-401-S45 (as rolled and stress relieved).
Blue, black, green, black, blue	S150 (bright and black bars for machining).
Blue, black, red, black, blue	S151 (bars and billets for forging - softened).
Blue, black, white, black, blue	BS970-403-S17 (softened).
Blue, black, yellow, black, blue	S151 (bright and black bars for machining).
Blue, brown, black, brown, blue	S152 (bars and billets for forging - softened).
Blue, brown, blue, brown, blue	BS970-410-S21 P.
Blue, brown, green, brown, blue	BS970-410-S21 (softened).
Blue, brown, red, brown, blue	S152 (bright and black bars for machining).
Blue, brown, white, brown, blue	S153 (bars and billets for forging - softened).
Blue, brown, yellow, brown, blue	BS970-420-S29-R.
Blue, green, black, green, blue	BS970-416-S29-R.
Blue, green, blue, green, blue	S153 (bright and black bars for machining).

COLOURS

Blue, green, brown, green, blue
Blue, green, red, green, blue
Blue, green, white, green, blue
Blue, green, yellow, green, blue
Blue, red, black, red, blue
Blue, red, blue, red, blue
Blue, red, brown, red, blue
Blue, red, green, red, blue
Blue, red, white, red, blue
Blue, red, yellow, red, blue
Blue, white, black, white, blue
Blue, white, blue, white, blue
Blue, white, brown, white, blue
Blue, white, green, white, blue
Blue, white, red, white, blue
Blue, white, yellow, white, blue
Blue, yellow, black, yellow, blue
Blue, yellow, blue, yellow, blue
Blue, yellow, brown, yellow, blue
Blue, yellow, green, yellow, blue
Blue, yellow, red, yellow, blue
Blue, yellow, white, yellow, blue
Brown, black, blue, black, brown
Brown, black, brown, black, brown
Brown, black, green, black, brown
Brown, black, red, black, brown
Brown, black, white, black, brown
Brown, black, yellow, black, brown
Brown, blue, black, blue, brown
Brown, blue, brown, blue, brown
Brown, blue, green, blue, brown
Brown, blue, red, blue, brown
Brown, blue, white, blue, brown
Brown, blue, yellow, blue, brown
Brown, green, black, green, brown
Brown, green, blue, green, brown
Brown, green, brown, green, brown
Brown, green, red, green, brown
Brown, green, white, green, brown
Brown, green, yellow, green, brown
Brown, red, black, red, brown
Brown, red, blue, red, brown
Brown, red, brown, red, brown
Brown, red, green, red, brown
Brown, red, white, red, brown
Brown, red, yellow, red, brown
Brown, white, black, white, brown
Brown, white, blue, white, brown
Brown, white, brown, white, brown
Brown, white, green, white, brown
Brown, white, red, white, brown
Brown, white, yellow, white, brown
Brown, yellow, black, yellow, brown
Brown, yellow, blue, yellow, brown
Brown, yellow, brown, yellow, brown
Brown, yellow, green, yellow, brown
Brown, yellow, red, yellow, brown
Brown, yellow, white, yellow, brown
Green, black, blue, black, green
Green, black, brown, black, green
Green, black, green, black, green

SPECIFICATIONS

S154 (bars and billets for forging - softened).
BS970-416-S29-S.
BS970-420-S29-S.
S154 (bright and black bars for machining).
BS970-416-S37-R.
S155 (bars for machining - normalised and softened).
S155 (forging stock - softened).
S156 (bright and black bars for machining).
S156 (forging stock - softened).
BS970-416-S37-S.
BS970-420-S45-R.
BS970-420-S37 (softened).
BS970-420-S45-S.
BS970-420-S45 (softened).
BS970-430-S15 (softened).
BS970-443-S65 (as rolled and stress relieved).
S157 (forging stock - softened).
S157 (bright and black bars for machining).
BS970-302-S25 (as rolled).
BS970-420-S29 (softened).
BS970-420-S37-R.
BS970-420-S37-S.
BS970-347-S17 (softened).
BS970-347-S17 (as rolled).
BS970-349-S52 (as rolled and stress relieved).
BS970-349-S54 (as rolled and stress relieved).
BS970-352-S54 (as rolled and stress relieved).
BS970-352-S52 (as rolled and stress relieved).
BS970-302-S25 (softened).
BS970-302-S25 (cold drawn).
AIR 9160B-15CDV6 (annealed).
BS970-303-S21 (as rolled).
BS970-303-S41 (cold drawn).
BS970-303-S21 (cold drawn).
BS970-304-S15 (cold drawn).
BS970-304-S12 (as rolled).
BS970-310-S24 (as rolled).
QQ-S-764B-303 SE-A (cold finished).
BS970-315-S16 (as rolled).
BS970-310-S24 (softened).
BS970-316-S12 (as rolled).
BS970-315-S16 (softened).
BS970-316-S12 (softened).
BS970-316-S16 (as rolled).
BS970-316-S16 (cold drawn).
BS970-316-S16 (softened).
BS970-326-S36 (softened).
BS970-325-S21 (cold drawn).
BS970-326-S36 (cold drawn).
BS970-331-S40 (as rolled or softened).
BS970-331-S42 (as rolled or softened).
BS970-381-S34 (as rolled and stress relieved).
BS970-317-S12 (softened).
BS970-317-S12 (as rolled).
BS970-317-S16 (as rolled).
BS970-317-S16 (softened).
BS970-320-S17 (as rolled).
BS970-320-S17 (softened).
BS970-665-A19 (as rolled or forged and bright bars).
BS970-665-H20 (as rolled or forged and bright bars).

COLOURS	SPECIFICATIONS
Green, black, red, black, green	
Green, black, white, black, green	BS970-665-H23 (as rolled or forged and bright bars).
Green, black, yellow, black, green	BS970-665-M20 (as rolled or forged and bright bars).
Green, blue, black, blue, green	AIR 9160B-35NC6 (annealed), MIL-T-8504 (annealed).
Green, blue, brown, blue, green	BS970-805-A17 (as rolled or forged and bright bars).
Green, blue, green, blue, green	BS970-805-A15 (as rolled or forged and bright bars).
Green, blue, red, blue, green	BS970-805-H17 (as rolled or forged and bright bars).
Green, blue, white, blue, green	BS970-805-H20 (as rolled or forged and bright bars).
Green, blue, yellow, blue, green	BS970-805-A20 (as rolled or forged and bright bars).
Green, brown, black, brown, green	BS970-805-A22 (as rolled or forged and bright bars).
Green, brown, blue, brown, green	BS970-805-H22 (as rolled or forged and bright bars).
Green, brown, green, brown, green	QQ-S-763-TYPE 440C-A (annealed).
Green, brown, red, brown, green	BS970-805-M22 (as rolled or forged and bright bars).
Green, brown, white, brown, green	AIR9160C-25CD4S (hardened and tempered - 880/1080 MPa.
Green, brown, yellow, brown, green	BS970-805-A24 (as rolled or forged and bright bars).
Green, red, black, red, green	BS970-815-A16 (as rolled or forged and bright bars).
Green, red, blue, red, green	BS970-815-H17 (as rolled or forged and bright bars).
Green, red, brown, red, green	BS970-820-A16 (as rolled or forged and bright bars).
Green, red, green, red, green	BS970-805-H25 (as rolled or forged and bright bars).
Green, red, white, red, green	BS970-822-A17 (as rolled or forged and bright bars).
Green, red, yellow, red, green	BS970-820-H17 (as rolled or forged and bright bars).
Green, white, black, white, green	BS970-527-A60 (as rolled or forged).
Green, white, blue, white, green	BS970-527-H60 (as rolled or forged).
Green, white, brown, white, green	BS970-805-A60 (as rolled or forged).
Green, white, green, white, green	BS970-250-A61 (as rolled or forged).
Green, white, red, white, green	BS970-805-H60 (as rolled or forged).
Green, white, yellow, white, green	BS970-925-A60 (as rolled or forged).
Green, yellow, black, yellow, green	BS970-832-H13 (as rolled or forged and bright bars).
Green, yellow, blue, yellow, green	BS970-835-A15 (as rolled or forged and bright bars).
Green, yellow, brown, yellow, green	BS970-835-H15 (as rolled or forged and bright bars).
Green, yellow, green, yellow, green	BS970-822-H17 (as rolled or forged and bright bars).
Green, yellow, red, yellow, green	BS970-080-A67 (PART 5 - as rolled or forged).
Green, yellow, white, yellow, green	BS970-070-A78 (PART 5 - as rolled or forged).
Red, black, blue, black, red	BS970-503-M40-S.
Red, black, brown, black, red	BS970-441-S49 (softened).
Red, black, green, black, red	BS970-897-M39-Z.
Red, black, red, black, red	BS970-503-M40-R.
Red, black, white, black, red	BS970-823-M30 (as rolled).
Red, black, yellow, black, red	BS970-416-S41-R.
Red, blue, black, blue, red	BS970-441-S29-T.
Red, blue, brown, blue, red	BS970-823-M30-U.
Red, blue, green, blue, red	BS970-823-M30-V.
Red, blue, red, blue, red	BS970-823-M30-T.
Red, blue, white, blue, red	BS970-S23-M30-X.
Red, blue, yellow, blue, red	BS970-823-M30-W.
Red, brown, black, brown, red	BS970-441-S49 (hardened and tempered).
Red, brown, blue, brown, red	BS970-608-H37 (as rolled).
Red, brown, green, brown, red	BS970-608-H37 (heat treated).
Red, brown, red, brown, red	BS970-823-M30-Z.
Red, brown, white, brown, red	BS970-708-H37 (heat treated).
Red, brown, yellow, brown, red	BS970-708-H37 (as rolled).
Red, green, black, green, red	BS970-708-H42 (heat treated).
Red, green, blue, green, red	BS970-441-S29 (hardened and tempered).
Red, green, brown, green, red	BS970-640-H35 (as rolled).
Red, green, red, green, red	BS970-708-H42 (as rolled).
Red, green, white, green, red	BS970-304-S12 (softened), BS1449-304-S12 (softened).
Red, green, yellow, green, red	BS970-416-S21-P.
Red, white, black, white, red	BS970-416-S41-P.
Red, white, blue, white, red	BS970-605-H32 (as rolled).
Red, white, brown, white, red	BS970-605-H32 (heat treated).
Red, white, green, white, red	BS970-605-H37 (as rolled).

COLOURS	SPECIFICATIONS
Red, white, red, white, red	BS970-535-A99 (as rolled).
Red, white, yellow, white, red	BS970-605-H37 (heat treated).
Red, yellow, black, yellow, red	BS970-441-S49-T.
Red, yellow, blue, yellow, red	BS970-640-H35 (heat treated).
Red, yellow, brown, yellow, red	BS970-304-S15 (softened).
Red, yellow, green, yellow, red	BS970-303-S21 (softened).
Red, yellow, red, yellow, red	BS970-325-S21 (softened).
Red, yellow, white, yellow, red	BS970-441-S29 (softened).
White, black, blue, black, white	AIR9160B-15CDV6 (hardened and tempered - 980/1130 MPa).
White, black, brown, black, white	AIR9160B-15CDV6 (hardened and tempered - 1030/1180 MPa).
White, black, green, black, white	QQ-A-250/4E (2024-T351), BS970-015-A03 (as rolled or forged).
White, black, red, black, white	AIR9160C-30 NCD16 (annealed), MIL-T-6736B-HT150, QQ-A-225/6D (2024-T351).
White, black, white, black, white	MIL-S-6758A (condition A and B - forged or rolled).
White, black, yellow, black, white	BS970-030-A04 (as rolled or forged).
White, blue, black, blue, white	MIL-S-6758A (condition C - annealed).
White, blue, brown, blue, white	MIL-S-7720A (condition C - hot rolled or forged), QQ-A-200/3D (2024-T351).
White, blue, green, blue, white	AIR9160B-35NC6 (hardened and tempered - 880/1080 MPa), AMS5572C.
White, blue, red, blue, white	AIR9160B-35NC6 (hardened and tempered - 1030/1180 MPa).
White, blue, white, blue, white	QQ-A-250/5F (2024-T351), BS970-050-A04 (as rolled or forged).
White, blue, yellow, blue, white	MIL-S-7720A (condition B - cold finished).
White, brown, black, brown, white	QQ-A-250/11E (6061-0).
White, brown, blue, brown, white	MIL-S-6758A (condition F - hardened and tempered).
White, brown, green, brown, white	MIL-T-6736B-HT125, BS970-045-A10 (as rolled or forged).
White, brown, red, brown, white	
White, brown, white, brown, white	AIR9160C-Z100 CD17 (annealed).
White, brown, yellow, brown, white	
White, green, black, green, white	AMS5643 (17/4 PH).
White, green, blue, green, white	
White, green, brown, green, white	QQ-A-250/4E-T3 (as supplied), BS970-060-A10 (as rolled or forged).
White, green, red, green, white	MIL-T-6736B (condition N - normalised).
White, green, white, green, white	MIL-S-7720A (condition A - annealed).
White, green, yellow, green, white	BS970-050-A12 (as rolled or forged).
White, red, black, red, white	
White, red, blue, red, white	MIL-T-6736B (condition A - annealed), BS970-040-A15 (as rolled or forged).
White, red, brown, red, white	QQ-A-250/11E - T4 (as supplied), BS970-050-A15 (as rolled or forged).
White, red, green, red, white	
White, red, white, red, white	QQ-A-250/4E-0 (as supplied), BS970-060-A12 (as rolled or forged).
White, red, yellow, red, white	
White, yellow, black, yellow, white	QQ-A-225/9D (7075-T351), BS970-080-A15 (as rolled or forged).
White, yellow, blue, yellow, white	
White, yellow, brown, yellow, white	QQ-A-250/11E-T6 (as supplied), BS970-040-A17 (as rolled or forged).
White, yellow, green, yellow, white	BS970-050-A17 (as rolled or forged).
White, yellow, red, yellow, white	AIR9160C-35CD4 (annealed).
White, yellow, white, yellow, white	MIL-T-6736B-HT180, BS970-060-A15 (as rolled or forged).
Yellow, black, blue, black, yellow	BS970-080-A17 (as rolled or forged).
Yellow, black, brown, black, yellow	BS970-040-A20 (as rolled or forged).
Yellow, black, green, black, yellow	BS970-060-A20 (as rolled or forged).

COLOURS	SPECIFICATIONS
Yellow, black, red, black, yellow	BS970-080-A20 (as rolled or forged).
Yellow, black, white, black, yellow	BS970-050-A22 (as rolled or forged).
Yellow, black, yellow, black, yellow	BS970-060-A17 (as rolled or forged).
Yellow, blue, black, blue, yellow	BS970-080-A22 (as rolled or forged).
Yellow, blue, brown, blue, yellow	BS970-060-A25 (as rolled or forged).
Yellow, blue, green, blue, yellow	BS970-080-A25 (as rolled or forged).
Yellow, blue, red, blue, yellow	BS970-070-M26 (as rolled or forged).
Yellow, blue, white, blue, yellow	BS970-060-A27 (as rolled or forged).
Yellow, blue, yellow, blue, yellow	BS970-060-A22 (as rolled or forged).
Yellow, brown, black, brown, yellow	BS970-060-A30 (as rolled or forged).
Yellow, brown, blue, brown, yellow	BS970-070-M26 (normalised).
Yellow, brown, green, brown, yellow	BS970-070-M26-P.
Yellow, brown, red, brown, yellow	BS970-080-M30 (cold drawn from hot rolled).
Yellow, brown, white, brown, yellow	BS970-060-A32 (as rolled or forged).
Yellow, brown, yellow, brown, yellow	
Yellow, green, black, green, yellow	BS970-080-M36 (normalised).
Yellow, green, blue, green, yellow	BS970-070-M26-Q.
Yellow, green, brown, green, yellow	BS970-080-M36 (cold drawn from hot rolled).
Yellow, green, red, green, yellow	BS970-060-A40 (as rolled or forged).
Yellow, green, white, green, yellow	BS970-060-A47 (as rolled or forged).
Yellow, green, yellow, green, yellow	BS970-060-A35 (as rolled or forged).
Yellow, red, black, red, yellow	BS970-060-A37 (as rolled or forged).
Yellow, red, blue, red, yellow	BS970-080-M36-Q.
Yellow, red, brown, red, yellow	BS970-060-A42 (as rolled or forged).
Yellow, red, green, red, yellow	BS970-080-M46 (normalised).
Yellow, red, white, red, yellow	BS970-080-M46-R.
Yellow, red, yellow, red, yellow	BS970-070-M26 (cold drawn from hot rolled).
Yellow, white, black, white, yellow	BS970-080-M36 (as rolled or forged).
Yellow, white, blue, white, yellow	BS970-080-M36-R.
Yellow, white, brown, white, yellow	BS970-060-A52 (as rolled or forged).
Yellow, white, green, white, yellow	BS970-080-M46-Q.
Yellow, white, red, white, yellow	BS970-080-M46-S.
Yellow, white, yellow, white, yellow	BS970-080-M46 (as rolled or forged).
Green, black, green, brown, green	BS970-304-S15 (as rolled).
Yellow, green, yellow, red, yellow	BS970-303-S41 (softened).

BL/3-1

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BASIC METROLOGY

MEASUREMENT OF BRITISH ASSOCIATION AND WHITWORTH FORM SCREW THREADS

1 INTRODUCTION This leaflet gives guidance on the inspection of screw threads produced by recognised methods such as machining, dieing, tapping, rolling, etc. Where it is necessary to achieve the maximum resistance to fatigue, bolts produced by a rolling process are usually preferred.

1.1 The accuracy of screw threads should be verified by a system of gauging, and a suitable system, together with the ancillary checks considered necessary to ensure compliance with the specified drawing requirements, is defined in this leaflet.

1.2 Guidance on the measurement of Unified Screw Threads is given in Leaflet **BL/3-2.**

2 SCREW THREAD SPECIFICATIONS The specifications for screw threads of Whitworth form, i.e. British Standard Whitworth (B.S.W.), and British Standard Fine (B.S.F.), are defined in British Standard, No. 84: 1956, whilst those for British Association (B.A.) threads are given in British Standard, No. 93 : 1951. The specifications for British Standard Pipe (B.S.P.) parallel threads were given in B.S. 84 : 1940, but are not included in the latest issue of this specification since they are now covered in B.S. 2779 : 1956 entitled "Fastening Threads of B.S.P. Sizes".

2.1 The above specifications define the basic series of diameters and corresponding pitches, together with recommended tolerances and limits. In B.S. 84 : 1956 there are also included recommended tolerances for other threads of Whitworth form up to twenty inches diameter.

2.2 There is no specification in the B.S. range dealing with brass threads, which are of Whitworth form, 26 threads per inch.

3 SCREW THREAD TERMINOLOGY For the benefit of those not familiar with screw thread terminology, a glossary is given below. Reference should also be made to Figures 1 and 2.

3.1 **Angle of Thread.** The included angle between the flanks of a thread, measured in an axial plane section.

3.2 **Axis of Thread.** The longitudinal centre line through the threaded portion.

3.3 **Basic Size.** The nominal standard dimensions of the threads from which all variations are made.

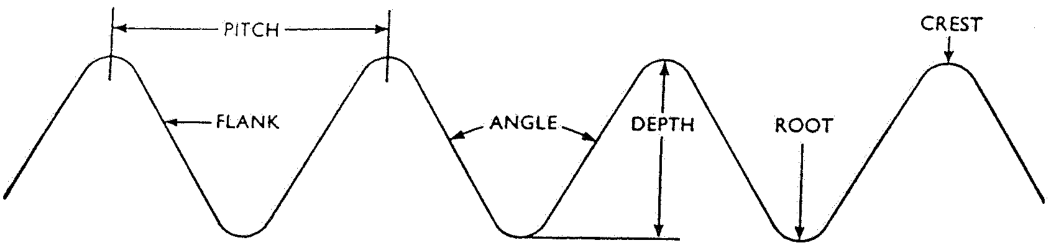

Figure 1 SCREW THREAD TERMINOLOGY

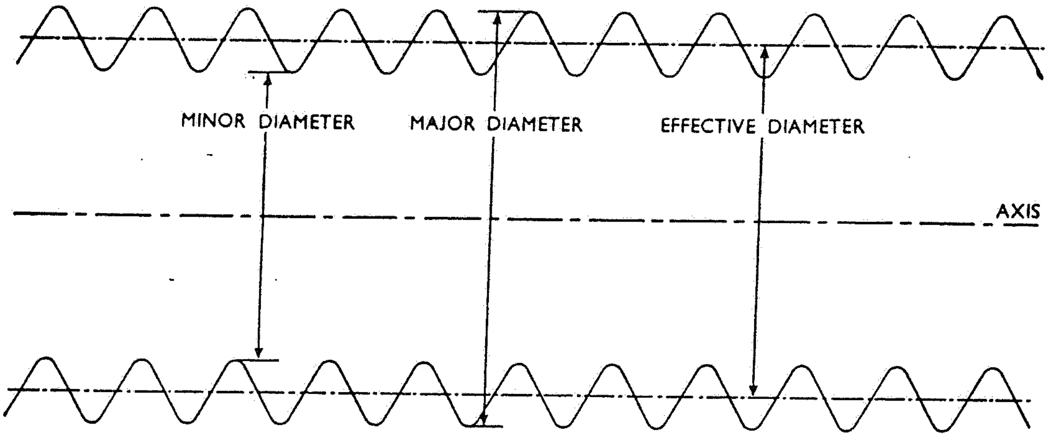

Figure 2 SCREW THREAD TERMINOLOGY

3.4 **British Association Threads.** A system of metric threads, confined to small sizes ranging from 6 mm. to 0·25 mm. in diameter and from 1 mm. to 0·070 mm. pitch. The diameters are designated in numbers ranging from 0 to 25. The thread is of a symmetrical "V" formation of 47½° included angle, having its crests and roots rounded with equal radii, such that the basic depth of the thread is 0·60 of the pitch.

3.5 **British Standard Fine.** A thread of Whitworth form, but of a finer pitch for a given diameter.

3.6 **British Standard Pipe.** A thread of Whitworth form, designated originally by the bore of the pipe on which it was formed and not by its major diameter, which is a decimal size, slightly smaller than the outside diameter of the pipe.

3.7 **British Standard Whitworth.** The standard British thread. It is a symmetrical "V" thread of 55° included angle, with a radius at root and crest of 0·1373 × pitch. The pitch of the thread is standardised for given diameters.

3.8 **Crest.** That part of the surface of a thread which connects adjacent flanks at the top of the ridge.

3.9 **Depth of Thread.** The distance between the root and crest, measured at right angles to the axis.

3.10 **Effective Diameter**

3.10.1 **Simple Effective Diameter.** The diameter of the pitch cylinder of the parallel thread or the pitch cone of a taper thread, in a specified plane normal to the axis. With Whitworth threads of nominal form, the simple effective diameter occurs half-way down the flanks and its nominal value may be obtained by subtracting one depth of thread from the nominal major diameter.

3.10.2 **Virtual Effective Diameter.** The effective diameter of an imaginary thread of perfect pitch and angle, having the full depth of flanks, but clear at the crests and roots, which would just assemble with the actual thread over the prescribed length of engagement. The virtual effective diameter exceeds the simple effective diameter with external threads, but is less than the simple effective diameter with internal threads, by an amount corresponding to the diametrical effects due to any errors in the pitch and/or flank angles of the thread.

3.11 **Flank.** The surface of the thread which connects the root and the crest.

3.12 **Flank Angle.** The angle between the flank of the thread and a line drawn perpendicular to the axis.

3.13 **Lead.** The distance a screw advances axially in one complete turn.

3.14 **Length of Engagement.** The axial distance over which two mating threads are designed to make contact.

3.15 **Major Diameter.** The largest diameter of the thread measured in a plane normal to the axis.

3.16 **Minor Diameter.** The smallest diameter of the thread measured in a plane normal to the axis.

3.17 **Pitch.** The distance from the centre of one crest to the centre of the next, measured parallel to the main axis.

3.18 **Root.** That part of the surface of the thread which connects adjacent flanks at the bottom of the groove.

3.19 **Truncation.** A truncated thread is one having flat crests, e.g. in the truncated Whitworth form thread, the basic rounded crests at the major diameter of an external thread and the minor diameter of an internal thread are removed at their junctions with the straight flanks of the basic thread form.

4 LIMITS AND TOLERANCES OF THREADS To permit control of screw thread dimensions during production, drawings should stipulate the nominal size, specification reference and class, whilst for screw threads of special diameter/pitch relationships, or for interference fits, the drawings should specify the toleranced sizes for the major, effective and minor diameters. If such information is not given, the guidance of the designer should be sought.

4.1 The major diameter of internal threads is controlled in practice by the major diameters or the taps of screwing tools used to cut the threads, thus a tolerance is not usually specified, but only a minimum size, which should be the same as the basic major diameter. However, a sharp root radius should be avoided, and the screwing tools used should be capable of producing a root radius equal at least to one-half of the standard radius for the pitch concerned.

4.2 The tolerances permitted for the major, effective and minor diameters of a screw thread provide, in effect, an envelope of limiting boundaries within which the thread form must lie. The accuracy of pitch, however, should be assessed over the specified length of engagement of the mating parts, since no separate tolerance is given. In a similar manner, no tolerance is usually quoted for the flank angle.

4.3 **Effect of Pitch and Flank Angle Errors.** Errors in the pitch and flank angles of a thread virtually increase the effective diameter of an external thread, and decrease that of an internal thread (see paragraph 3.10). For threads to be acceptable, therefore, it is necessary to ensure that any compounding of the effective diameter by pitch and flank angle errors does not cause the upper limit of the effective diameter of external threads, or the lower limit of that of internal threads, to be exceeded.

4.3.1 The size of the effective diameter, whether or not influenced by pitch or flank angle errors, is automatically safeguarded provided the thread is found to be acceptable by the gauging system detailed in paragraph 7. However, if the requisite gauges are not available, e.g. during experimental or pre-production conditions, and the accuracy of the threads is to be verified by direct measurement, it will be necessary to measure all elements of the threads, and to compute the effective diameter in relation to possible errors in the pitch and flank angles from the following formulae.

4.3.2 IF Z = maximum pitch error over specified length of engagement.
A_1 and A_2 = errors in opposite flank angles, regardless of sign, in degrees.
E = virtual change in effective diameter.
P = basic pitch of thread.

(i) For Whitworth threads:

Pitch error	$E = 1{\cdot}921 \times Z$.
Flank angle error	$E = 0{\cdot}0105 \times P(A_1 + A_2)$.

(ii) For B.A. threads:

Pitch error	$E = 2{\cdot}273 \times Z$.
Flank angle error	$E = 0{\cdot}0091 \times P(A_1 + A_2)$.

4.4 **Classes of Fit**

4.4.1 **Whitworth Form Threads.** Three classes of fit for external threads and two classes for internal threads are provided in B.S. 84 : 1956 and are as follows:

(i) **Close Class External Threads.** This class applies to threads where a good snug fit is required. It is obtainable consistently only by the use of the highest quality production equipment, supported by an accurate system of inspection and gauging. It is normally used for special work where refined accuracy of pitch and thread form is particularly required.

NOTE : An efficient system of inspection, including gauging, is necessary for all screw threaded work whether close class or not.

(ii) **Medium Class Internal and External Threads.** This class of fit applies to the better class ordinary interchangeable screw threads.

(iii) **Free Class External Threads.** This class applies to the majority of ordinary commercial quality bolts.

(iv) **Normal Class Internal Threads.** This class applies to the ordinary commercial quality nuts which are intended for use with medium or free class bolts.

4.4.2 **B.A. Threads.** Provision is made in B.S. 93 : 1951 for one class of fit for internal threads, sizes 0 B.A. to 16 B.A., and two classes for external threads, i.e. close class for sizes 0 B.A. to 10 B.A. and normal class for sizes 0 B.A. to 16 B.A. Close class fit are not given for external threads, sizes 11 B.A. to 16 B.A., since such bolts are not normally highly stressed.

(i) **Close Class External Threads.** The contents of paragraph 4.4.1 (i) are equally applicable in this instance.

(ii) **Normal Class External Threads.** This class applies to threads produced for general commercial use, and is suitable for general engineering purposes.

4.5 **Plated Threads.** In order to avoid any undue restriction of screwing tolerances, and also to prevent the removal of the plating during assembly, for threads which are plated with metals such as cadmium, nickel, etc., where the usual thickness of the plating is in the order of 0·0002 in., the following arrangements are permitted by B.S. 84 : 1956 and B.S. 93 : 1951.

4.5.1 For Whitworth external threads of either medium or free class, it is necessary to ensure that the threads prior to plating are not undersize, and that the maximum sizes are not exceeded after plating. For external threads to the close class, the tolerances may be displaced by an amount not exceeding 0·001 in. before plating.

4.5.2 For B.A. external threads of normal class, sizes 11 B.A. to 16 B.A. and all close class threads, the lower limits of the minor, effective and major diameters may be reduced by an amount not exceeding 0·001 in. before plating.

4.5.3 Due to the tendency of close fitting bolts and nuts manufactured of stainless steel to seize when tightened together, it is recommended that Whitworth form bolts manufactured in this material, in sizes up to and including ¾ in., should not be made to "close" class limits before plating, but rather to the "medium" or "free" class limits for unplated bolts, whilst B.A. bolts made of stainless steel should be made to the "normal" class limits for unplated bolts.

4.5.4 The recommended gauging system for checking plated threads is given in paragraph 7.3.

5 INSPECTION OF SCREW THREADS An inspection of the threads should be made to verify that the drawing requirements in respect of dimensional accuracy, thread form and standard of finish are met. Information on implementing these inspections is given in paragraph 7 to 11, whilst a description of the equipment to be used is given in the following paragraph.

6 THREAD GAUGES The system of "Workshop" and "Inspection" grade gauges recommended in B.S. 919 : 1940 has been superseded in B.S. 919 : 1952 by a system of gauges designated "General" and "Reference" grade gauges. General and Reference grades are provided for "Go" screw plug, ring and caliper gauges and their associated setting plugs, but for "Not Go" screw gauges and "Go" and "Not Go" major diameter gap gauges and minor diameter plug gauges, B.S. 919 : 1952 recommends the use of General grade gauges only.

6.1 **General Gauges.** These gauges are so dimensioned as to control the thread flanks within the specified work limits, i.e., the gauge tolerances lie within the work limits. The use of General gauges is recommended for medium and free fit class Whitworth form threads and for all classes of B.A. threads.

6.2 **Reference Gauges.** These gauges are designed around the nominal size of the thread with a minimum encroachment into or outside the work tolerance. The principal uses of Reference gauges are as referees in cases of doubt, thus serving as a check on the continued accuracy of General gauges, and for checking threads which have been manufactured to close class tolerances.

6.3 **"Go" Gauges.** These gauges are designed to control the maximum diameter and pitch of the external thread and the minimum diameter and pitch of the internal thread. The gauges are manufactured to the thread form and gauge length specified in B.S. 919 : 1952.

6.4 **"Not Go" Gauges.** "Not Go" effective diameter gauges are also designed to comply with the requirements of B.S. 919 : 1952, where it is specified that the threads should be cleared at the crests and roots in order to permit control of the effective diameter only. To minimise the possibility of pitch error affecting the result, the gauges embody not more than two or three turns of thread.

6.5 **Accuracy of Gauges.** It is important that all thread gauges should be checked periodically to ensure that they are not worn beyond permissible limits or are otherwise inaccurate. Checking is normally done by skilled inspectors, and if the gauges are in continuous use, a daily check is desirable. If the work is of an intermittent nature, a weekly check should suffice, but if the work is being handled in "short runs", a check before and after use is recommended.

6.5.1 Each gauge should bear a serial number, and records of all checks should be kept.

6.5.2 Where resetting is necessary in the instance of adjustable gauges, setting plugs of guaranteed accuracy should be used. (See paragraph 6.6).

6.6 **Setting Plugs.** Setting plugs are screw plug gauges to which adjustable screw ring and caliper gauges are set. They have truncated crests and are cleared at the roots to ensure contact only with the flanks of the threads of the gauge being set. General setting plugs should be used for General "Go" gauges and Reference setting plugs should be used for Reference "Go" gauges.

6.7 **General.** It is recommended that the handles of the various types of gauges, i.e. general, reference, pre-plating, etc., should be painted in different colours to reduce the risk of an incorrect gauge being used.

7 GAUGING SYSTEM

7.1 **Gauging of External Threads.** The following gauges should be used when checking external threads to ensure compliance with the drawing requirements.

7.1.1 A "Go" full form caliper or ring gauge to control the maximum diameter of the thread, and to ensure that the pitch is acceptable over the specified length of engagement.

7.1.2 A "Not Go" effective diameter thread caliper gauge to control the minimum effective diameter of the thread.

NOTE : The use of "Not Go" effective diameter ring gauges is not recommended for general applications.

7.1.3 A "Not Go" major diameter gap gauge to control the minimum major diameter of the thread.

7.1.4 When truncated threads are to be checked, "Go" and "Not Go" major diameter gap gauges, specially dimensioned for truncated threads, should be used to control the major diameter.

7.2 **Gauging Internal Threads.** The following gauges should be used when checking internal threads to ensure compliance with drawing requirements.

7.2.1 A "Go" full form screw plug gauge to control the minimum diameter of the thread, and to ensure that the pitch is acceptable over the specified length of engagement.

7.2.2 A "Not Go" effective diameter screw plug gauge to control the maximum effective diameter of the thread.

7.2.3 A "Not Go" minor diameter plug gauge to control the maximum minor diameter of the thread.

7.2.4 When truncated threads are to be checked, "Go" and "Not Go" minor diameter plug gauges, specially dimensioned for truncated threads, should be used.

7.2.5 Observation should be made to ensure that the axis of the thread through the nut is at right angles to the end faces. This is particularly important in larger nuts which may be used at predetermined torque loadings on ground-threaded high tensile bolts or studs (Leaflet **AL/7-8**).

7.3 **Gauging Plated Threads.** Reference was made in paragraph 4.5 to the special arrangements permitted in regard to manufacture when threads are to be metal plated. The gauging system recommended for checking such threads, both before and after plating, is given in the following paragraphs.

7.3.1 **External Threads.** Prior to plating, the threads should be checked with a "Not Go" effective diameter caliper gauge to control the minimum effective diameter specified prior to plating, and a "Not Go" major diameter gap gauge, made to control the minimum major diameter specified prior to plating.

(i) After plating, the threads should be checked with a "Go" full form thread caliper or ring gauge to control the maximum diameter of the thread.

(ii) When plated truncated threads are to be checked, a "Go" major diameter gap gauge, specially dimensioned for truncated threads, should be used to control the major diameter.

7.3.2 **Internal Threads.** Prior to coating, the threads should be checked with a "Not Go" effective diameter screw plug gauge to control the maximum effective diameter specified prior to plating, and a "Not Go" minor diameter plug gauge, made to control the maximum minor diameter specified prior to plating.

(i) After plating, the threads should be checked with a "Go" full form screw plug gauge to control the minimum diameter of the thread.

(ii) When plated truncated threads are to be checked, a "Go" minor diameter plug gauge, specially dimensioned for truncated threads, should be used to control the minor diameter.

7 4 **Relaxation of Gauging.** When a quantity of identical threads are to be produced, and it has been verified by inspection that a satisfactory production technique has been established, the gauging operations described above may be selectively applied at the discretion of the Chief Inspector. For rolled threads, evidence of identical conditions of manufacture would consist of ensuring that the machines producing the threads had been fed with blanks adequately controlled as to size and ductility, that the machines had been correctly set prior to each run, and that the threads produced by each machine had been checked periodically during each run to verify their continued dimensional accuracy.

8 THREAD FORM A standard gauging system is not in itself sufficient to verify completely the thread form, since the form at the crest and root is not controlled by the gauges. For this reason, and as a periodic check on the general quality of thread production, a supplementary inspection of the threads should be made, either by the use of optical instruments or by projecting the threads on to a screen at an appropriate magnification and comparing them with a standard line diagram representing the thread form, drawn to the same magnification. An optical examination or projection of the threads should be carried out on initial production to verify that a satisfactory screw production technique has been established. When checking external threads, this is a convenient point to confirm that the radius between the shank and the head is within permissible limits.

8.1 When internal threads are to be examined by a projection process, it will be necessary to take a cast of the threads, care being taken to ensure that the cast is a true reproduction of the thread form.

8.2 The form of the thread should be checked to ensure that it is regular and, where radiused roots and crests are specified, that these are correctly formed and blend uniformly with the flanks. When the threads have been truncated, it should be ascertained that the specified length of thread flank has been maintained. (See paragraph 3.19).

9 STANDARD OF FINISH The threads should be examined to ensure that the required standard of surface finish has been attained, and that there is no evidence of tearing or chatter; it is recommended that a magnifying glass of suitable magnification or some other suitable optical instrument is used for this purpose. The standard of finish is largely influenced by the type of material being threaded. One of the most difficult materials to thread is B.S.S. S80, but with a suitable combination of cutting speed, tool materials and angles, and cutting lubricants, a finish equal to the simpler materials can be achieved.

10 NOTES ON USING GAUGES Three types of gauges are in general use for checking external threads, i.e., roller type caliper gauges, anvil type caliper gauges, and ring gauges; of these, the two former types are usually preferred for general gauging.

10.1 Caliper gauges, which can be used for checking both left and right hand threads consist of two pairs of rollers or anvils, arranged as illustrated in Figure 3. The gauging elements can be adjusted to suit various diameters and are set by means of the special setting plugs described in paragraph 6.6. After setting, the adjusting mechanism of the gauge should be sealed to prevent unauthorised adjustments.

10.2 Caliper gauges, unlike ring gauges, permit the external threads to be checked for ovality and, to this end, threads should always be checked in two positions at right angles to each other.

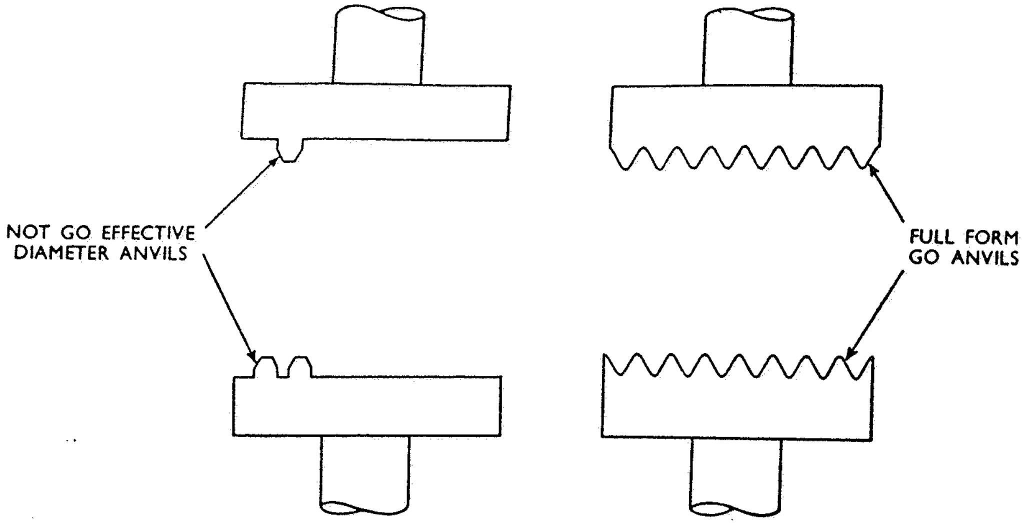

Figure 3 ARRANGEMENT OF CALIPER GAUGES

10.3 It is essential that the threads should be free of swarf and dirt before gauging is begun, and care should be taken to employ only a light pressure on the gauge to minimise the possibility of springing the frames. When anvil type gauges are used, the items to be checked should be applied from the front of the gauge, and should never be drawn through from the rear.

10.4 If the threads will not pass through the "Go" gauge, but will slip easily through the "Not Go" portion, this is indicative of an error in either the thread form or the pitch. The nature of the error can be established by trying the first thread only of the item into the "Go" gauge, and if the thread passes through, it can be assumed that the error is in the pitch, but if it fails to pass through then, assuming the major diameter to be correct, a serious error in flank angle, or malformation of the root or crest, will be indicated.

10.5 Ridging or flashes may occur on external threads which have been produced by a moulding or diecasting process, and it is recommended that threads produced by either of these methods should be checked for continuity with a ring gauge.

11 GENERAL INSPECTION In addition to gauging the threads, the parts should be inspected for general dimensional accuracy. The majority of thread drawings specify that a "lead", or chamfer, should be applied to the first half or full thread, and this also should be checked for accuracy.

11.1 Bolts, and in particular those having short plain shanks, which are produced on automatic machines using automatic die chucks, should be checked to ensure that the final thread is correctly formed, since, for various reasons, the thread form cutter may fail to cut a full final thread.

11.2 Rolled threads may be affected by chips in rolling dies, which will produce similar identically repeated bumps on each thread produced from the dies. A proportion of the threads should be examined visually for such defects, since they may not necessarily be revealed by gauging.

BL/3-2

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BASIC

METROLOGY

MEASUREMENT OF UNIFIED THREADS

1 INTRODUCTION This Leaflet gives guidance on the measurement and inspection of Unified screw threads produced by recognised methods such as grinding, machining, dieing, tapping or rolling. In modern practice the majority of external threads are produced by rolling and internal threads by tapping. It has been found by experience that these methods produce a thread with the greatest resistance to fatigue.

1.1 The Unified system of screw threads was introduced by Canada, the United States and the United Kingdom to provide a common standard between the three countries. The International Standards Organization (I.S.O.) has recommended the system as an international system of screw threads in inch units, in parallel with a similar system in metric units. Both systems use a similar form of thread profile and tolerance. Data relating to the inch series threads of ¼ inch diameter and over is contained in British Standard 1580 and for threads below ¼ inch diameter in British Standard 3155.

1.1.1 The range of threads included in BS 1580 is as follows:—

(i) UNC Unified coarse pitch thread with progressive pitch sizes (i.e. pitch varies with diameter).

(ii) UNF Unified fine pitch thread with progressive pitch sizes.

(iii) UNEF Unified extra fine pitch thread with progressive pitch sizes.

(iv) UN Unified thread with constant pitch (e.g. an 8UN thread has 8 threads per inch regardless of the diameter).

(v) UNS Unified thread of special pitch/diameter combination not included above, but for which the tolerances are derived from the standard formulae.

(vi) In addition to the above, modified profile threads may be used for special applications, e.g. 'Mod' after the designation, means that the major diameter is decreased for threads used in high temperature zones; effective diameter is the same as for the standard thread.

1.1.2 The range of threads included in BS 3155 and accepted for use in the aircraft industry are nominated as UNC or UNF and conform generally to the requirements of BS 1580 except that they are normally only manufactured in one class of fit (i.e. Class 2A and 2B, see paragraph 4).

1.1.3 **Abbreviation System.** The abbreviation system recommended for the indentification of Unified threads consists of a combination of the diameter, pitch, series and class of fit, e.g. $\frac{1}{4}$–28 UNF 2A (or 0·250–28 UNF 2A). For a left handed thread the suffix 'L' is added. The numbered threads are designated in a similar way, e.g. 10–32 UNF 2A (or 0·190–32 UNF 2A). For products manufactured to aircraft specifications the part number is prefixed by the specification number. In circumstances where the thread is to be coated, additional information may be added to a drawing for manufacturing purposes. This will include the major and effective diameters before and after coating and additional symbols may also be used to specify particular forms of thread or lengths of engagement.

1.1.4 Of the above threads UNF and UNC are those selected for general use within the aircraft industry and a single range of sizes has been chosen in which the majority of fasteners are manufactured. These are: 0–80 UNF, 2–64 UNF, 4–40 UNC, 6–32 UNC, 8–32 UNC, 10–32 UNF, $\frac{1}{4}$–28 UNF, $\frac{5}{16}$–24 UNF, $\frac{3}{8}$–24 UNF, $\frac{7}{16}$–20 UNF, $\frac{1}{2}$–20 UNF, $\frac{9}{16}$–18 UNF, $\frac{5}{8}$–18 UNF, $\frac{3}{4}$–16 UNF, $\frac{7}{8}$–14 UNF and 1–12 UNF. Special threads (UNS and UNS Mod.) have some particular uses but in the main are being replaced by threads of UNJ form (see paragraph 1.2).

1.2 **UNJ Threads.** A recent addition to the Unified range of threads is the UNJ thread form, which is designed for increased fatigue strength where working stress levels are high. It features an enlarged root radius on the external thread (Figure 4) and is particularly suitable for aircraft applications. The requirements for high strength are further met by restricting the tolerances to those of a Class 3A (external) or 3B (internal) fit. Data relating to UNJ threads is contained in British Standard 4084 and is discussed in paragraph 5 of this Leaflet.

1.3 **General.** The accuracy of fastener threads should be verified, during manufacture, by a system of gauging and optical projection. A suitable system is defined in BS 919 Part 1, and explained in this Leaflet.

1.4 Specifications for aircraft fasteners having Unified threads are included in the British Standards 'A' series of specifications, in the Society of British Aerospace Companies 'AS' series and in the Aircraft General Standards series.

2 UNIFIED THREAD FORM The basic form of a Unified thread is illustrated in Figure 1 and is derived from an equilateral triangle with one side parallel to the axis of the thread. The triangle is truncated by an amount equal to $\frac{1}{8}$ of its height at the major diameter and $\frac{1}{4}$ of its height at the minor diameter.

2.1 The design form of the thread (Figure 2), i.e. the thread in its maximum metal condition, varies from the basic form in that the root of the external thread is rounded to a specified radius below the flat. It will be seen from Figure 2 that contact between the design forms of the external and internal thread is confined to the flank over a radial depth of $\frac{5}{8}$ the height of the basic triangle. In practice the root of the internal thread is rounded outside the major diameter to avoid sharp corners.

2.2 Modern mass production methods often result in partial or even complete rounding of the external thread crests, but this is not detrimental to the strength of the fastener and does not conflict with the checking methods used. It does render the thread less susceptible to damage and has the added advantage of minimising the plating faults which often occur at sharp corners.

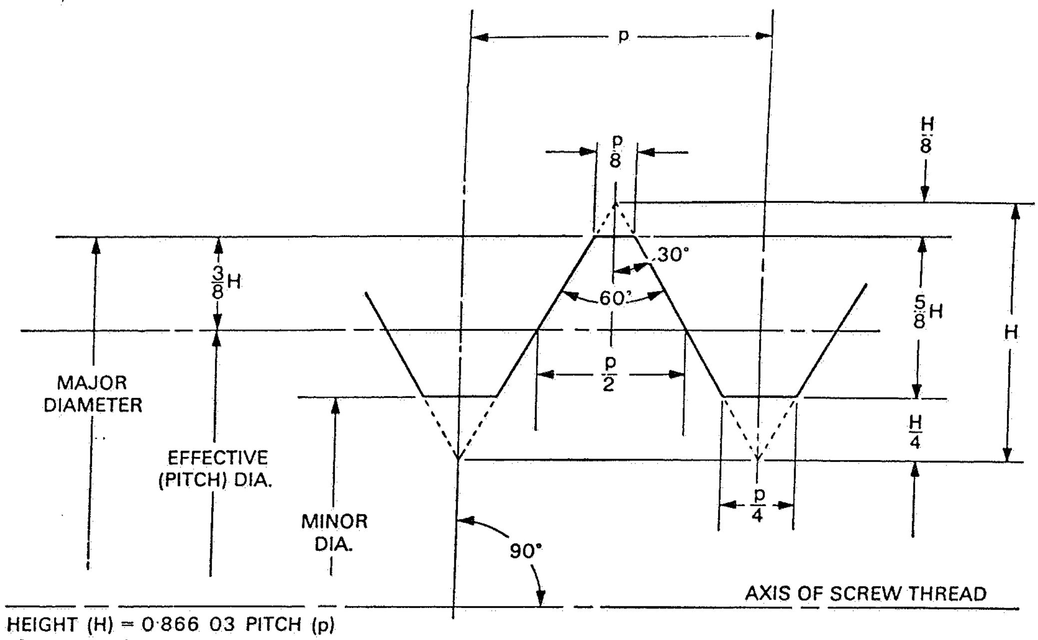


Figure 1 BASIC FORM OF UNIFIED THREAD

3 LIMITS AND TOLERANCES In order to provide for interchangeability and ensure the correct class of fit for a particular application, standard Unified threads are controlled by a system of tolerances which are defined in BS 1580. This Standard relates to threads of ¼ inch diameter and larger but the principles employed are also applicable to the numbered sizes (i.e. 0–80 to 10–32) the tolerances for which are listed in BS 3155.

3.1 The tolerances permitted for the major, effective and minor diameters of a screw thread provide, in effect, an envelope of limiting boundaries within which the thread surface must lie. The accuracy of pitch, however, should be assessed over the specified length of engagement of the mating parts, since no separate tolerance is given. In a similar manner no separate tolerance is normally quoted for the flank angle.

3.2 **Effective Diameter Tolerance.** This is derived from a three part formula which takes account of diameter, pitch and length of engagement. For UNC, UNF, UNJ, 4UN, 6UN and 8UN threads, a length of engagement equal to one diameter is used; for all other threads a length of engagement of 9 pitches is used.

3.3 **Major Diameter Tolerance.** With external threads the tolerance on major diameter is derived solely from a formula based on pitch. With internal threads no tolerance is quoted, it being considered that this dimension will be adequately controlled by the crest of the tap or cutting tool.

3.4 **Minor Diameter Tolerances.** The minor diameter tolerance on external threads is related directly to the effective diameter tolerance. The minor diameter of an internal thread is formed by an operation prior to threading and the tolerance is related to pitch and diameter.

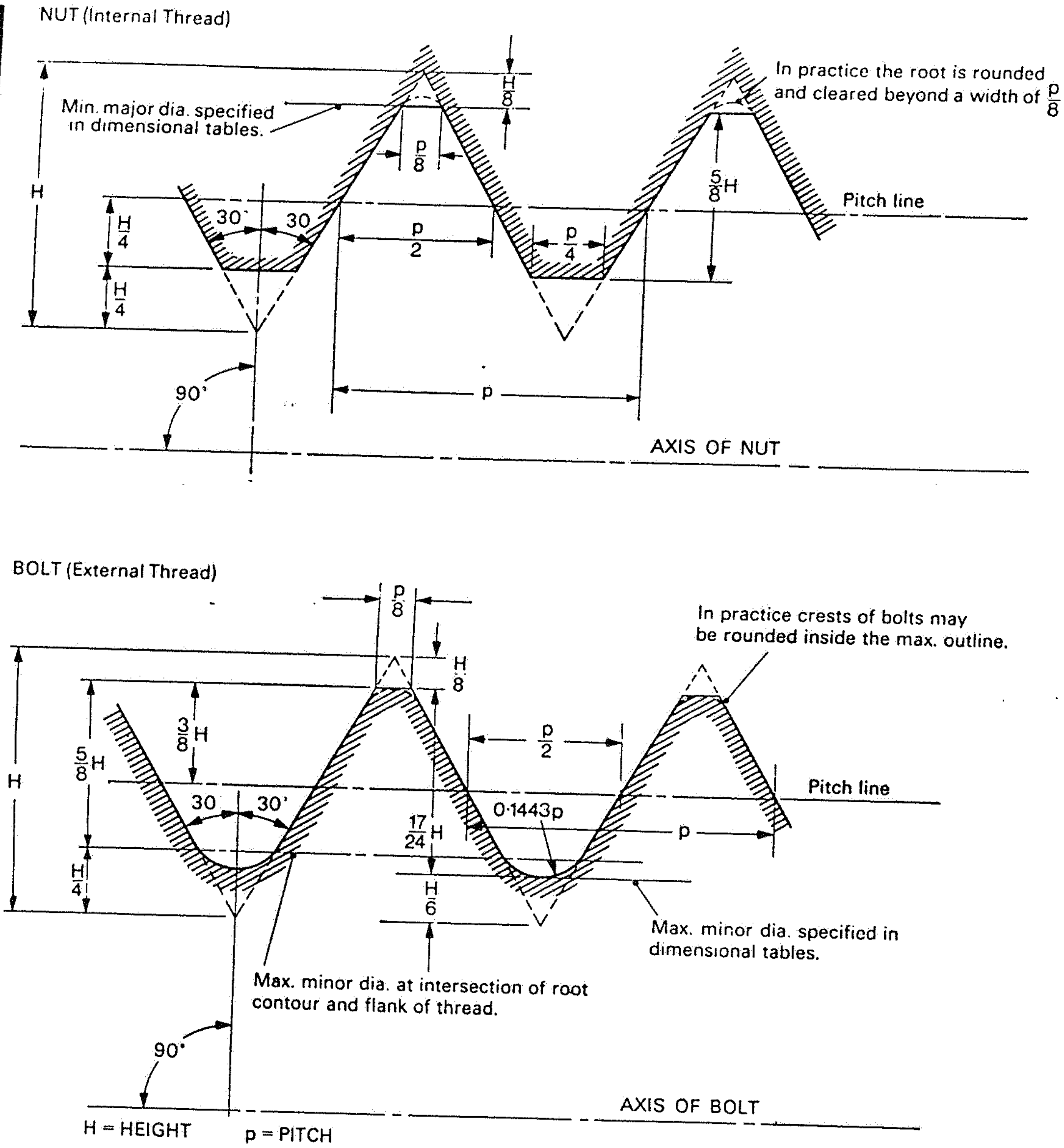


Figure 2 DESIGN FORM OF UNIFIED THREAD (MAXIMUM METAL CONDITION)

3.5 **Depth of Engagement.** The depth of engagement (i.e. radial amount of thread overlap) is 5H/8 for standard Unified threads and 9H/16 for UNJ threads when mating threads are in the maximum metal condition. This is reduced by the tolerances permitted on the major diameter of the external thread and the minor diameter of the internal thread.

3.6 **Allowance.** This is the design clearance permitted between mating threads and is deducted from the basic size of the external thread. The allowance for Class 1A and 2A threads is 30 per cent of the Class 2A effective diameter tolerance but there is no allowance permitted for Class 3A threads.

NOTE: Due to the tendency of close fitting fasteners of unplated stainless steel to seize when tightened it is recommended that stainless steel bolts should not be made to Class 3A limits.

3.7 **Provision for Coated Threads.** Where specified, a depth of coating (e.g., cadmium or tin) of 0·0002 inch is normally required on all threads and this coating would interfere with the thread tolerances if not taken into account during manufacture. The allowance for Class 2A threads is normally permitted to be absorbed by the coating (but see paragraph 4.4) and it is, therefore, unnecessary for the thread to be reduced in size before coating. For other external threads and all internal threads, diametral limits are laid down in the appropriate specification, to which the thread must conform before the coating is applied. The appropriate limits, as applicable to the effective diameter, are illustrated in Figure 3.

3.8 **Effect of Pitch and Flank Angle Errors.** Errors in pitch and flank angle have the effect of increasing the simple effective diameter of an external thread and decreasing that of an internal thread. No specific tolerances are given for these parameters, but they are adequately controlled by the effective diameter tolerance. For example, if a bolt has a simple effective diameter on the maximum size, no pitch or flank angle deviations will be accepted by the checking gauge, but if the simple effective diameter is of minimum size then some deviations in pitch and/or flank angle will be accepted.

3.8.1. Should the requisite gauges not be available, e.g. during experimental or pre-production conditions, and the accuracy of the threads is to be verified by direct measurement, it will be necessary to measure all elements of the threads and to compute the effective diameter in relation to possible errors in pitch or flank angle from the following formula:—

If Z=maximum pitch error over specified length of engagement, in inches,

A_1 and A_2=errors in opposite flank angles, regardless of sign, in degrees,

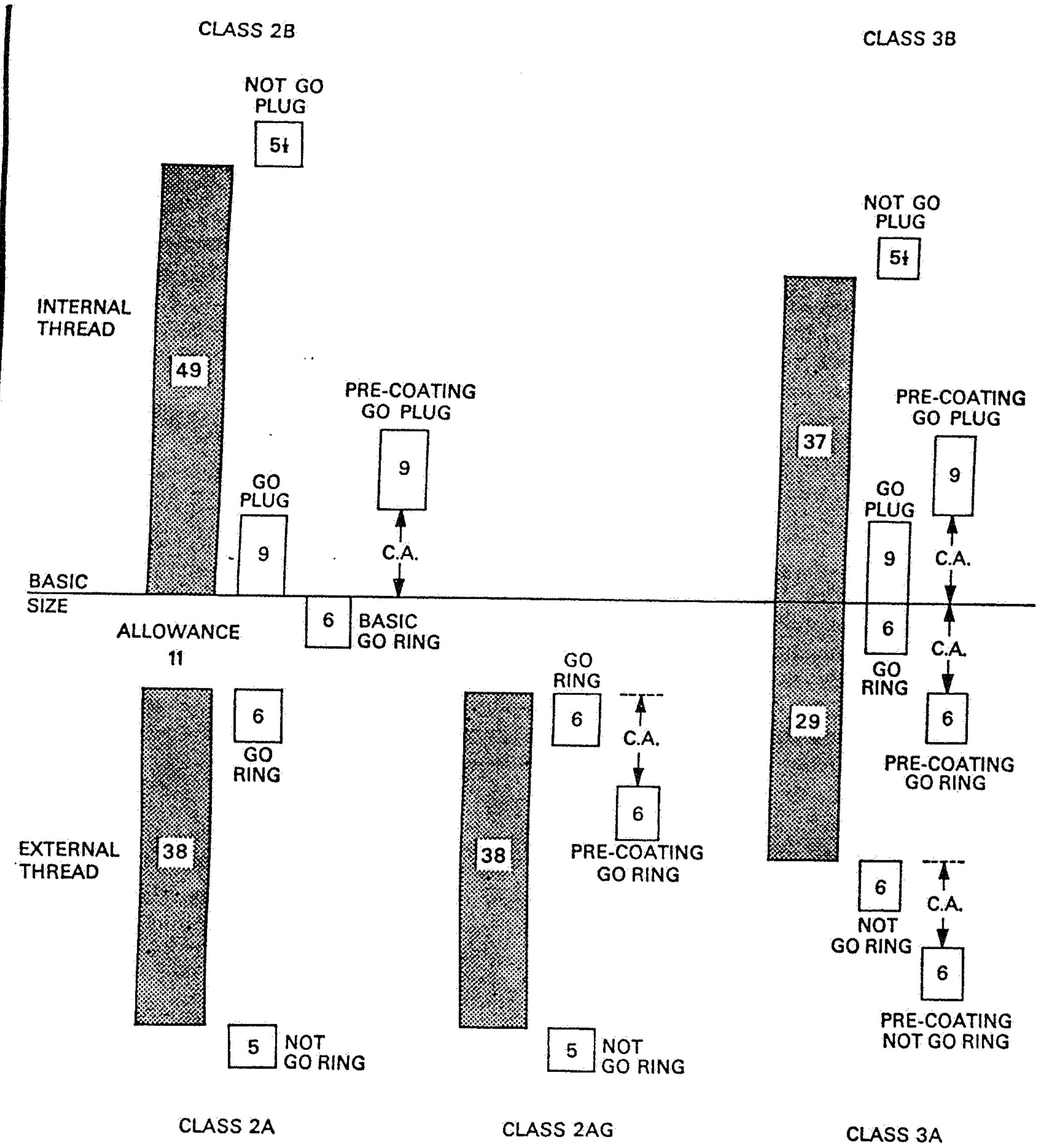
E=virtual change in effective diameter,

P=basic pitch of thread, then,

Pitch error .. .. $E=1{\cdot}732 \times Z$

Flank angle error .. $E=0{\cdot}01 \times P\,(A_1+A_2)$

NOTE: In the basic form of the Unified screw thread, the lengths of straight flank above and below the pitch line are not equal For this reason the virtual change in effective diameter resulting from positive flank angle errors on the bolt and negative flank angle errors on the nut will be slightly less than that resulting from negative flank angle errors on the bolt and positive flank angle errors on the nut. The factor 0·01 in the expression above is the mean value of the corresponding factors applying to these two sets of conditions and is sufficiently accurate for practical purposes.



C.A. = Coating allowance = 0·001 inch in sizes of ¼ inch dia. and larger.
1 UNIT = 0·0001 inch.
[shaded] = PRODUCT TOLERANCE
[blank] = GAUGE TOLERANCE

Figure 3 EFFECTIVE DIAMETER TOLERANCES

4 CLASSES OF FIT Three ranges of tolerances are specified in BS 580 for Unified threads of ¼ inch diameter and larger, but threads in the numbered sizes are limited to Class 2 and UNJ threads to Class 3.

4.1 **Class 1A External Thread, Class 1B Internal Thread.** These classes apply to the majority of fasteners of ordinary commercial quality and correspond in general to the 'free' class fit of BS 84 (Screw threads of Whitworth Form).

4.2 **Class 2A External Thread, Class 2B Internal Thread.** These classes apply to the majority of fasteners used in the aircraft industry and correspond to the 'medium' class fit of BS 84.

4.3 **Class 3A External Thread, Class 3B Internal Thread.** These classes apply to threads which have a snug fit and correspond to the 'close' fit grade of BS 84. They are being used in increasing quantities in the aircraft industry, particularly in aircraft engine applications.

4.4 **Class 2AG External Threads.** This class of thread is used where a Class 2A fit is required and it is necessary to maintain the allowance after coating (i.e. for use in high temperature zones or where a lubricant is specified); it is applicable to the external thread before coating. The basic diametral limits are 0·001 inch less than those quoted for a Class 2A fit on threads ¼ inch diameter and larger, with corresponding smaller reductions for the numbered sizes.

4.5 **General.** Normally the same class of internal and external thread are used together, but different grades of fit may be obtained, if required, by using different classes. It should also be noted that nuts with UNJ threads may be used in place of those with standard Unified threads.

5 UNJ THREAD FORM The basic and design forms of Unified threads are shown in Figures 4 and 5 respectively. These threads are described in BS 4084 and comprise a coarse thread series (UNJC) and a fine thread series (UNJF) similar to those in the standard Unified range.

5.1 **Tolerances.** As mentioned in paragraph 1.2, UNJ threads are only manufactured to Class 3 tolerances and no provision is therefore made for an allowance on the internal thread. Tolerances on effective and major diameters are calculated in the same way as for standard Unified threads, the length of thread engagement used in the formula for calculating effective diameter tolerance being equal to the basic thread diameter. Minor diameter tolerances for internal threads are calculated in the same way as for standard Unified threads but the formula used gives a slightly larger diameter to allow for the increased root radius of the mating external thread.

5.2 **Gauging.** The general principles to be observed when inspecting UNJ threads are the same as those required for standard Unified threads. BS 4084 stipulates that the root of the external thread shall also be inspected by optical projection to check the root radius and the blending of the curve with the flanks.

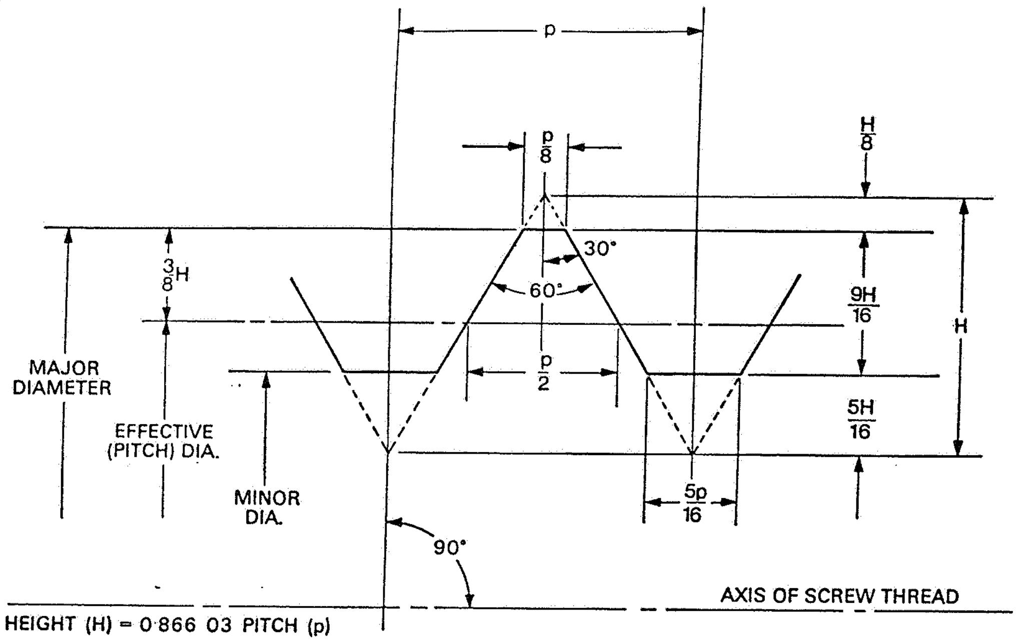


Figure 4 BASIC FORM OF UNJ THREAD

6 THREAD GAUGES BS 919 Part 1 gives full details of the types of gauges to be used when checking screw threads of Unified form and also lists the tolerances which are acceptable during manufacture. Following American practice only one series of gauges is specified for use during both manufacture and inspection. Typical gauges are illustrated in Figure 6.

6.1 **GO Gauges.** These gauges are designed to ensure that the product does not exceed the maximum metal condition specified in the appropriate Standard (BS 1580, BS 4084 or BS 3155) for the type and size of thread. A GO screw plug gauge will ensure that the major and effective diameters of an internal thread are not below the minimum size specified; it will not check the minor diameter however as the gauge thread roots are cleared beyond the minor diameter for practical reasons. The minor diameter of the internal thread is checked with a plain GO plug gauge. A GO screw ring or caliper gauge will ensure that the effective diameter of an external thread is not greater than the maximum size specified and that it will assemble with an internal thread of minimum size. It will not ensure that the major diameter is not too large; this is checked by a plain ring or caliper gauge. GO gauges are normally made to a length at least equal to the length of engagement of the product threads.

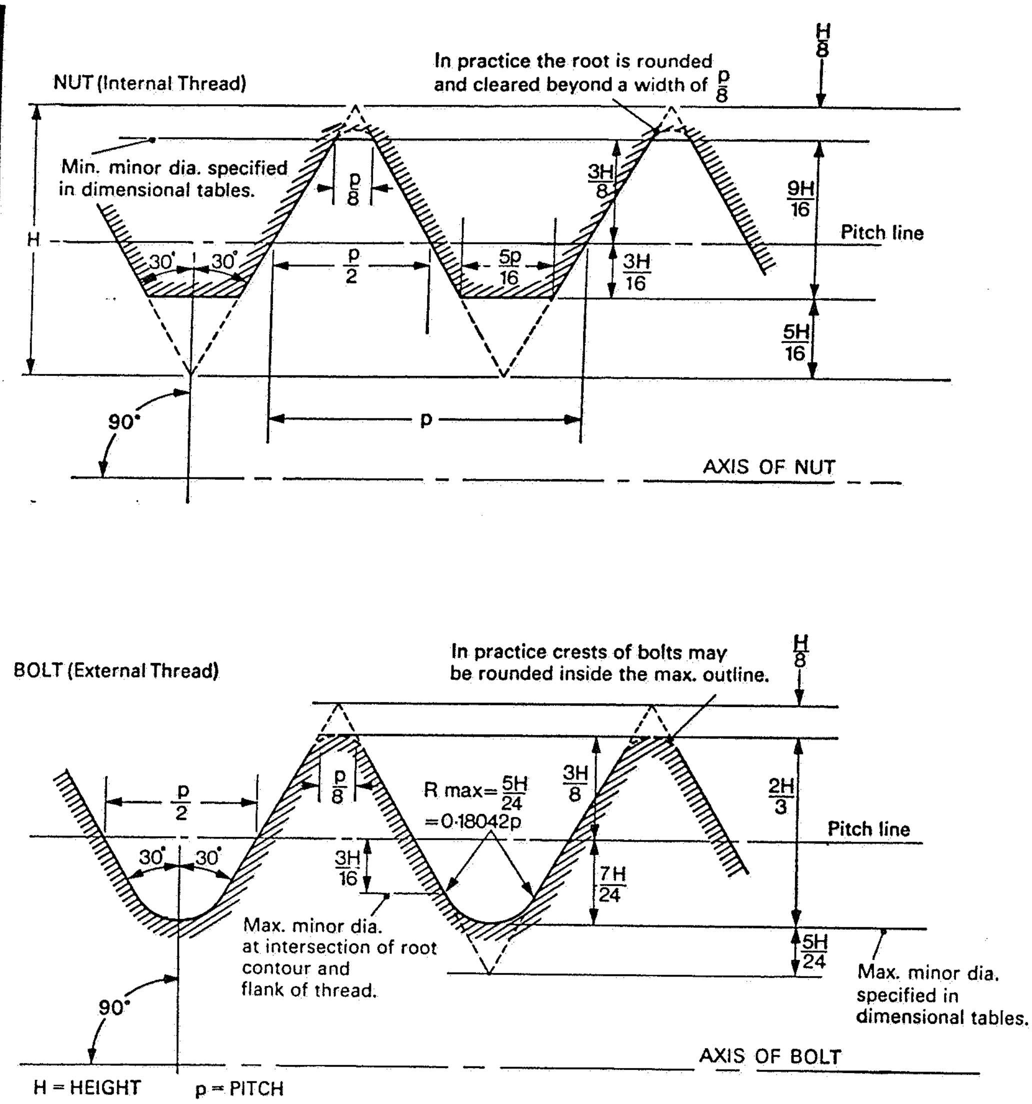


Figure 5 DESIGN FORMS OF UNJ THREAD (MAXIMUM METAL CONDITION)

6.2 **NOT GO Gauges.** These gauges are designed to ensure that the product meets the minimum metal limit specified in the appropriate Standard and are similar in appearance to GO gauges. NOT GO gauges for crest diameters are plain plug gauges for internal threads and plain ring or caliper gauges for external threads, made to the minimum metal limit of the product thread. NOT GO screw gauges for checking the minimum metal limit on effective diameters are of two types, namely, low addendum or high addendum. A low addendum gauge only contacts the thread over a short length of flank whereas the high addendum gauge has a much larger area of contact. The low addendum gauge is a better method of checking simple effective diameters where flank angle or other thread malformations are present, and is used widely in the United Kingdom. The high addendum gauge is, however, recommended for checking Unified threads in the numbered sizes. To minimise the effect of pitch errors, NOT GO screw gauges embody only 2 or 3 turns of thread.

6.3 **Gauge Tolerances.** The manufacturing tolerances for GO gauges are placed within the limits specified for the product thread to ensure that no work is accepted which is outside these limits and that mating threads will always assemble. The manufacturing tolerances for NOT GO gauges, however, are placed outside the product limits in British practice, but the tolerances are so small that acceptance of threads outside the limits is unlikely.

6.4 **Adjustable Gauges.** To permit their continued use after wear has taken place, ring and caliper gauges are often manufactured in an adjustable form. To set the size of an adjustable ring gauge a 'double-length' setting plug is used. The effective diameter of this setting plug remains constant over its whole length, but while the major diameter of one half is at the maximum size the other half is truncated to the minimum size. On GO gauges this form of setting plug enables the thread form to be checked and on NOT GO gauges it is possible to verify that both the effective diameter and major diameter are satisfactory. Adjustable caliper gauges are set with a 'single length' setting plug which has a length approximately equal to that of the gauge.

6.5 **Check Gauges.** GO and NOT GO check gauges are required for verifying the size of a new solid type ring gauge and are similar to the plug gauges used for checking product threads but are made to finer limits. NOT GO effective diameter check gauges are also required to ensure that solid ring gauges are not kept in use when worn beyond limits. Check gauges are an alternative to direct measurement and are indispensable in sizes below ¼ inch diameter.

6.6 **Marking of Gauges.** Each gauge must be adequately marked to show the use for which it is intended and the size of the limits it is intended to control. Examples of typical markings are given below:—

(i) GO screw plug gauge (low addendum)	:	'¼–28 UNF 2B GO EFF 0·2268'
(ii) NOT GO screw caliper	:	'¼–28 UNF 2A NOT GO EFF 0·2258'
(iii) GO Pre-coating screw plug gauge	:	'¼–28 UNF 2B GO EFF 0·2278 BEF COAT'.

6.6.1 The letters 'LH' are also added if the thread is left hand, and a system of serial numbers is recommended for record and checking purposes.

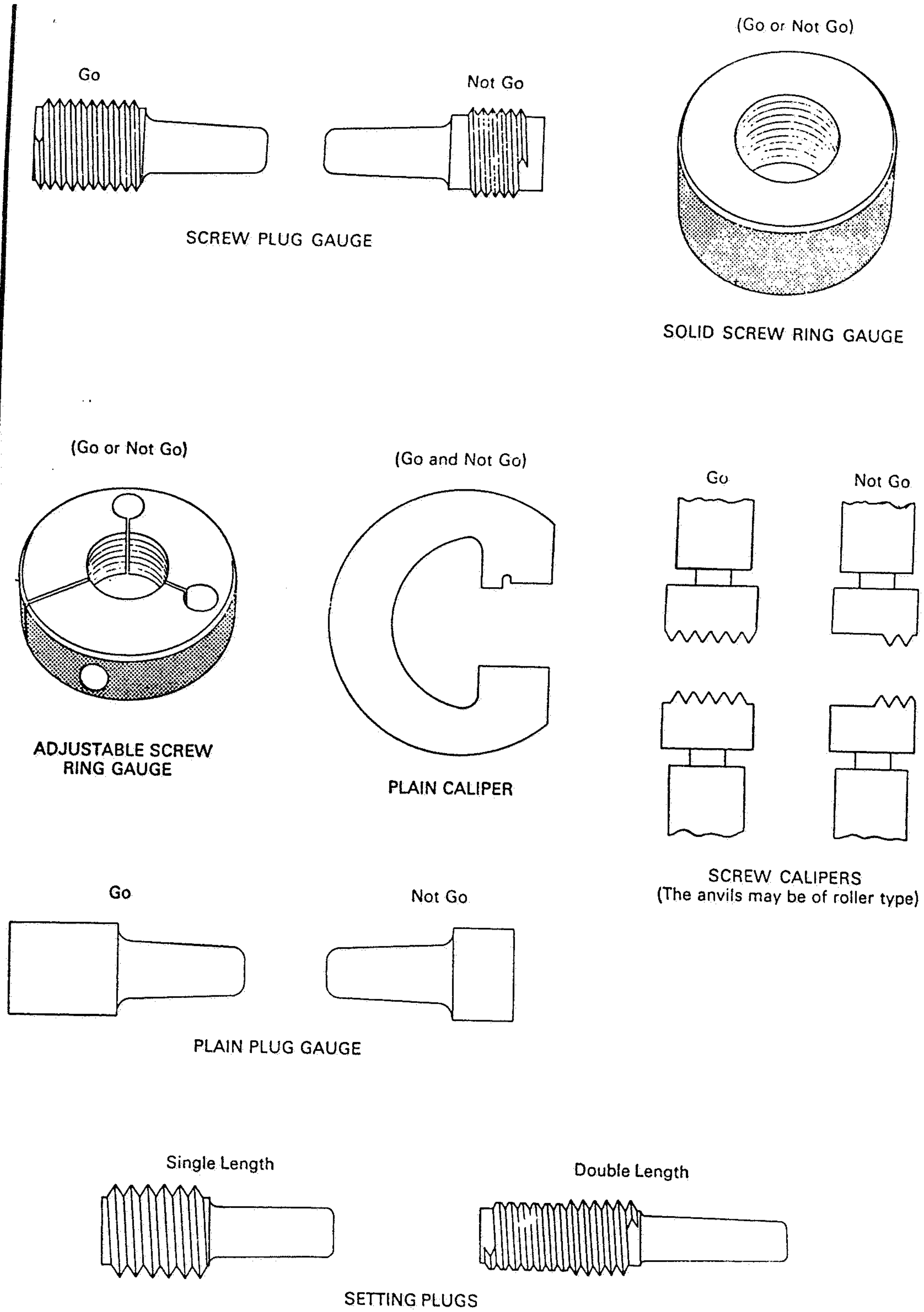


Figure 6 TYPICAL THREAD GAUGES

6.7 **Notes on the Use of Gauges.** The primary purpose of GO screw gauges is to prove that the whole of the surface of the product thread falls within the maximum metal limits specified. A solid plug gauge is used on internal threads and a solid ring gauge is most reliable for external threads. The ring gauge in particular is prone to wear, however, and adjustable ring gauges are often used although these too have limitations, mainly due to being slightly out of shape after adjustment. Caliper gauges, whether of the anvil or roller type may also have shortcomings due to the 'give' of the frame, Inspectors, therefore, have a choice of gauges for any particular purpose and should select the most appropriate for the product and method of manufacture.

6.7.1 Cleanliness of the product thread and gauges is most important. The presence of dirt and swarf in a thread, besides giving a false indication of fit, may also damage the gauge.

6.7.2 The position of the gauge tolerance zones in relation to the product limits is shown in Figure 3. Since all internal work is slightly bell-mouthed and external work often slightly tapered, it may be possible for a product on the minimum metal limit to be partly accepted by the NOT GO gauge. Provided not more than two threads are engaged this is acceptable at the discretion of the Chief Inspector.

6.7.3 Caliper gauges, unlike ring gauges, only check a small part of the thread circumference. This is advantageous in that, by checking at different radial positions on the thread, it is possible to detect ovality and some types of lobing. Unless used with extreme caution 'thread chaser' type anvils will accept threads which deviate from design and for this reason roller or semi-roller type calipers are often used.

6.7.4 **Setting Adjustable Gauges.** Adjustable ring gauges are initially ground to a size slightly larger than the setting plug. If this is not done, and the gauge has to be opened out to permit entry of the setting plug, the diameter of the ring gauge threads will be less than that of the plug and tend to touch at the corners of the ring slots, resulting in a tendency to shave the setting plug threads. It is not possible to obtain a perfect fit all round the ring but a satisfactory fit may be obtained in the following way:—

(i) Enlarge the ring until an easy fit is obtained on the plug.

(ii) Slightly tighten and lock the ring alternately until a firm fit is obtained. It will assist the closing of the threads if the gauge is lightly tapped during this operation.

(iii) Remove the plug, then re-insert it to check the fit.

(iv) When proper adjustment has been obtained the ring should be sealed.

7 INSPECTION OF SCREW THREADS Gauges of the types described in paragraph 6 are generally used to ensure that production threads conform to specification; they do not, however, ensure that a completely satisfactory thread is formed. The form and finish of the roots of both internal and external threads are not precisely controlled by gauges and reliance must be placed on the accuracy of the cutting or rolling tools used. Maintenance of a satisfactory product thread is achieved by careful inspection of these tools and by the use of optical projection to ensure a good thread profile. It will be necessary to make an accurate cast of an internal thread in order to apply projection methods.

7.1 **Gauging.** It will be evident from the foregoing paragraphs, and from Figure 3, that a number of gauges will be required to check a particular product during manufacture. It will also be seen that the tolerances applied to a particular type of gauge are the same regardless of thread class, and certain gauges may therefore be used for more than one purpose. Table 1 lists the effective diameter thread gauges and crest diameter plain gauges which will be necessary for inspecting product threads of any class.

7.1.1 The gauging of minimum metal limits after coating is not recommended. These limits must be controlled before the application of the coating by the use of appropriate GO and NOT GO gauges. Provided that the product is accepted by the GO gauge after plating the thread should be satisfactory.

7.1.2 As mentioned in paragraph 3.7 the coating of Class 3B threads is not recommended due to the fact that the coating allowance absorbs an unduly large proportion of the product tolerance. If a Class 2B nut is used instead, the effective diameter tolerance, after coating, will approximate to Class 3B limits. If required, a Class 3B internal thread may be coated, but the GO plug gauge used before coating should be of basic diameter plus 0·001 inch (for threads ¼ inch diameter and larger).

7.2 **Standard of Finish.** Product threads should be examined to ensure that the required standard of finish has been obtained and that there is no evidence of tearing or chatter; it is recommended that a magnifying glass of suitable magnification or some other optical instrument should be used for this purpose.

7.2.1 The standard of finish is affected by the speed and method of manufacture and also by the type of material being threaded. Suitable techniques should be selected for a particular material in order to achieve a satisfactory finish. Where cutting tools are used on stainless steel such as S80, frequent checks may be necessary to ensure that tool wear has not degraded the thread finish.

7.3 **Additional Inspections for Nuts.** In addition to the checks made to ensure that the thread form is satisfactory, additional checks are normally specified for nuts.

7.3.1 **Concentricity.** A nut thread is cut after the drilling of the hole which forms the minor diameter; the effective and minor diameters, therefore, are not necessarily coaxial. Concentricity may be checked by the use of a GO screw plug gauge having a plain extension equal in size to the plug gauge used for checking the minor diameter; eccentricity will result in non-acceptance of this type of gauge.

TABLE 1

GAUGES REQUIRED FOR CHECKING UNIFIED THREADS

(Screw Gauges for Effective Diameters and Plain Gauges for Crest Diameters)

Thread Class and Limit	*Gauges Required*		
	Uncoated	*Before Coating*	*After Coating*
1A Max. limit	2A GO	2A GO — ·0015 in	2A GO
2A Max. limit	2A GO	2A GO	Basic
2AG Max. limit	—	2A GO — ·001 in	2A GO
3A Max. limit	Basic	Basic — ·001 in	Basic
1A Min. limit	1A NOT GO	1A NOT GO	None recommended
2A Min. limit	2A NOT GO	2A NOT GO	None recommended
2AG Min. limit	—	2A NOT GO	None recommended
3A Min. limit	3A NOT GO	3A NOT GO —·001 in	None recommended
1B Min. limit	Basic	Basic +·001 in	Basic
2B Min. limit	Basic	Basic +·001 in	Basic
3B Min. limit	Basic	Basic +·001 in	None recommended
1B Max. limit	1B NOT GO	1B NOT GO	None recommended
2B Max. limit	2B NOT GO	2B NOT GO	None recommended
3B Max. limit	3B NOT GO	3B NOT GO	None recommended

NOTE: A 'Basic' gauge is a GO gauge of nominal size.

7.3.2 **Squareness.** In order to check that the bearing face of a nut is at right angles to the thread axis, the nut is screwed onto a tapered screw gauge having a close fitting sleeve. Any error may be measured by means of a feeler gauge inserted between the nut face and the sleeve. The permitted squareness tolerances are quoted in BS A100.

7.4 **Direct Measurement.** Occasions are likely to occur when a threaded product is manufactured in quantities which render the provision of suitable gauges uneconomical. In these circumstances direct measurement of the diameters, pitch and flank angles of the threads is resorted to. Measurement of the crest diameter is a simple matter but measurement of the effective diameter presents difficulties. Thread measuring wires are normally used for checking the effective diameter of external threads, the virtual effective diameter being calculated by measurement of the pitch and flank angles and reference to the equivalence tables included in BS 919 Part 1. It is also essential that inspection by optical projection is carried out to determine that the thread roots and flanks are correctly formed. Measurement of the effective diameters of an internal thread is usually avoided by fitting it to a mating component of satisfactory size and form, and by careful inspection of the cutting tool.

7.5 **Selective Inspection.** When a large quantity of identical threads is to be produced and it has been verified by inspection that a satisfactory production technique has been established, the inspection described above may be selectively applied at the discretion of the Chief Inspector. For rolled threads, maintenance of identical conditions of manufacture would consist of ensuring that the machines producing the threads were fed with blanks adequately controlled for size and ductility, that the machines had been correctly set prior to each run, and that the threads produced by each machine had been checked periodically during each run to verify their continued dimensional accuracy.

7.6 **General Inspection.** In addition to gauging the threads, a product should be checked for general dimensional accuracy. The majority of specifications for threaded components require a 'lead' or chamfer to be applied to the thread and it is usually necessary to provide a 'run-out' at the shank end of the thread to minimise stress concentration. These details should be checked against the specification.

7.6.1 Bolts with plain shanks may also require checking for straightness, and bolt specifications normally include checks for concentricity of the thread with the shank and squareness of the head with the shank.

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BASIC

METROLOGY

SURFACE TEXTURE MEASUREMENT

1 INTRODUCTION This Leaflet gives guidance on the assessment of material surfaces where the texture must be inspected to defined limits or to an agreed standard.

1.1 A controlled surface texture is necessary on many aircraft components, not only between mating surfaces, but also on exterior surfaces.

1.1.1 In general, sliding surfaces require a smooth finish, in order to minimize friction or to provide a positive seal area. A smooth finish is particularly important with highly stressed parts, to improve resistance to fatigue failure and corrosion. Structural parts made from notch-sensitive materials, such as very high tensile steel and high strength aluminium alloys, require the smoothest possible finish; the quality of the surface often being more important than minor dimensional inaccuracies.

1.1.2 Mating surfaces in an assembled joint generally require a smooth surface, in order to provide the maximum contact area. The surface texture of parts which are assembled with an interference fit is also important, particularly where the hardness of the parts differs, since an excessively rough surface on the harder part will result in abrasion of the softer material. The effect of this would be an impairment of the standard of fit, and the possibility of concealed corrosion.

1.1.3 A controlled amount of surface roughness may be essential in some cases, examples being the bore of an engine cylinder, where oil is retained on the wall to reduce friction and prolong cylinder life, and in seal grooves to prevent seal roll.

1.2 A particular degree of surface roughness is often specified for the surfaces of a component, therefore, and a manufacturing process is chosen which will produce the surface required.

1.3 Special care should be taken when handling items for which a particular surface texture is specified, since any physical damage may require re-working in order to obtain the texture required. Items should be protected from damage and corrosion whilst in storage, as outlined in Leaflet BL/1-7.

1.4 Detailed information on the assessment of surface texture is provided in British Standard (BS) 1134, and International Organization for Standardization ISO/R 468, and specifications for roughness comparison specimens are contained in BS 2634. A glossary of related terms is included in paragraph 8 of this Leaflet.

2 FORMS OF SURFACE TEXTURE Surface texture is defined (in BS 1134) as those irregularities, with regular or irregular spacing, which tend to form a pattern on the surface. The texture consists of roughness and waviness, which may be superimposed on any errors of form (i.e. departures from the required geometric form, which are within the manufacturing tolerances) which may be present. These irregularities are shown in Figure 1, in which, because of the small height of the irregularities compared with the spacing of their crests, the vertical scale is greatly expanded. Surface irregularities take the form of a series of peaks and valleys, which may vary both in height and spacing, and produce a texture which is generally characteristic of the production process. Cutting tools produce a regular, well-defined pattern, whilst grinding produces a less regular but equally directional pattern. Lapping, honing, and other abrasive processes, generally produce an irregular, multi-directional pattern, which may vary from point to point on the surface. Roughness is generally produced by the cutting tool or grinding wheel, and is inherent in the particular production process; it also depends on the cutting speeds and feeds used. Roughness is superimposed on waviness, which has a longer spacing, and results from machine or workpiece deflection, vibration, or chatter.

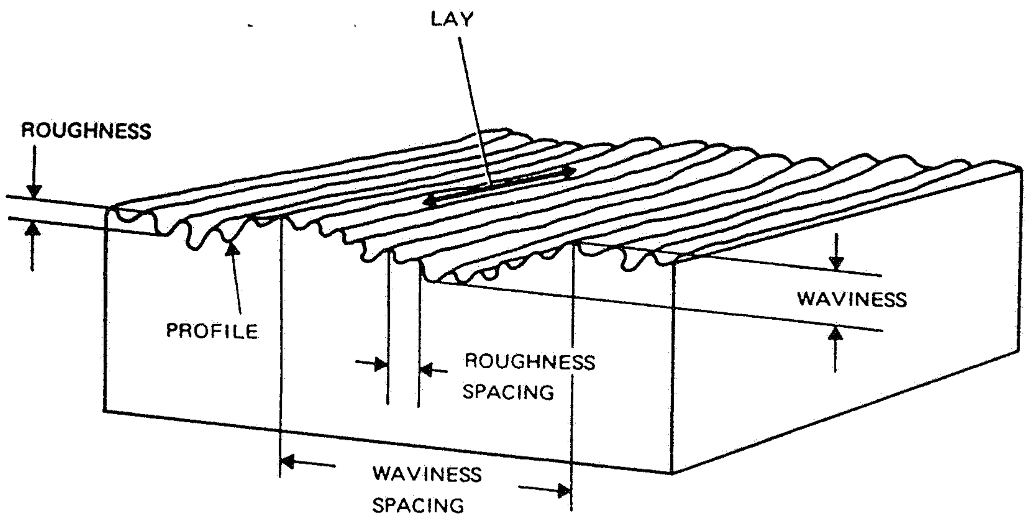


Figure 1 SURFACE IRREGULARITIES

2.1 In some instances the production processes (e.g. machining on numerically controlled machines) may produce a particular type of surface, with pronounced waviness and mismatching (i.e. a surface irregularity caused by successive cutter paths failing to produce a continuous surface). With this type of surface, waviness and mismatching are treated separately from surface roughness, and separate limitations on depth and spacing are imposed. When specified separately, waviness is measured from the graph produced by a profile recording machine, and mismatching is measured by normal metrological methods.

3 SURFACE MEASUREMENT PARAMETERS As may be seen from Figure 1, the shape of a surface is basically three-dimensional, but a simple and realistic means of assessing the surface texture is to measure the profile of a plane section taken through the surface, and thus reduce the problem to a two-dimensional one. On surfaces with a predominantly directional texture, the measurements must be taken at 90° to the lay, or misleading results will be obtained. On surfaces with a multi-directional texture the direction of measurement may be unimportant, but if necessary will be quoted on the appropriate drawing.

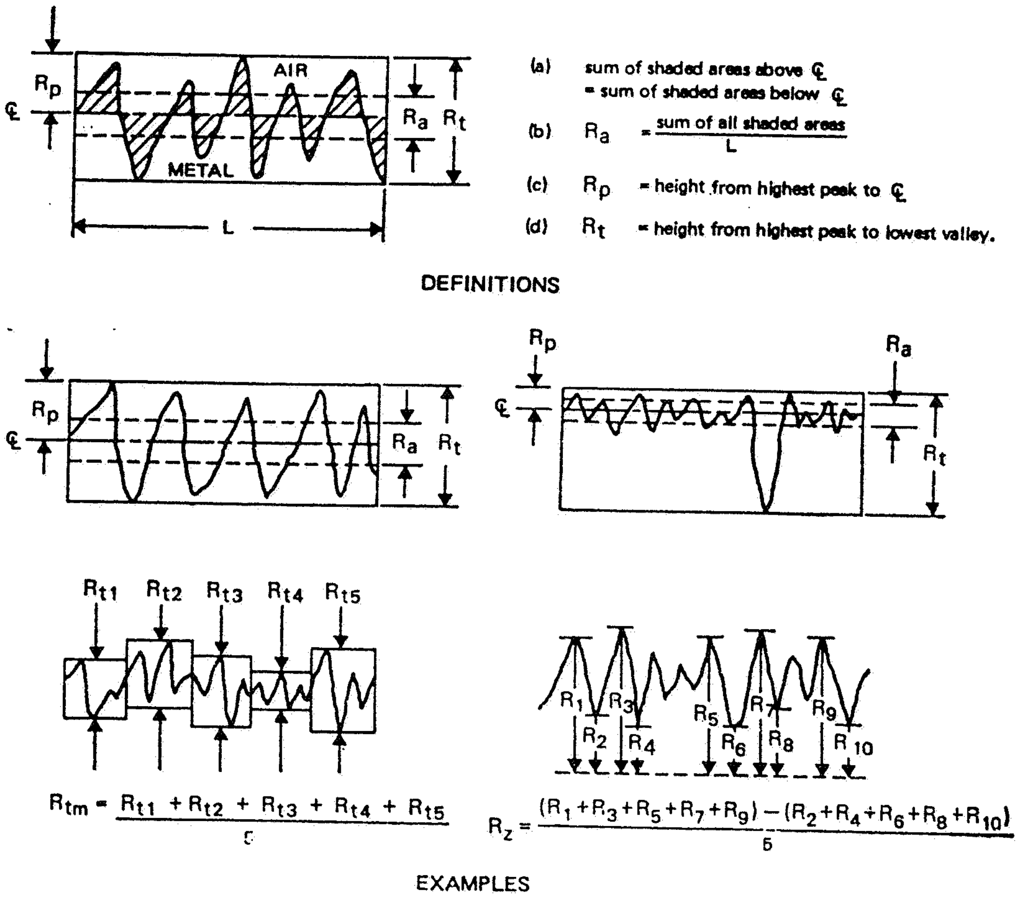


Figure 2 SURFACE MEASUREMENT PARAMETERS

3.1 **Grading of Surface Texture.** The method which has been adopted internationally as the standard means of grading surface texture, is known as the arithmetical mean deviation (formerly known as centre-line-average—CLA) and is termed the R_a parameter. R_a represents the average roughness of the surface. Other means of grading the surface are the measurement of total profile deviation (highest peak to lowest valley) and the smoothing depth (highest peak to reference line (see paragraph 8.15)); the former is known as R_t and the latter R_p. Where CLA values are quoted on drawings, the units will generally be μin (millionths of an inch or micro-inches), but where R values are quoted the units will generally be μm (millionths of a metre or microns). Definitions and parameters are shown in Figure 2.

3.1.1 The R_a value may be determined by electrical or other instruments which plot the surface contours and measure their average height, or by graphical assessment of a profile recording (paragraph 4.3).

3.1.2 In some cases the measurement of average peak-to-valley height is required. When this is measured by means of an electrical instrument, the mean R_t value over a number of sampling lengths is taken, and the parameter is known as R_{tm}. When the average peak-to-valley height is determined by graphical assessment of profile recordings, the five highest peaks and five lowest valleys are measured, and the parameter is known as R_z (paragraph 4.3.2).

3.1.3 A range of preferred R_a values, together with a list of equivalent Roughness Grade Numbers, is included in Table 1 (see page 13). The Roughness Grade Numbers may be used on drawings in order to avoid the misinterpretation of numerical values.

3.2 **Sampling Length.** A sampling length is the length of profile chosen for the purpose of making an individual measurement of surface texture. Figure 3 illustrates a section through a surface possessing roughness, waviness, and errors of form. The various sampling lengths (L) which could be used are shown on the illustration, and it can readily be seen that the value obtained for the total height (H) of the surface irregularities, will depend on the sampling length selected. If a short sampling length (L_1) is selected, surface roughness only will be recorded, but if a sampling length greater than the peak-to-peak distance of the waviness is selected (L_2), then both roughness and waviness will be recorded. To assess the whole surface, including errors of form, a sampling length of L_3 would be required. In practice, a sampling length of 0·8 mm has been found satisfactory where only roughness is to be considered, and this length is generally used for assessing the finer textures. Where waviness has to be included in the surface texture measurement, then a longer sampling length must be chosen; the actual length will depend on the class of work and the manufacturing process being used.

3.2.1 When measuring roughness only, and using a short sampling length, the texture of various parts of the surface may appear to vary considerably because of irregularities with a spacing longer than the sampling length. The effect of these irregularities may be reduced by taking a number of observations in a row, and measuring the mean height of each sampling length separately. By averaging out a number of consecutive sampling lengths a satisfactory result may be obtained.

3.2.2 A range of standard samplirg lengths is listed in BS 1134, and meter cut-off wavelengths (paragraph 5.2.1) of the same value are used. When specifying the surface texture required for a particular surface, on a drawing, the meter cut-off to be used should normally be quoted in parenthesis following the surface texture value, e.g. 0·1 μm R_a (0·25), but may be omitted in the case of the standard 0·8 mm cut-off.

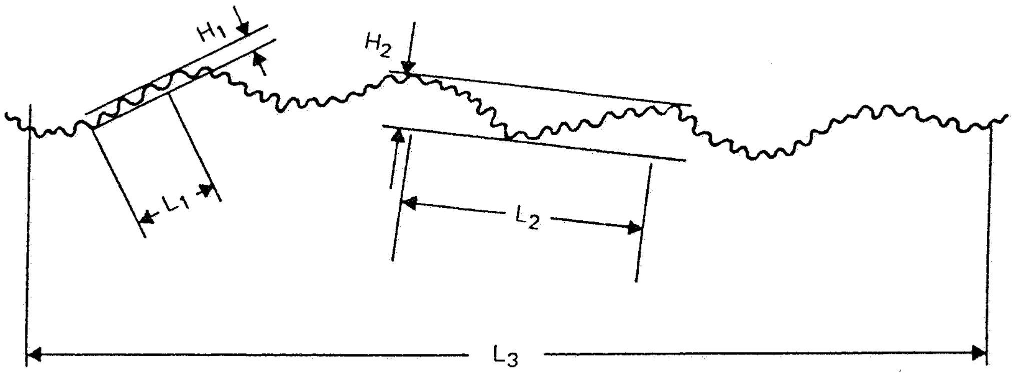


Figure 3 SAMPLING LENGTH

4 ASSESSMENT OF SURFACE TEXTURE The texture of a surface may be measured with instruments which operate on mechanical, electro-mechanical, pneumatic or optical principles, but for normal purposes the electro-mechanical instruments are the more versatile, and are used internationally (paragraph 5). These instruments measure the mean deviation of the surface relative to a defined centre line, the measurement taking no account of the form of the deviations, which may vary considerably. Figure 4 illustrates some of the forms which are likely to be found, and a surface could resemble any of these or a combination of any number of forms. The numerical measurement of R_a values is not, therefore, a complete expression of the shape of the surface, but when the production process is also known, a reasonable assessment of the surface can be made.

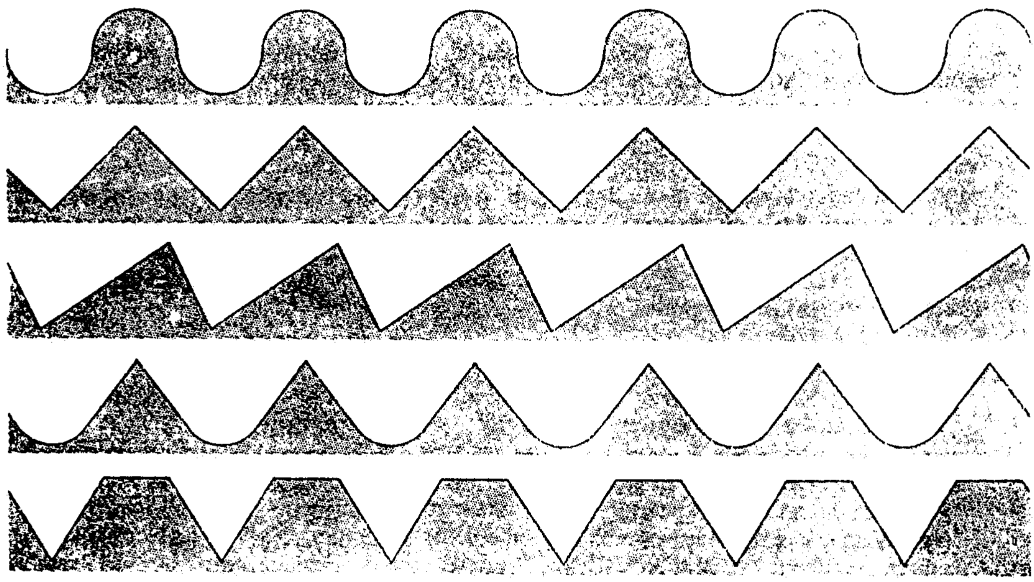


Figure 4 FORMS OF SURFACE TEXTURE

4.1 **Replicas.** When it is necessary to make an assessment of an internal surface, or a surface which is not easily accessible for examination, a replica of the surface can be made and tested. The surface of the replica will be an inverse profile of the actual surface, and, because of the different material, will both look and feel different. However, these differences, and any random faults such as shrinkage or bubbles in the material, can usually be ignored, and reasonably accurate results can generally be obtained. Before making a replica, the surface to be reproduced must be thoroughly cleaned, to remove all traces of oil, grease and moisture. A suitable solvent should be applied with a soft brush, and care should be taken not to scratch or otherwise damage the surface.

4.1.1 One method of producing a replica, is to soften a strip of cellulose acetate with a solvent such as acetone, and press it firmly against the surface until it sets. When removed, the cellulose acetate strip hardens sufficiently to permit testing with a lightly-loaded stylus.

4.1.2 A more accurate method of reproducing a surface is by the use of synthetic resins, which are marketed under a variety of trade names. These materials are usually supplied as a separate powder and liquid, which must be mixed in the correct proportions before use. After mixing, the material may be poured onto the surface which is to be reproduced, and allowed to set; it may be necessary to use a dam of modelling clay or putty to contain the mixture while it is setting. When set, the cast can be removed and its surface tested.

4.1.3 If doubt exists as to the accuracy of a replica, the process may be tested by making a replica of a sample part, which can be measured, and comparing the two surfaces. For finer surfaces a cast may also be taken of an "optical flat", so that differences between the optical flat and its replica will indicate errors resulting from the replica process. For the results to be valid, the comparisons must be made at exactly the same position on the original surface and on the replica.

4.2 **Roughness Comparison.** When a single R_a value is quoted for the surface on a particular part, this indicates the upper limit of roughness, and the production process should aim at producing a surface which is smoother than this limit. In such a case it is often sufficient for the machine operator to be provided with a roughness comparison specimen of the required R_a value (or preferably two specimens, one of the required R_a value and another of half that value), with which he may compare, by appearance and touch, the part he is producing. The specimen should be of the same material as the finished article, and should be produced by an identical process, using similar tools and feed rates. The methods of manufacture of roughness comparison specimens and the tolerances which are acceptable, are detailed in BS 2634.

4.2.1 In some instances a roughness comparator may be used for direct numerical comparison of the surfaces. This instrument is set to the roughness comparison specimen and indicates directly on a scale. Some instruments are provided with a stylus head which can be used while the work is still in the machine, and, by the use of various attachments, straight, convex and concave surfaces can be compared. These instruments are generally not sufficiently accurate to be used as measuring instruments, and their use should be confined to the comparison of surfaces against a known standard. It should be noted that the use of a comparator on a roughness comparison specimen will affect the surface of the specimen and greatly reduce its useful life.

4.3 **Graphical Determination of Roughness Values.** In order to make a graphical assessment of roughness values, a profile graph of the surface must be obtained from a recording instrument. These graphs usually have different values of magnification for the vertical and horizontal scales, in order to provide profiles similar to those shown in Figures 5 and 6. The vertical magnification is generally of the order of 10 to 500 times the horizontal magnification.

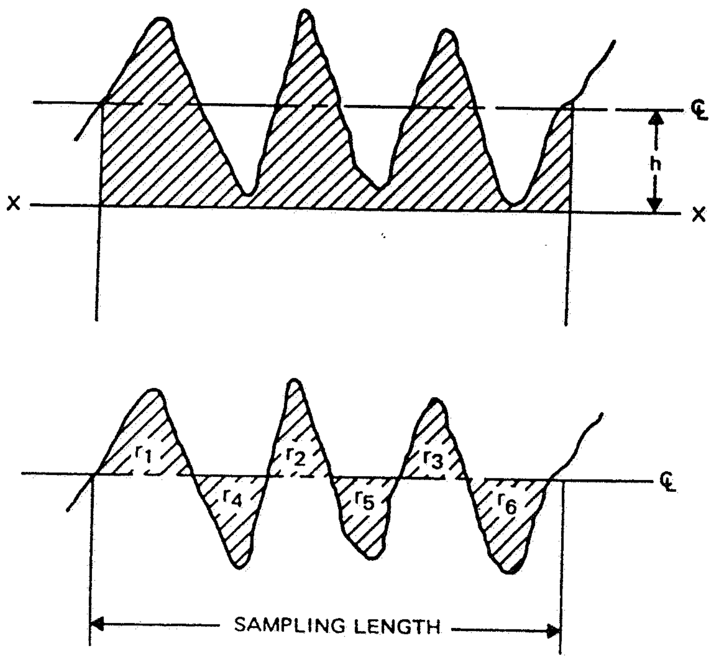


Figure 5 GRAPHICAL ASSESSMENT OF R_a VALUES

4.3.1 **R_a Values.** Figure 5 shows a graphical recording of a surface over one prescribed sampling length (L). If the profile has a distinguishable periodicity this sampling length must include a whole number of periods.

(a) To determine the R_a value of this surface, it is first necessary to find the centre line of each sampling length, and this is done by drawing a line (X–X) parallel to the general direction of the profile and including the lowest valley. The area of the section above this line is then calculated by measuring equally spaced co-ordinates, or by use of a planimeter; this area, divided by the sampling length gives the height (h) of the centreline above the line X–X.

(b) The arithmetic mean height of the surface deviations is then found from the formula:—

$$R_a(\mu m) = \frac{\text{sum of areas } r_1, r_2, r_3, r_4, r_5, r_6\ (mm^2)}{\text{sampling length (mm)}} \times \frac{1000}{V_v}$$

where V_v = the vertical magnification of the scale.

4.3.2 **R_z Values.** For some purposes an assessment of average peak-to-valley heights of surface irregularities is required. These values are numerically different from R_a values, and are generally 4 to 7 times the R_a values, depending on the shape of the profile. The profile graph used for measuring the R_z value of a surface is produced in the manner described in paragraph 4, but a different magnification and sampling length from those specified for R_a values may be chosen.

(a) An arbitrary line (X–X) is drawn on the profile graph (Figure 6), parallel to the general direction of the profile. The height of the five highest peaks (p) and the five lowest valleys (v) above this line are drawn in and measured (in millimetres). The R_z value (μm) is then determined from the formula:—

$$R_z = \frac{(p_1 + p_2 + p_3 + p_4 + p_5) - (v_1 + v_2 + v_3 + v_4 + v_5)}{5} \times \frac{1000}{V_v}$$

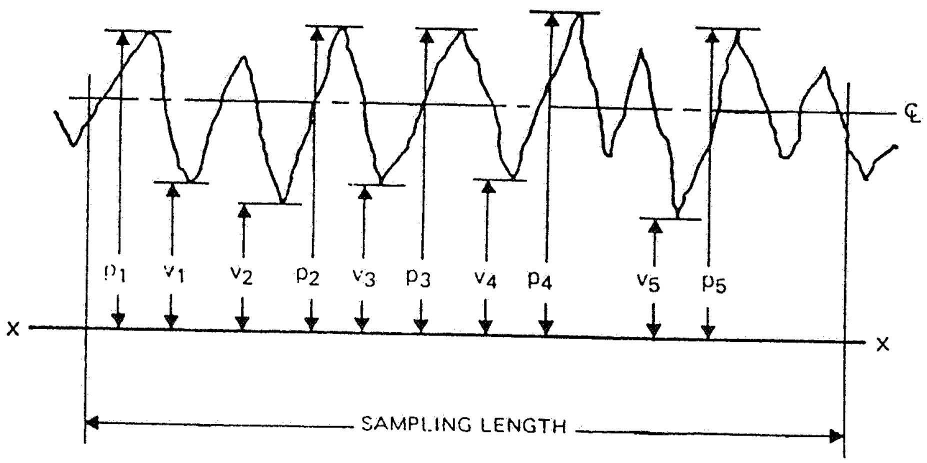


Figure 6 GRAPHICAL ASSESSMENT OF R_z VALUES

5 INSTRUMENTS The majority of instruments used for assessing surface texture use a stylus, which rests on the surface and is traversed across it. Vertical movements of the stylus are converted, by means of an electro-magnetic or piezo-crystal transducer into an electric current, which is amplified and indicated on a direct-reading meter or graph. Many instruments employ a skid as the datum for the stylus (Figure 9), and some are also capable of measuring a particular geometric form, e.g. straightness or roundness, by use of a suitable traverse datum.

5.1 **Stylus.** The accuracy with which an instrument is able to assess the profile of a surface, depends to a large extent on the shape of the stylus and on the method used for guiding the stylus over the surface.

5.1.1 The stylus should, ideally, have a geometrically sharp point, but since this is not possible it is finished with a rounded tip. A radius of 2 µm is used with profile recording instruments, while a radius of 10 µm is considered satisfactory for instruments giving average readings only; the cone angle of the point is generally between 60° and 90°. The effects of using a rounded stylus are shown in Figure 7. It can be seen that the path traced by the stylus does not follow the contour of the surface, but produces a rounded crest and shallow valley. The stylus would also be incapable of producing an accurate record of a vertical wall in the shape of the profile, and would miss any fine deep scratches or cracks. However, the irregularities on most surfaces tend to be quite shallow, and the errors resulting from the rounding of the tip are small. In addition, these errors are masked by the differences in the magnification of the vertical and horizontal scales on a profile graph, and the loss of depth and rounding of the crests tend to offset each other in an average reading instrument. Reproduction of the surface using a rounded stylus does not, therefore, result in serious defects, and the radii chosen for the tip has been shown to be satisfactory for normal uses.

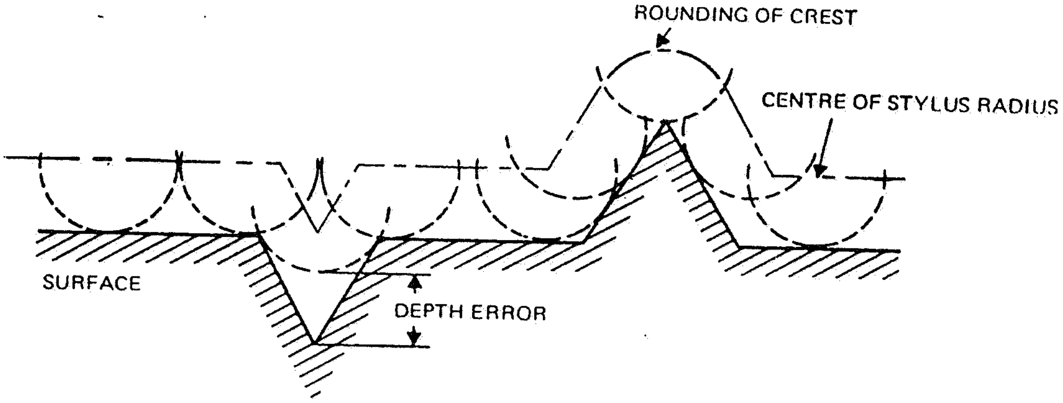


Figure 7 EFFECTS OF USING A ROUNDED STYLUS

5.1.2 The ideal datum for the stylus would be a mechanism which followed the nominal contour of the surface. A simpler method is normally used, however, and consists of a skid, with a large radius in the direction of traverse, which rests on the surface and follows its general contour. The stylus is connected to and follows the movement of the skid, and it is the vertical movement of the stylus about this datum which is measured and recorded by the instrument.

5.1.3 Figure 8 illustrates the errors which may be introduced by the skid on a surface with widely spaced ridges. The skid will rise over the ridges and fall in the valleys, and a large skid radius is required to minimize this effect. It is usually recommended that the radius of the skid should be at least 50 times the meter cut-off value (paragraph 5.2.1).

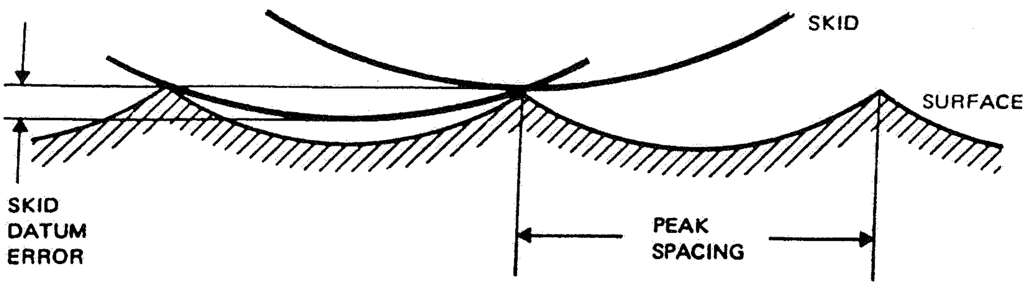


Figure 8 SKID ERROR

5.1.4 Further errors may be introduced by the position of the stylus relative to the skid. If the stylus is located behind the skid, and the spacing of ridges is, for example, twice the distance between the skid and the stylus, then the errors will be doubled. One method of minimizing errors of this type is to mount the stylus in a pick up with parallel skids (Figure 9). This method is often used, and the resulting errors in measuring closely spaced texture are usually ignored.

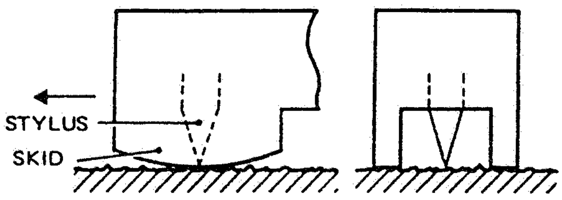


Figure 9 PICK-UP WITH PARALLEL SKIDS

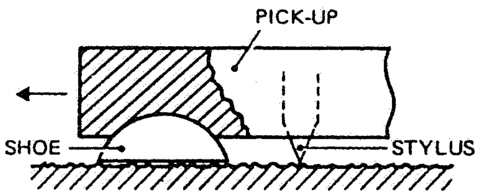


Figure 10 SWIVELLING SHOE

5.1.5 When the spacing of ridges on the surface is too wide for accurate measurement with a skid, a swivelling shoe may be used. This is illustrated in Figure 10, and consists of a shoe the contact face of which is shaped to the general contour of the surface, and is mounted in such a way that widely spaced ridges will swivel the shoe in its mounting, thus reducing their effect. This type of surface may also be measured using an independently mounted guide, which has the nominal shape of the surface, but no contact with it.

5.1.6 To ensure satisfactory contact with the surface but to prevent damage to it, BS 1134 prescribes a static measuring force on the stylus of up to 0·7 N for a stylus with a 2 μm radius, and up to 16 N for a stylus with a 10 μm radius. BS 1134 also prescribes that the surface roughness of the skid shall be not greater than 0·1 μm R_a, and that the force exerted by the skid on the surface shall be not greater than 0·5 N.

5.2 **Electrical Measuring Instruments.** Electrical measuring instruments are mainly of two types; those which are used in workshops and provide meter readings only, and those which are used for inspection purposes and generally provide both profile recordings and meter readings. In either type the pick-up is traversed across the surface of the test piece at a set speed, and any vertical movement of the stylus is transmitted through the instrument's circuits, to drive the recording pen or meter needle. Some meter instruments indicate R_a values only, but others are available which will indicate R_t, R_{tm}, R_p and the average wavelength of the irregularities of a surface.

5.2.1 **Meter Cut-off.** When a generator type pick-up is traversed across a surface, the spacing of any ridges on the surface will give rise to a definite current frequency; the frequency depending on the speed of traverse and the spacing of the ridges. By the use of frequency-dependent electronic filters, only those spacings which are less than the sampling length are passed to the meter, and those spacings greater than this are attenuated. The wavelength separating the transmitted from the attenuated components in the profile, is known as the meter cut-off. Most meter instruments are provided with controls for altering the meter cut-off, so that the instrument may be used over a range of sampling lengths. Since the frequency of the signals derived from the stylus depends on its speed of traverse, the pick-up of a meter instrument must be motor driven at a speed suitable for the pick-up, and the instrument circuits must be designed accordingly.

(a) Instruments providing profile graphs only, need not be motor driven, since a complete record of the actual surface is produced. Most instruments of this type also provide meter readings, however, so that the majority of profile measuring instruments have motor-driven pick-ups.

5.2.2 **Traversing Length.** The traversing length (or stroke) of the pick-up, is its linear movement during the measurement of a surface. BS 1134 provides a table of traversing lengths to be used, depending on the value of the meter cut-off, but it may often be necessary to vary this movement.

(a) Electrical integrating instruments indicate the average roughness over a number of sampling lengths, and the pick-up must traverse at least this distance for a reading to be given.

(b) Use of a long traversing length may reveal unexpected irregularities in the surface, which would not have been revealed by a short traversing length.

(c) Examination of a ground surface will reveal patterns which appear several times across the surface, and are of approximately the same width. The traversing length must be at least equal to, or preferably slightly greater than, the width of these patterns, in order to obtain a representative reading for the whole surface.

(d) The traversing length may be limited by the size of the surface to be checked, or the physical limitations of the measuring equipment.

(e) Use of a long traversing length may be unnecessary when measuring very fine surfaces.

6 CARE AND USE OF MEASURING INSTRUMENTS The instruments used for the measurement of surface texture are generally robust, and are designed to withstand normal workshop use. These instruments are, nevertheless, precision instruments, and care is essential in their handling to ensure that they retain their accuracy. An instrument should normally be checked daily on a roughness comparison specimen, to ensure that the readings are within the prescribed limitations, and regular servicing should be carried out. Checks on the accuracy of an instrument should be made at regular intervals, using a master roughness standard which has evidence of traceability to National Physical Laboratory Standards. Many texture measuring instruments have a number of switches or controls, which must be correctly set before a measurement is taken, and operators should be aware of the effects of incorrect selection on the readings obtained. The manufacturer's instructions regarding the setting-up of a particular instrument should be carefully followed, and with the more sophisticated instruments, special training may be required. The pick-up, and the surface which is to be measured, must be clean and free from swarf and other debris, and care must be taken to ensure that the pick-up will not be obstructed throughout its traversing distance. This is particularly important when the instrument is being used on production machines, for checking work during manufacture.

6.1 When a surface texture measurement is required on a surface, the appropriate meter cut-off should be used for all normal checking and inspection. To ensure that no significant irregularities are overlooked, and in instances when, for example, it is necessary to check the production process, a number of methods may be used to select the most appropriate meter cut-off, depending on the equipment available.

6.1.1 When initially selecting a meter cut-off for use during production or inspection of a component, the use of a profile recording machine can be very helpful. If a number of tracings of the surface are taken, without applying any cut-off value, the tracings can be examined and the spacing between irregularities can be noted. Estimation of the size of the spacings can then be made, and a meter cut-off value which will take account of these spacings can be applied.

6.1.2 If a profile recording machine is not available, the surface should be visually examined, and the spacing of any dominant patterns in the texture should be measured. Three or more measurements of the surface texture should then be made, using a meter cut-off slightly longer than the dominant pattern spacing, and the average R_a value should be noted. A further series of measurements should then be taken using a longer meter cut-off; any significant irregularities beyond the range of the first meter cut-off will be indicated by a large increase in the average R_a value. Provided that the two series of R_a values are similar, the original meter cut-off may be used.

6.1.3 In some cases the meter cut-off value may be applied according to the R_a value of the surface. Again three or more readings should be taken, and the average R_a value should be noted. If this value is less than 0·1 μm a cut-off of 0·25 mm may be used, if it is between 0·1 and 2·0 μm a cut-off of 0·8 mm should be used, and if it is over 2·0 μm, then a cut-off of 2·5 mm should be used.

6.1.4 In instances where it is only required to study the roughness of a surface, the meter cut-off should be reduced so as not to record any waviness which may be present.

6.2 When inspecting a surface for compliance with a prescribed standard, the surface should first be examined visually to ensure that the texture of the surface is uniform and free from blemishes, and a sampling area should be chosen which is truly representative of the surface as a whole. With large areas, a number of readings should be taken to confirm the consistency of the texture.

7 DRAWING NOTATION When the surface texture of a component has to be controlled, all the necessary factors must be stated on the appropriate drawing.

7.1 **Surface Texture Values.** The surface texture values required, are expressed in μm (or μin on older drawings), and are applicable to the material surface before any protective treatments are applied. These are normally R_a values, but in some cases other parameters may be specified (e.g. R_z or R_t). On some drawings the instructions relating to the surface texture are written on the face of the drawing, but on others the required roughness values are quoted over the machining symbol for each surface. The R_a values may be quoted as a single figure (e.g. 0·8 μm R_a), representing the maximum acceptable roughness of the surface, or they may be quoted in the form of two figures (e.g. $\frac{0{\cdot}4}{0{\cdot}8}$ μm R_a, or 0·4 — 0·8 μm R_a), representing the range within which the roughness of the surface must fall. When a non-standard meter cut-off is to be used, this is also quoted (e.g. 0·8 μm R_a (2·5)).

7.1.1 Table 1 lists preferred roughness values, and Table 2 shows the range of roughness values which may be expected to result from various production processes.

TABLE 1

PREFERRED ROUGHNESS VALUES

Roughness Grade No.		N12	N11	N10	N9	N8	N7	N6	N5	N4	N3	N2	N1
Nominal R_a values	(μm)	50	25	12·5	6·3	3·2	1·6	0·8	0·4	0·2	0·1	0·05	0·025
	(μin)	2000	1000	500	250	125	63	32	16	8	4	2	1

TABLE 2

ROUGHNESS (R_a) VALUES PRODUCED BY VARIOUS PROCESSES

Process	Roughness (μm)
Sawing	25 — 3·2
Planing, Shaping	25 — 0·8
Drilling, Chemical Milling	6·3 — 1·6
Milling	6·3 — 0·8
Broaching, Reaming	3·2 — 0·8
Boring, Turning	6·3 — 0·4
Grinding	1·6 — 0·1
Honing	0·8 — 0·1
Polishing, Lapping	0·4 — 0·05
Sand Casting	25 — 12·6
Forging	12·5— 3·2
Extruding, Cold Rolling	3·2 — 0·8

7.2 **Direction of Lay.** When it is necessary to specify the direction of lay, a symbol may be placed after the machining symbol on the drawing. The symbols shown in Table 3 are in accordance with BS 1134, and will generally be found on manufacturers' drawings. If these are insufficient to clarify the direction of lay, a note is usually added to the drawing.

TABLE 3

SYMBOLS FOR DIRECTION OF LAY

Symbol	Meaning
√=	Parallel to the plane of projection of the view to which it is applied.
√⊥	Perpendicular to the plane of projection of the view to which it is applied.
√X	Crossed in two slant directions relative to the plane of projection of the view to which it is applied.
√M	Multi-directional.
√C	Circular relative to the centre of the surface to which it is applied.
√R	Radial relative to the centre of the surface to which it is applied.

8 GLOSSARY The following terms relate to surface texture measurement, and are, for the most part, taken from BS 1134.

8.1 **Centre Line.** A line representing the form of the Geometric Profile and parallel to the general direction of the profile throughout the sampling length, such that the sums of the areas contained between it and those parts of the profile which lie on each side of it are equal.

8.2 **Effective Profile.** The contour that results from the intersection of the Effective Surface by a plane conventionally defined with respect to the Geometrical Surface.

8.3 **Effective Surface.** The close representation of a Real Surface obtained by instrumental means.

8.4 **Electrical Mean Line.** In an electrical meter instrument, a Reference Line established by the circuits determining the meter cut-off, which line divides equally those parts of the modified profile lying above and below it.

8.5 **Geometrical Profile.** The profile that results from the intersection of the Geometrical Surface, by a plane conventionally defined with respect to this surface.

8.6 **Geometrical Surface.** The surface defined by the design, neglecting errors of form and surface roughness.

8.7 **Horizontal Magnification.** In a profile recording instrument, the ratio of the movement of the recorder chart to that of the stylus along the surface.

8.8 **Irregularities.** The peaks and valleys of a Real Surface.

8.9 **Lay.** The direction of the predominant surface pattern, ordinarily determined by the production method used.

8.10 **Measuring Traversing Length.** The length of the modified profile used for measurement of surface Roughness parameters.

8.11 **Meter Cut-off** (B_{max}). In a Profile Meter Instrument, the conventionally defined wavelength separating the transmitted from the attenuated components of the Effective Profile.

8.12 **Profile Meter Instrument.** An instrument used for the measurement of Surface Texture parameters.

8.13 **Profile Recording Instrument.** An instrument recording the co-ordinates of the profile of the surface.

8.14 **R_a.** Arithmetical mean deviation of the profile above and below the Reference Line, through the prescribed Sampling Length.

8.15 **R_p.** The distance from the highest peak to the Reference Line, over the prescribed Sampling Length. The "smoothing depth".

8.16 **R_t.** The maximum Roughness (highest peak to deepest valley) over the prescribed Sampling Length.

8.17 **R_{tm}.** The mean value of R_t over a number of Sampling Lengths.

8.18 **R_z.** Ten-point height of irregularities. The average distance between the five highest peaks and the five deepest valleys, measured from a line parallel to the Reference Line but not crossing the profile.

8.19 **Real Surface.** The surface limiting the body, separating it from surrounding space.

8.20 **Real Profile.** The contour that results from the intersection of the Real Surface by a plane conventionally defined with respect to the Geometrical Surface.

8.21 **Reference Line.** The line chosen by convention to serve for the quantitative evaluation of the Roughness of the effective profile.

8.22 **Roughness.** The irregularities in the Surface Texture which are inherent in the production process, but excluding Waviness and error of form.

8.23 **Sampling Length.** The length of profile selected for the purpose of making an individual measurement of Surface Texture.

8.24 **Spacing.** The average distance between the dominant peaks on the Effective Profile.

8.25 **Static Measuring Force.** The force which the stylus exerts along its axis on the examined surface, disregarding the dynamic components arising from its movement over the surface.

8.26 **Surface Texture.** Those irregularities, with regular or irregular spacing, which tend to form a pattern on the surface.

8.27 **Vertical Magnification.** In a Profile Recording Instrument, the ratio of the movement of the indicating device of the recorder to the displacement of the stylus in a direction normal to the surface.

8.28 **Waviness.** The component of Surface Texture upon which Roughness is superimposed.

BL/3-4

Issue 1.
1*st November*, 1964.

BASIC

METROLOGY

MEASURING INSTRUMENTS BASED ON THE VERNIER PRINCIPLE

1 INTRODUCTION This leaflet gives guidance on the use and maintenance of measuring instruments based on the vernier principle. In general the use of these instruments presents no difficulty but a certain degree of skill and care is required if accurate results are to be assured; in common with most measuring instruments, care is also necessary in handling and use to avoid damage which could result in inaccuracies.

1.1 Precision vernier instruments manufactured in the United Kingdom are produced in accordance with the requirements of British Standard 887, entitled "Vernier Callipers", British Standard 1643, entitled "Vernier Height Gauges" and British Standard 1685, entitled "Bevel Protractors (Mechanical and Optical)". It should be borne in mind when using vernier instruments that the accuracy cannot be assumed to be greater than the maximum errors permitted by the above standards. For example, the maximum permissible errors for vernier callipers and height gauges reading up to twelve inches, from twelve to twenty-four inches and from twenty-four to forty-eight inches, are ±0·001 in., ±0·0015 in. and ±0·002 in. respectively. For bevel protractors, B.S. 1685 states "Protractors with vernier scales shall be graduated to read direct to five minutes of arc, and the error of indication in any position of the blade, including the acute angle attachment if fitted, shall not exceed plus or minus five minutes of arc".

1.2 In addition to the more usual vernier callipers, height gauges and bevel protractors, vernier callipers adapted for gear tooth measurement and depth measurement, and as standard reference verniers are also available.

NOTE: It should be appreciated that these measuring instruments should be used only when the work and the instrument temperatures are equal.

2 THE VERNIER SYSTEM A brief description of the vernier system as a means of defining linear dimensions is as follows.

2.1 Assuming two lines of equal length, each divided separately so that the total number of division in one is greater by one division than the number of divisions in the other, the displacement or reading is equal to the linear difference between any two divisions. For example, one of the most commonly used scales is where the main scale is divided into 20ths (0·050) of an inch and the vernier scale comprises 50 divisions over a distance of 2·45 in., each division equalling 0·049 in. Thus the difference between any division on the main scale and any division on the vernier scale is 0·001 in. This principle is illustrated in Figure 1.

2.2 One other widely used scale is where the main scale is divided into 40ths (0·025) of an inch and the vernier scale is divided into 25 equal divisions over a distance of 1·225 in., each division equalling 0·049 in. The same principle as described in the previous paragraph applies but, with this type, the vernier scale is read on alternative lines of the main scale, the two divisions together equalling 0·050 in.

2.3 There are two other types of scales in use but these have largely been superseded due to the necessity of having to use some form of magnification to obtain a true reading. In one, the main scale is divided into 40ths (0·025) of an inch and the vernier scale is divided into 25 divisions over a distance of 0·60 in., each division equalling 0·024 in. In the other the main scale is divided into 50ths (0·020) of an inch and the vernier scale has 20 divisions over a distance of 0·380 in., each division equalling 0·019 in.

2.4 In addition to the decimal inch scaled instruments described above, vernier instruments graduated to the metric system are obtainable. Some of these are composite types with inch and metric scales on opposite sides, whilst others read inches or metric dimensions only.

2.5 **Reading the Inch-Unit Vernier.** To read the measurement registered by this vernier, the number of inches and sub-divisions of an inch that the zero line of the vernier scale has moved over the main scale should be noted, and to this reading should be added the thousandths of an inch, which is indicated where a line of the vernier scale is coincident with a line on the main scale. For example, in Figure 1, the scale registers the following settings. Main scale: inches=5, tenths=1 and the 43rd line of the vernier scale is coincident with a line on the main scale. The reading thus obtained is 5·000+0·100+0·043=5·143 in.

2.5.1 **Reading the Metric-Unit Vernier.** This instrument reads in a similar manner to the inch-unit vernier, has main scale graduation of centimetres, millimetres and half millimetres. The vernier scale (equal to 24 half millimetres) is divided into 25 equal divisions, producing a difference between main scale and vernier scale graduations of $0{\cdot}5 \times \frac{1}{25} = \frac{1}{50}$ mm. (0·02 mm.).

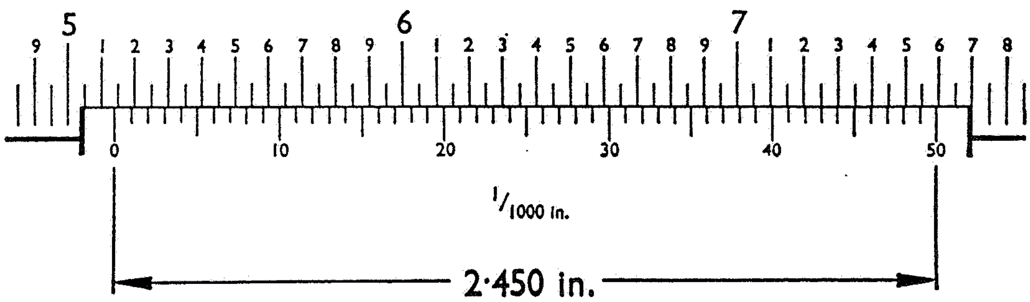


Figure 1 THE VERNIER SCALE

2.5.2 In some instances difficulty may be experienced in deciding which two lines are in fact coincident. In such cases a decision may be helped by the fact that the lines on either side of the most nearly coinciding lines appear to be equally stepped (see Figure 1). It should be borne in mind that it is a fundamental of the vernier system that not more than one line of the vernier scale can be truly coincident with a line on the main scale.

2.5.3 **Measuring Capacity.** The measuring capacity of a vernier instrument is its graduated length minus the length of the vernier scale. Thus an instrument having a scale such as that described in paragraph 2.1 may have, for example, a graduated scale of 14·450 in. minimum but would be supplied as having a measuring capacity of 12 in.

3 THE VERNIER CALLIPER GAUGE This instrument consists of a beam, on which is marked the main scale, and two jaws between which the item to be measured is placed. One jaw is integral with the beam whilst the other, upon which is mounted the vernier scale, slides along the beam (Figure 2). The measuring faces of the jaws are accurately machined to be straight and parallel.

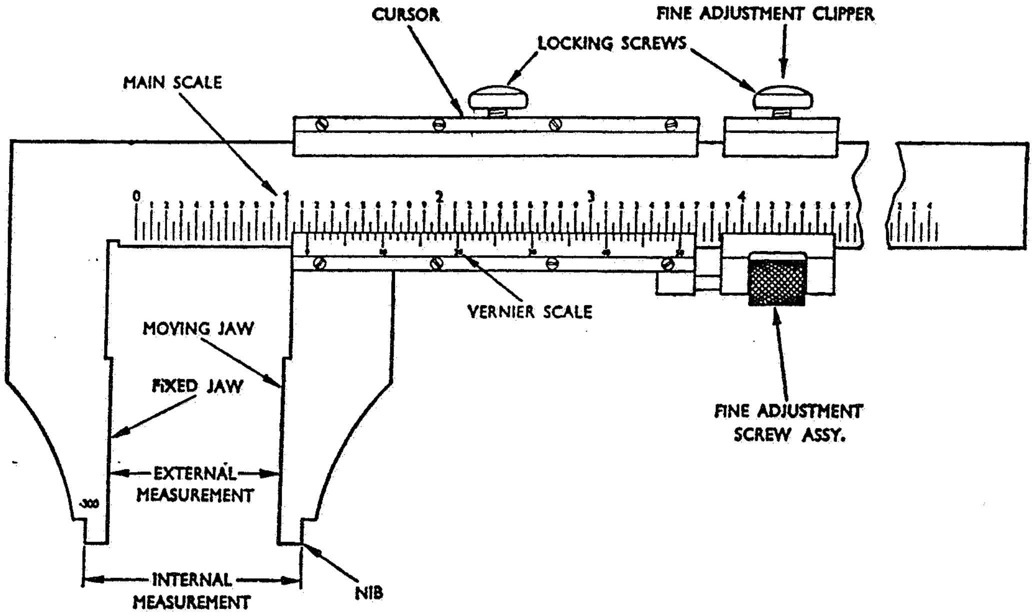


Figure 2 VERNIER CALLIPER

3.1 With precision calliper gauges the movable jaw is connected to a clamping device (termed the "fine adjustment clipper") by means of the fine adjustment screws assembly. The clipper can be locked on to the beam at any position by means of a locking screw, the accurate setting of the measurement being achieved by rotating the knurled wheel of the fine adjustment screw assembly in the required direction.

3.2 A vernier calliper is used where insufficient accuracy would be obtained with ordinary callipers. However, some degree of skill is necessary (unless the instrument is provided with a friction lock) to obtain the correct "feel", otherwise inaccurate readings will be obtained and, if overtightened, the instrument may be permanently damaged. Thus, the jaws should always be closed gently on to the workpiece, no attempt being made to alter the measurement by force.

3.3 When setting the callipers to a given measurement, the clipper should be securely locked at the approximate measurement and the final adjustment made by means of the fine adjustment screw. After setting the instrument, the jaw locking-screw should also be tightened before the calliper is used.

3.4 The parts to be measured should be perfectly clean, since foreign matter will not only affect the reading obtained but may damage the accurately finished faces of the jaws.

3.5 For the measurement of internal dimensions, some instruments are provided with a pair of "knife-edge" jaws mounted immediately above those used for external measurement. Other instruments have the outside lower portion of the external measuring jaws rounded (the "nibs" shown in Figure 2), the overall dimension of the nibs with the calliper closed usually being some convenient figure (e.g. 0·3 in.) which must be added to the indicated reading. The allowance to be made for the width of the nibs is usually indicated on the fixed jaw (see Figure 2). No attempt must be made to force a locked calliper between two surfaces, otherwise wear or out-of-parallelism may result

3.6 Some makes of callipers are marked with two spots, or "targets", one on the fixed jaw and one on the movable jaw, from which dividers or trammels may be set after the calliper has been set.

3.7 Before use (in particular, before using a particular instrument for the first time) the calliper should be checked by closing the jaws and holding the instrument up to the light, checking for full contact of the measuring surfaces. Without disturbing the jaws, the reading of the calliper should then be checked to ensure that the zero lines of the main scale and the vernier scale are coincident. Guidance on the general maintenance and checking of vernier instruments is given in paragraph 7.

4 VERNIER HEIGHT GAUGE In principle the vernier height gauge is an adaptation of the vernier calliper gauge but instead of the measurement being based on the distance between fixed and movable jaws, it is calculated on the distance between a movable jaw and the surface on which the instrument stands (usually a surface table). See Figure 3.

4.1 The instrument is provided with a relatively heavy base having a lapped underface; the upper surface of the movable jaw (termed the measuring jaw) is the surface from which measurements are taken and this surface is parallel with the underface of the base. The measuring jaw is provided with a detachable scriber to permit the accurate marking out of workpieces. The scriber itself is produced within fine tolerances, it being a requirement of B.S. 1643 that the measuring faces must be flat and parallel to within 0·0002 in.

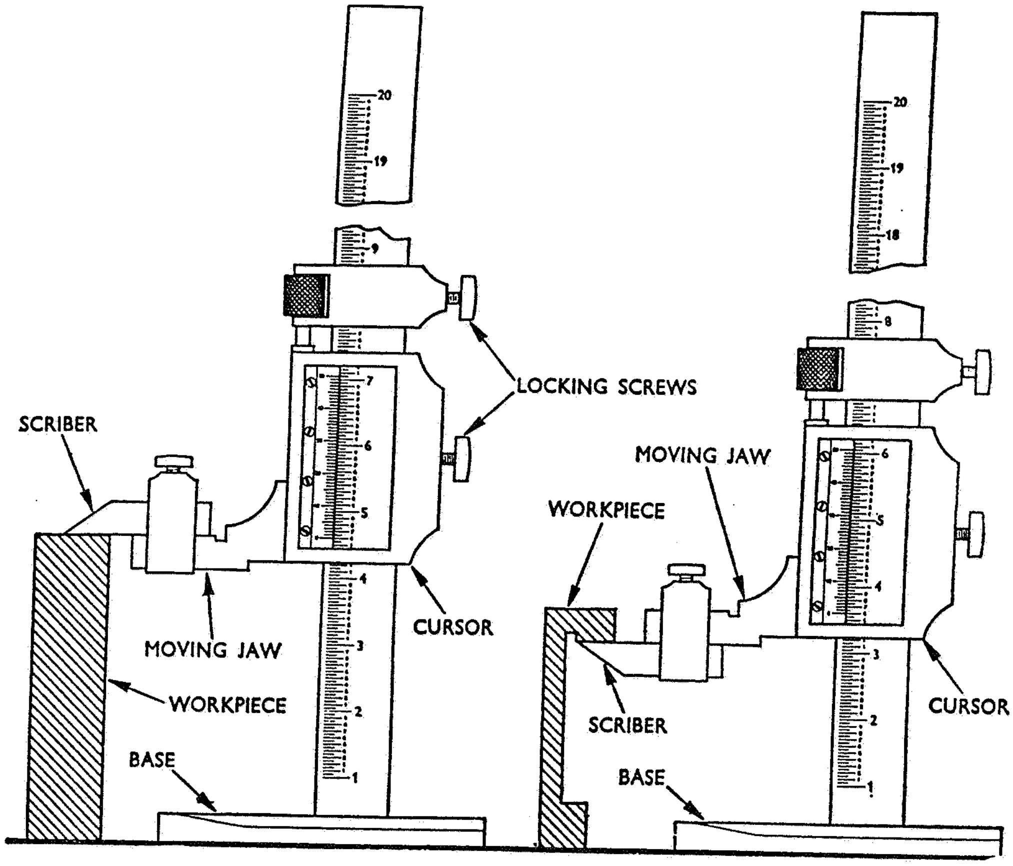
4.2 The main scale of the instrument does not commence at zero, since as the measurement is taken from a surface table, this surface is, in fact the zero (see Figure 3).

4.3 Since it is the top of the measuring jaw from which measurements are taken, it is necessary to fit the scriber for external measurements, but for internal measurements the scriber may be removed. However, in some instances the measuring jaw may not project sufficiently to permit an internal measurement to be taken, in which case the scriber may be fitted to the measuring jaw as shown in Figure 4. When so used the thickness of the measuring jaw (usually marked on it) must be subtracted from the indicated reading. If the scriber is fitted to the top of the measuring jaw for internal measurement (again in an upside down position), the thickness of the scriber (usually marked on it) must be added to the indicated reading.

4.4 When assessing external measurements it is advisable not to pre-set the height gauge, otherwise the scriber may ride over the workpiece, giving an incorrect reading. The scriber should be lowered gently on to the surface to be measured, care being taken to hold the base firmly on the surface table. and the setting locked. Conversely, when making internal measurements, the measuring jaw should be raised gently to the surface to be measured to avoid lifting the workpiece.

NOTE: It is particularly important to hold the base down firmly when using the fine adjustment screw.

4.5 When setting the instrument to an external flat surface the use of the lighting method described in paragraph 7.2 may be found useful in checking the final setting.



Figures 3 *and* 4 VERNIER HEIGHT GAUGE

4.6 It is essential that at all times the base of the instrument, the surface table, any ancillary measuring equipment used and the workpiece itself should be kept perfectly clean to ensure accuracy of measurement. If a height gauge is left on a surface table but is not in immediate use, steps should be taken to ensure that it is not knocked over and damaged.

5 BEVEL PROTRACTORS A typical bevel protractor consists of a solid base or "stock", one face of which is machined flat so that it can be laid accurately on a flat surface, e.g. a surface table. An adjustable straightedge attached to the instrument can be set to any angle relative to the base.

5.1 Angular movement of the straightedge rotates a disc on which is mounted a circular protractor scale (graduated in degrees) which, in conjunction with the vernier scale, permits the units (minutes) to be read in a similar manner to the vernier calliper. Thus, the number of whole degrees which have been passed by the vernier zero mark should be noted and then, continuing to read in the same direction (this is important as the scales are identical to the right and left of the zero lines), add the number of minutes indicated by the coincidence of a line on the vernier scale with a line on the main scale. In the example shown in Figure 5, the reading is 14° 20′.

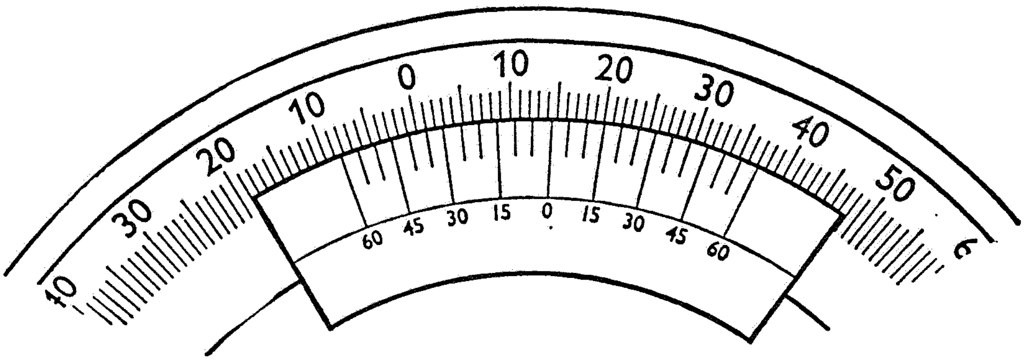


Figure 5 VERNIER PROTRACTOR SCALE

5.2 In the scale shown in Figure 5, a length of 23° of the main scale is divided into twelve equal parts to form the vernier scale. Thus one division of the vernier scale equals $\frac{23^\circ}{12}$, or 1° 55′, the difference between one division of the vernier scale and two divisions of the main scale being 5′. The instrument can, therefore, be read to an accuracy of 5′, but if greater accuracy is required, the angle should be measured by the sine bar method.

5.3 In order to facilitate the reading of the protractor, some manufacturers provide a magnifying glass or eyepiece which can be mounted on the instrument.

DEPTH GAUGES This instrument is again based on the vernier calliper principle, except that in this case the beam carrying the main scale passes at right-angles through a jaw on which is mounted the vernier scale. The jaw is placed over the depth to be measured (e.g. a blind hole) and the beam is lowered into the hole until contact is made with the bottom or some other predetermined point of contact, when the indicated measurement is read in the manner described for the vernier calliper.

7 MAINTENANCE OF VERNIER INSTRUMENTS At regular intervals (such periods being determined by the nature and conditions of the work involved) vernier instruments should be examined and check-calibrated in accordance with the manufacturers' instructions in a suitably equipped Standards Room. A record of all such checks should be kept. The general methods of maintenance and checks applicable are described in the following paragraphs.

7.1 **Indicated Dimensions.** The dimensions indicated by the instrument should be checked by means of slip gauges or precision blocks of known accuracy. On larger instruments, length bars should be used for the longer dimensions. Where a calliper is provided with knife-edge jaws for internal measurement, the indicated measurement should be checked against a micrometer of known accuracy.

7.2 **Straightness of Measuring Faces.** The straightness of measuring faces should be checked by placing a knife-edge straightedge on each jaw in turn, holding the instrument before a source of diffused light. If the lighting is satisfactory an error of as little as 0·0001 in. should be readily visible.

7.3 **Parallelism.** The parallelism of the measuring faces may be checked by placing a precision parallel roller between the jaws of the instrument and gently closing them until contact is made, the movable jaw then being locked. Any error of parallelism of 0·0001 in. or more can be detected against a suitable source of diffused light.

7.3.1 An alternative method, or a method to be used when the error in parallelism appears excessive, is to check the variation of size between the measuring faces by means of slip gauges.

7.3.2 It is recommended that, where an excessive error in parallelism is detected, the instrument should be returned to the manufacturer for rectification.

7.4 **Nib Dimension**

7.4.1 The jaws of the vernier calliper should be brought together and the nibs checked for general wear or flats by the use of a micrometer at two or three positions around the nibs.

NOTE: Flats are most likely to occur in a plane parallel to the beam.

7.4.2 The original dimension across the nibs is usually indicated on the fixed jaw; if any "truing-up" of the nibs is carried out which results in a change in this dimension, the new dimension (which has to be allowed for when making internal measurements) should be etched on the fixed jaw and the original dimension should be cancelled by an etch mark.

7.5 **Cleaning and Lubrication.** The instrument should be kept thoroughly clean and the moving parts lightly lubricated with acid-free machine oil.

7.5.1 Graduation and scale marks should be cleaned with a suitable solvent and a soft brush; a pointed instrument or wire brush must never be used. The instrument should never be polished, especially near graduation markings since, apart from the possible detriment arising from the abrasive action, bright reflections from the instrument may make reading difficult.

NOTE: Reflection has been eliminated on most modern vernier instruments by the application of a hard satin-chrome finish on the scales.

7.5.2 To ensure against jerkiness in the moving parts (which could seriously affect the "feel" of the instrument) those moving parts which the manufacturer stipulates may be removed periodically, dismantled, cleaned in a suitable solvent, dried, lubricated and reassembled. A check calibration should always be made after reassembly.

7.6 **Repair.** In general it is recommended that all repairs to vernier instruments should be undertaken by the instrument manufacturer. When instruments are returned after repair, it should be ensured that the new dimensions of the nibs and, in the case of height gauges, the measuring jaw (if altered), have been appropriately etched on the instrument.

7.7 **Storage.** When not in use, vernier instruments should be kept in their appropriate cases and it is recommended that they should be stored in a warm cupboard. However, it is essential that the instruments should not be subjected to excessive heat otherwise, due to expansion, accuracy may be affected. Instruments should never be stored in the fully closed or locked positions.

BL/3-5

Issue 1.

30*th April*, 1966.

BASIC METROLOGY

MEASURING INSTRUMENTS—MICROMETERS

1 INTRODUCTION This leaflet gives guidance on the construction, use and maintenance of the micrometer type of measuring instruments. In general, the use of these presents little difficulty, but a certain degree of skill and appreciation of their precision construction is required, if accurate measurement is to be attained. In common with all precision measuring instruments, considerable care is necessary in handling them to avoid unnecessary and costly depreciation.

1.1 Micrometer instruments manufactured in the United Kingdom should conform with the requirements of British Standard 870—"External Micrometers", British Standard 959—"Internal Micrometers (including stick micrometers)" and British Standard 1734—"Micrometer Heads". It should be appreciated that the degree of accuracy in using these instruments is governed by the permitted tolerances in the Standards. For example, the maximum permissible error ranges in the traverse of micrometer screws, is 0–0·0001 in. or 0·003 mm. for British and Metric reading micrometers measuring up to 12 inches or 300 mm., and 0–0·0002 in. or 0·005 mm. for instruments measuring 12 to 24 inches, or 300–600 mm.

1.2 In addition to the standard external and internal micrometers, there are other specially adapted instruments for various other tasks of measurement, and some of these are described in later paragraphs.

1.3 Information on measuring instruments of the vernier type is given in Leaflet BL/3-4.

2 THE STANDARD EXTERNAL MICROMETER

2.1 Figure 1 illustrates the typical standard type of micrometer for the measurement of external dimensions. The main components of the instrument are the frame, anvil, barrel, sleeve (or thimble) and the spindle. The jaws of the frame are suitably machined to receive the anvil (which is usually a press fit), and the barrel, which is frequently fitted into the frame with a fit which permits rotational adjustment by spanner or special key (see paragraph 8.2). The barrel is engraved with a graduated scale equal in length to the measuring range of the instrument (usually 1 in. or 25 mm.), and is bored and internally screwed with a fine and accurate right-hand thread. This thread accommodates the spindle which is machined with a matching male thread. An integral sleeve on the spindle surrounds the barrel when the spindle is inserted and screwed into the assembly, and this is usually knurled at the outer end to facilitate easy finger operation. The inner end of the sleeve is bevelled to prevent barrel scale shadows, and the bevelled portion is graduated into equal divisions around its periphery.

2.2 Some micrometers may have a fixed barrel and a removable or adjustable anvil which might be located by a grub screw or a pin. Others may be equipped with a spindle locking device (as illustrated) which, when used, ensures that the instrument remains set at any specific dimension or reading. The spindle attachment containing a spring loaded ratchet (also illustrated) is a common fitment, and this produces preset "feel" to the operation of the instrument. Many micrometers are provided with tungsten or carbide tipped anvils and spindles to reduce wear on the measuring faces.

NOTE: British Standard 870 prescribes that when a friction or ratchet attachment is fitted to the spindle, the force it exerts between the measuring faces shall be between 1½ to 2½ lb.

2.3 The details of micrometers for the measurement of British dimensions are given in paragraph 4.1, whilst those for measurement of Metric dimensions are covered in paragraph 4.2.

NOTE: Some instruments not to British Standard, although quite accurate, may not be provided with the general means of adjustment. Due allowance for "zero" error (see paragraph 8.2) must therefore be made, and the error must be added to all measurements made.

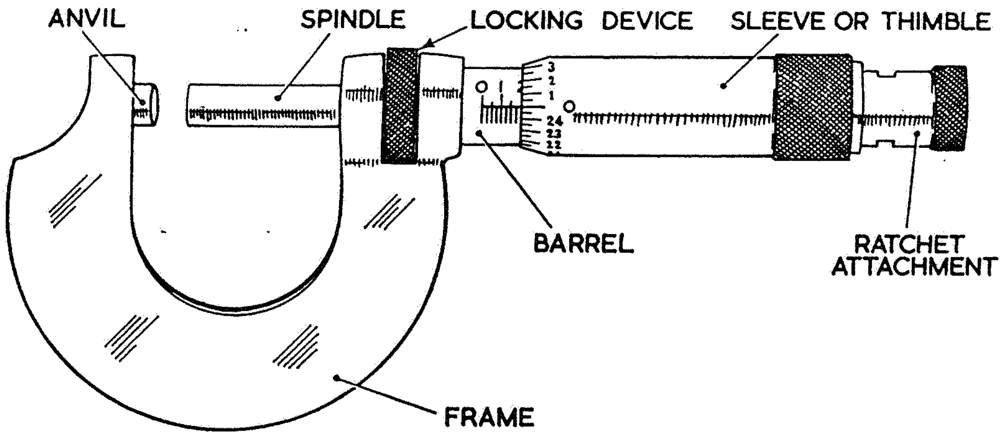


Figure 1. TYPICAL STANDARD EXTERNAL MICROMETER

NOTE: The British Standard prescribes that micrometer frames up to 4 in. shall be of a suitable quality of steel, those above 4 in. and up to 12 in. may be of a suitable quality of steel or malleable cast iron, and those above 12 in. may be of suitable steel, malleable cast iron or light alloy. The Standard recommends that suitable heat-insulating grips should be attached to the frame in convenient positions, and that frames should be heat-treated to avoid secular changes that might take place in the material.

3 THE INTERNAL MICROMETER

3.1 Internal micrometers are designed for internal measurement only. There are two common categories; the end-measuring or "stick" type and the "three-point" measuring type. Both of these measure internal dimensions with the same systems of graduation as the standard micrometer (paragraph 4.1 and 4.2).

3.2 **End-measuring or "Stick" Micrometers.** These instruments are usually available in combination-set form, and consist of a measuring head (similar to the standard type barrel and sleeve), and sets of extension rods which fit into the barrel to give various stages of measurement over the total range. Common sets are provided with three, five or nine extension rods, and in most of these it is usual for an auxiliary handle to be included, which can be screwed into the side of the barrel to enable check measurements to be made at the extreme ends of deep bores, etc.

NOTE: One manufacturing range consists of combination sets for measurements of 1-2 inches, 1-3 2-6, 2-8, 2-12. 8-32, 12-36, 12-48, 32-52, 36-60, and 52-72 inches.

3:3 An anvil is located in the head of the sleeve and in the outer end of each extension rod, and these are usually adjustable for wear on the anvil faces. (See paragraph 8.2.)

3.4 **Three-point Micrometers.** This type of internal micrometer incorporates three measuring anvils which are co-axially mounted in a measuring head at 120° to each other. The feature of three-point contact ensures greater accuracy in the measurement of internal dimensions. Generally, the larger type of micrometer head (paragraph 6) with 250 divisions, is embodied to enable the finer measurements to one ten-thousandth (0·0001) of an inch to be made, with the more convenient and simplest method of reading. The sleeve and spindle operation is similar to that of standard types, but the longitudinal spindle movement is transferred to axial anvil movement and, in operation, the barrel axis of the instrument will coincide with that of the hole or bore being measured.

NOTE: Some of these instruments may be provided with 50-division sleeves and barrels having a vernier scale (paragraph 4.3), whilst others may have 100-division sleeve scales only, with a measurement accuracy of two ten-thousands (0·0002) of an inch.

3.5 The anvils (Figure 2) are housed in a three-legged measuring head, with a central attachment lug on one side and a detachable screwed cap on the other, and the lug is internally threaded for attachment to the screwed barrel. The spindle incorporates a threaded propelling flange and conical measuring thread at the anvil end, and is threaded and locked into the head of the sleeve at the outer end. A spindle bearing is provided in the barrel at the sleeve end, and a ratchet attachment is embodied in the outer end of the sleeve. The inner ends of the anvils are angled and screw-cut to suit the conical measuring thread, and coil springs, fitted inside the cap, ensure constant contact between these components. Spindle movement is arranged through the engagement of the propelling flange with the internal threads of the measuring head lug.

NOTE: For better results in the measurement of ovality, some micrometers of this type have anvils set at unequal angles, and the manufacturer often defines the best operation method together with relevant formulae and calculations.

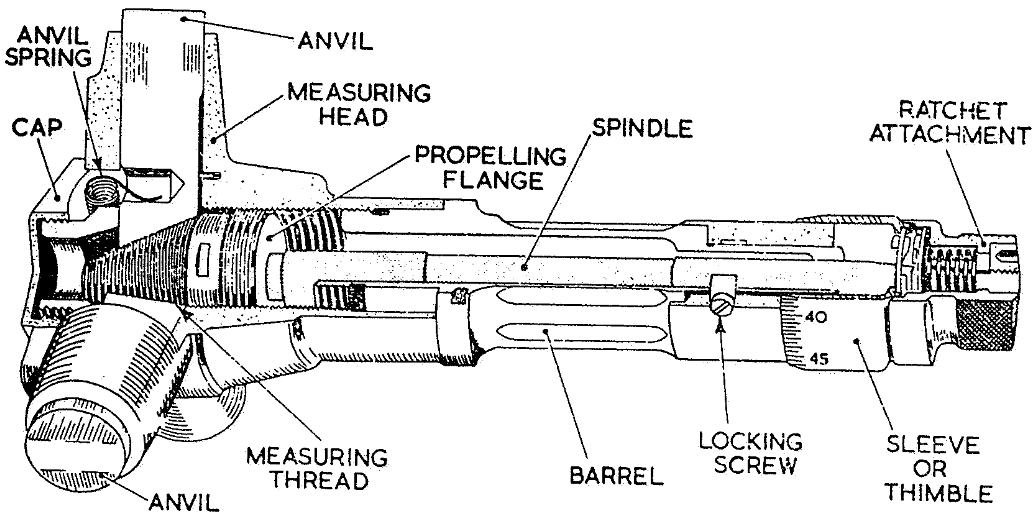


Figure 2. TYPICAL THREE-POINT INTERNAL MICROMETER

4 MICROMETER SYSTEMS

4.1 **The British System.** In the British micrometer, the spindle and barrel threads have a pitch of 0·025 in (40 T.P.I.). Thus, one complete turn of the spindle and sleeve will increase or decrease the distance between the anvil and spindle by 0·025 in. ($\frac{1}{40}$ in.), with left- and right-hand turning respectively. The barrel (or main) scale is graduated into tenths (0·10) and fortieths (0·025) of an inch, whilst the sleeve (or thimble) scale consists of 25 equal divisions. If the spindle is advanced or withdrawn by rotary movement equal to one sleeve graduation, then the distance between the measuring faces is decreased or increased by one thousandth (0·001) of an inch.

4.1.1 The micrometer measurement reading is equivalent to the total number of thousandths of an inch, indicated by that sleeve scale graduation which is coincident with the barrel scale line. (Datum or fiducial line).

4.1.2 To read the dimension recorded, the visible barrel scale graduation in tenths and fortieths are noted, and to this figure is added the number of thousandths shown on the sleeve scale at the intersection with the barrel scale line. Taking Figure 3 as an example, the barrel scale shows two tenths and three fortieths (0·200 + 0·075), and the sleeve scale shows the three thousandths line agreeing with the barrel scale line. Thus, 0·200 + 0·75 + 0·003 = 0·278 in., which is equivalent to the distance between the anvil and spindle end faces.

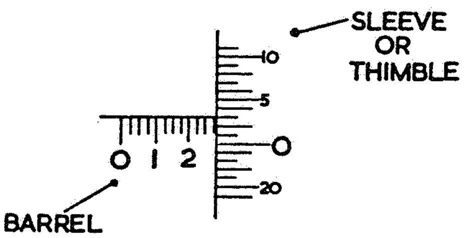


Figure 3. TYPICAL BRITISH MICROMETER READING

4.1.3 When a sleeve scale graduation is not exactly coincident, the relevant thousandth (0·001) graduation to be read is that immediately below the datum line. When a finer measurement is required, an estimation of a half (0·0005) or a quarter-thousandth (0·00025) of an inch can be made for the additional part-graduation visible below the datum line, and this can be added to the dimensional figure.

4.2 **The Metric System.** In the Metric micrometer, the spindle and barrel threads have a pitch of 0·5 mm. Thus, one complete turn of the spindle and sleeve will increase or decrease the distance between the anvil and the spindle by this amount. The barrel scale (Figure 4) is graduated into twenty-five divisions of 1 mm., and usually every fifth division is numbered in multiples of five. The millimetre divisions are sub-divided into half-millimetres (0·5 mm.), and the sleeve is graduated into fifty equal divisions. Thus, the movement of the sleeve, equal to one sleeve division, equals $\frac{0{\cdot}5}{50}$ or 0·01 mm.

4.2.1 To read the micrometer, the highest figure on the barrel scale is noted together with any additional visible half-millimetre division. To this is added the number of hundredths of a millimetre which are indicated by the coincident sleeve and datum lines. Thus, the reading of the metric micrometer scales, depicted in Figure 4, equals 5·00 mm. + 0·50 mm. + 0.14 mm., which equals 5.64 mm.

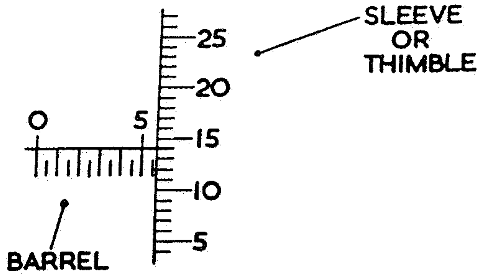


Figure 4. TYPICAL METRIC MICROMETER READING

4.3 **Vernier Scale Micrometers.** Micrometers with an additional scale based on the vernier principle are in common use, and these have a greater degree of measurement accuracy of one ten-thousandth (0·0001) part of an inch. Estimations (paragraph 4.1.3) are unnecessary; the standard thousandth reading is noted as in paragraph 4.1.2, and to this is added the coincident vernier scale reading in ten-thousandths (0·0001) of an inch (Figure 5).

4.3.1 Generally, vernier scale micrometer sleeves are graduated into 25 divisions and 25 half divisions. A convenient vernier scale length equal to 9 half-divisions of the sleeve scale is divided equally into 5 vernier scale divisions, and these are engraved on the barrel above and parallel to, and to the full extent of the datum line.

4.3.2 Thus, the vernier scale length is equal to 9 half-divisions on the sleeve (0·0045 in.). It follows that the difference in width between each sleeve division (two half-divisions) and each barrel division is one fith of a sleeve division. As each sleeve division is representative of 0·005 in., the difference is therefore 0·0001 in.

4.3.3 When a sleeve graduation line does not coincide with the datum line, it is necessary to note the vernier scale division which does coincide, and to add this number of ten-thousandths (0·0001) of an inch to the standard thousandths reading. In Figure 5, for example, the barrel scale shows four tenths and two forthieths (0·4000 + 0·0500), and the sleeve division below the datum line is 0·0190. There is a further half-division on the sleeve below the datum line (0·0005), and the coinciding vernier line is the fourth (0·0004). The micrometer reading is therefore 0·4000 + 0·0500 + 0·0190 + 0·0005 + 0·0004, which equals 0·4699 inches.

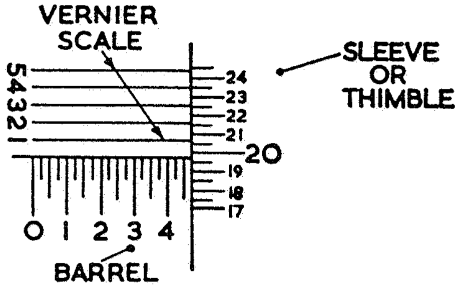


Figure 5. TYPICAL MICROMETER VERNIER SCALE

4.4 **Oblique Graduations.** Some micrometers may be manufactured with barrel scale graduations which are oblique to the datum line. These may be additional, in which case the normal parallel and the oblique graduations are engraved above and below the datum line, respectively. Oblique graduations prevent miscalculations in reading the instrument, for the following barrel scale graduation line is always visible, at least in part, in any position of the sleeve.

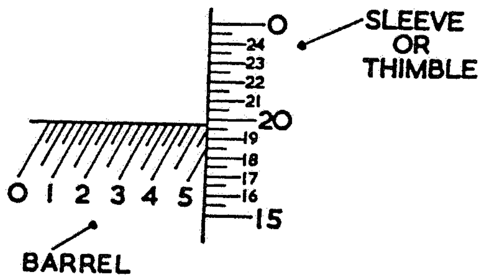


Figure 6. OBLIQUE GRADUATIONS

5 TYPES OF MICROMETER

5.1 Other than the standard type of micrometer (Figure 1) for measurement of external dimensions in British or Metric measurements, there are several other types of a special category for various manufacturing processes, curved profiles and for the measurement of soft materials, etc. Some of the more common of these and their particular applications are described in the following paragraphs.

5.2 **Variable-range Micrometers.** These instruments are made with large frames, and a set of detachable anvils is provided to cover each stage of measurement throughout the total range. Ranges are various, but common examples are 0–6 inches, 0–12 inches, 12–42 inches, 0–50 mm., 200–300 mm., and 900–1050 mm. Stages of measurement are generally of one inch or 25 mm. It will be appreciated that the shortest anvil will be fitted for the longest measurements and the longest anvil for the shortest. Various methods of anvil location are employed, but most anvils are provided with a flange or shoulder which abuts the frame face, and this ensures that the basic anvil setting is correct when the anvil is fitted.

5.3 **Recess Micrometers.** This type is similar to the standard instrument except that it is provided with a long anvil to facilitate the measurement of recessed dimensions. The anvil and spindle diameters are frequently of much smaller diameter, for use in connection with fine bores and drillings.

5.4 **Deep-frame Micrometers.** These micrometers are provided with deep "horseshoe" type frames, which enable measurements to be made of dimensions at some distance from the edges of larger components, sheets and plates, etc.

NOTE: In using this type, extreme care is required to avoid any distortion of the frame.

5.5 **Ball-end Micrometers.** In these instruments, the spindle or the anvil or both, are provided with rounded ends which permit the measurement of curved surfaces; they are particularly applicable to the "viewing" of ball bearing races. It is important to bear in mind, however, that the curved surface being measured must be of greater radius than the anvil/spindle ends, otherwise inaccurate measurements will be made.

5.6 **Hub Micrometers.** This type of micrometer has a very shallow frame, which enables it to be used inside bores, recesses, etc., having internal dimensions as small as 1 inch or less.

5.7 **Disc Micrometers.** The standard type of micrometer is not suited to the measurement of soft materials, since the spindle and anvil would tend to compress them, even during applications when the spindle ratchet attachment is used (Figure 1). This type, which is otherwise similar to the standard, is provided with anvils and spindles machined with integral face discs of various range diameters, e.g. $\frac{3}{8}$ in., $\frac{1}{2}$ in., $\frac{3}{4}$ in., etc.

5.8 **Depth Micrometers.** These instruments (Figure 7) have a similar application to the vernier depth gauge (Leaflet **BL/3-4**). They consist of the standard type barrel, sleeve and spindle, and the barrel is attached to, or is integral with, a base plate having hardened contact faces, which are ground and lapped square to the spindle axis. Some of these instruments are available in combination sets with detachable spindles, to cover various ranges of measurement and to widen the application, and others may be provided with detachable base plates of various dimensions and shapes.

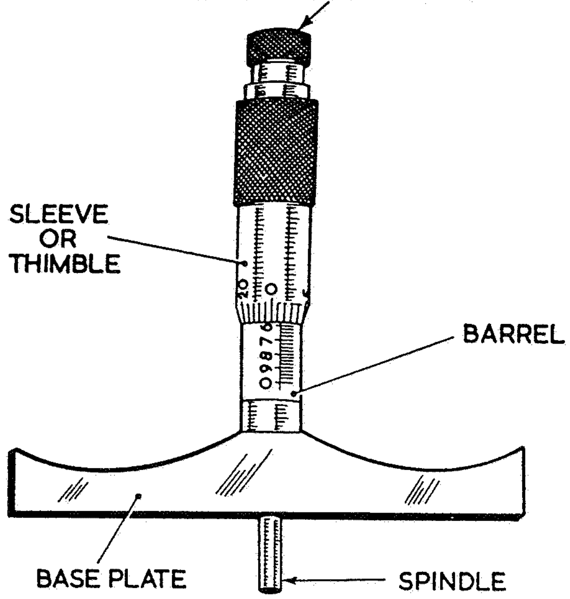


Figure 7. TYPICAL DEPTH MICROMETER

5.9 **Tube Micrometers.** These micrometers are similar to the standard type except for the frame and the anvil. The frame is usually of single jaw semi-"horseshoe" shape, and the anvil is a vertical shouldered and ground spindle-post, fitting into the frame at 90° to the spindle axis. Generally, these instruments are supplied with several anvils which differ in the diameter of the measuring tip, and this feature gives the instrument a wider range of tube thickness measurement.

5.10 **Calliper Micrometers.** This type of micrometer (Figure 8) is particularly suited to the measurement of small internal diameters. It consists of the standard barrel and spindle assembly, with an off-set pair of jaws located by a bracket attached to the inner end of the barrel. The stationary jaw is located on the outer end of a ground spindle, and this is recessed into the barrel bracket at its inner end. The moving jaw slides on the outer jaw spindle with a precision fit, and a split lug on the jaw clamps a split bush bearing in a recess machined in the end of the micrometer spindle. Some of these instruments are available with sets of removable jaws with differing nib widths, which stage and widen the measuring range of the calliper instrument.

NOTE: It should be borne in mind when taking internal measurements, that with instruments which give a zero reading with the jaws closed, the dimension over the nibs must be added to the micrometer readings.

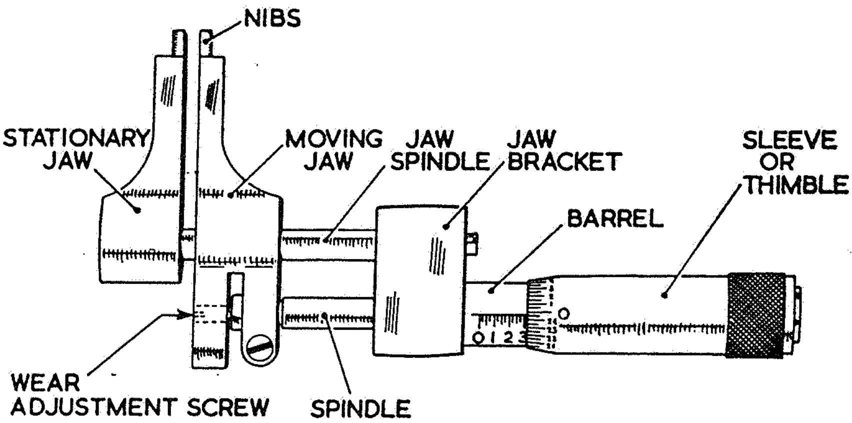


Figure 8. TYPICAL CALLIPER MICROMETER

5.11 **Vee-block Micrometers.** Drills, taps, reamers and certain cylindrical lapping tools, are manufactured with three, five or seven flutes, and these micrometers are necessary for the accurate measurement of the cutting or lapping dimensions of these tools. The micrometers are similar to the standard type, except that the anvil is integral with the frame, and, adjacent to the spindle, the anvil is vee-shaped to the appropriate angle to facilitate measurement of three, five or seven-fluted tools.

5.12 **Screw-thread Micrometers.** These instruments are similar to the standard type except that the spindle and anvil are provided with double and single points respectively (of the appropriate angle), for the measurement of thread dimensions of precision screw threads.

6 MICROMETER HEADS

6.1 As the term implies, these measuring devices are, in effect, the barrel, thimble and spindle of the orthodox micrometer. They are designed primarily for assembly into suitable bench brackets, and sets of matching extension pieces are supplied which fit over or into the micrometer head spindle to give various stages of measurement over the range. When mounted, the head with the appropriate extension piece is particularly suitable for tool-setting, checks for adjustable gauges and quick checkings of fixed points of measurement.

6.1.1 Some heads may be engraved with vernier scales (paragraph 4.3) for measurements to ten-thousandths (0·0001) of an inch. Others may be provided with large diameter thimbles, which are graduated into 250 divisions for direct scale readings, giving the same fine degree of measurement, or, with an additional vernier scale, a measuring accuracy of one hundred-thousandth (0·00001) of an inch.

6.1.2 To minimise wear at the measuring faces, some types of micrometer head are designed and manufactured with non-rotating spindles.

7 USING THE MICROMETER Apart from the correctness of the zero-reading of the instrument (paragraph 8.2), accuracy depends on the cleanliness of the measuring faces and the components undergoing measurement. Temperatures of instrument and component, and the correct method of manipulation, are also extremely important factors for consideration.

7.1 **Temperature conditions.** These have a significant effect on measurement results. Ideally, for very accurate work with small tolerances, the instrument and component temperatures should be equal (the Standard reference temperature is 68°F or 20°C); where this is not possible, then due allowances relevant to the co-efficients of expansion of the material being measured should be made.

7.1.1 Under certain conditions, an insulating lacquer might be applied to the instrument to reduce the temperature from hand operation, and precautions might be taken to avoid the handling of components with bare hands. (Some micrometers may be provided with a plastic covering in the appropriate places, to reduce the hand temperature effects.) Fine measurements should not be made during fluctuations in ambient temperature, in direct sunlight, or in the proximity of sources of heat.

7.1.2 When components are cleaned and afterwards dried with compressed air, chilling may result and cause temporary shrinkage. Therefore, sufficient time should be allowed to elapse, to enable components to regain ambient temperature.

7.1.3 Sometimes the micrometer is mounted in a suitable stand to reduce the amount of handling, and operators often wear gloves to minimise the handling of components undergoing measurement checks.

7.2 **Handling the Micrometer.** Ratchet attachments (when embodied) should always be used to ensure constant and co-related measurements. The sleeve should be turned gently at a constant rate towards the faces being measured; varying speeds of rotation will produce inaccurate readings. The average smaller size of micrometer will rest comfortably in one hand, the thimble or ratchet attachment can be manipulated by the thumb and forefinger, and the little finger can be extended to support the frame near to the anvil.

7.3 The instrument should not be set and forced over a measurement dimension; such a practice will strain the micrometer screw and wear the measuring faces. For similar reasons, the micrometer should never be drawn along parallel faces, particularly if these are rough or dirty.

8 MICROMETER MAINTENANCE Good maintenance of micrometers is attained by the appreciation that the instrument is a precision one, that correct handling is essential (paragraph 7), and that periodic dismantling, cleaning, adjustment and testing (paragraph 9), related to the conditions and extent of operational use, is carried out systematically. Micrometers should never be left lying on dusty benches, etc., but should be wiped clean after use, and replaced in the instrument case provided.

NOTE: Some manufacturers commendably number and colour-mark their instruments for identification, periods of issue and maintenance. Records of checks and maintenance are maintained in the Standards room of the Inspection Organisation. Classification is carried out for condition, and micrometers are allotted to various grades of work, e.g. rough turning, grinding, view room, etc. In some cases, dust-proof cupboards are provided for storage in the various workshops, and these are sometimes maintained at standard atmospheric temperature.

8.1 **Dismantling and Cleaning.** This should be done at regular intervals. No definite time cycle can be recommended, inasmuch that the frequency will vary with the extent of use, and the nature and conditions of operation. Component parts should be systematically laid out on clean surfaces (preferably under "view-room" conditions), washed in clean non-leaded petrol or naphtha, and then allowed to drain and dry. On assembly, the micrometer screw is to be lubricated with a light oil of instrument category, and all other surfaces should also be lightly smeared with oil.

8.2 **Micrometer Adjustments.** Adjustments consist of the setting of the "zero" reading of the instrument and, in instruments conforming to the Standards, the elimination of slackness in the micrometer screw.

8.2.1 **Setting the "Zero" Reading.** To facilitate accurate measurement, the "zero" reading should be checked and corrected before the instrument is used. In 0–1 inch instruments for external dimensions, the anvil and spindle faces are brought together, whilst in others for longer ranges, the measuring faces are closed upon round or cylindrical test pieces supplied with the instrument. When embodied, the ratchet attachment should always be used to ensure the correct "feel" in the setting.

8.2.2 With the instruments set in this manner, the barrel scale datum or fiducial line should be brought coincident with the zero division on the sleeve. Generally, micrometer barrels are movable within the frame by means of a special "C" spanner provided. Other types may be designed with adjustable anvils which either screw into the outer jaw of the frame, or the frame jaw is split and the anvil is locked in the correct position by a grub screw.

8.2.3 End measuring or "stick" micrometers (see paragraph 3.2) are usually equipped with adjustable anvils in the head of the sleeve, and at the outer end of each extension rod. Adjustments for these instruments are normally made (for the basic sleeve/anvil setting and each extension rod anvil setting) in the Standards room, against the measurement settings of a Micrometer Head (see paragraph 6).

8.2.4 Three-point internal micrometers are adjusted and corrected in the conventional way, except that setting rings are required. The anvils are inserted into the bore of the ring and are then set to the ring internal dimension by means of the ratchet attachment. A screw which locks the barrel-scale sleeve to the barrel is slackened, the sleeve is turned until the micrometer reading equals the bore dimensions, and the screw is then retightened. (See Figure 2.)

8.2.5 Depth micrometers are checked and set against the face of a surface table or plate, With the base plate and spindle faces in contact with the surface table, the micrometer reading should be "zero". Some of these instruments will be equipped with an adjustable barrel but others may be provided with adjustable spindles.

8.2.6 Calliper micrometers are usually adjustable at the end of the spindle where the jaw is split and fitted with clamping and adjusting screws. The clamping screw is slackened, the instrument jaws are closed, the adjusting screw is set to obtain "zero" reading, and the clamping screw is then relocked.

8.2.7 Vee-block and screw-thread instruments are provided with the appropriate setting gauges to suit the profiles of the measuring faces. With these in position between the anvil and spindle, orthodox adjustments will be made.

8.2.8 **Adjustment of the Micrometer Screw.** Micrometers manufactured to conform with British Standards are provided with adjustment for micrometer screw wear (Figure 9). The outer end of the barrel (inside the sleeve) is reduced in diameter and screw-cut with a very fine tapered thread. This extension is split in one, two or several equidistant positions, and a special internally-tapered ring nut is fitted. When the nut is turned clockwise with the spanner provided, it reduces the barrel screw diameter to suit the worn threaded diameter of the spindle screw. It should be borne in mind, however, that when this adjustment is made, the "feel" of the micrometer screw should be equal throughout the entire traverse of the spindle.

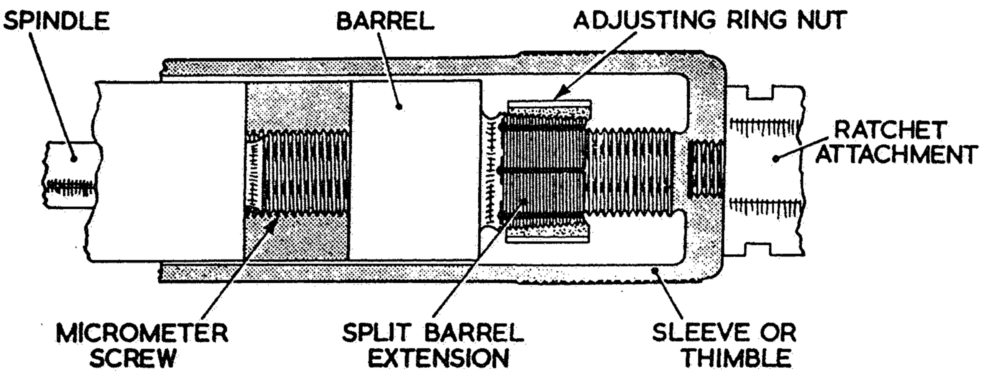


Figure 9. MICROMETER SCREW ADJUSTMENT

9 MICROMETER TESTING

9.1 **General Testing.** It will be appreciated that micrometers which have been adjusted (paragraph 8) and checked for measuring face flatness by slip gauge readings in various face positions, and for parallelism by concentricity checks between the anvil and the spindle, will be sufficiently accurate for most measurements and tolerances in the assembly and construction of aircraft.

9.2 **Finer Testing.** Micrometers which are to be used for small-tolerance, "Standard-room" or "View-room" work should be tested to a finer degree of accuracy. The following tests for flatness, parallelism and screw calibration are recommendations from British Standard 870.

9.2.1 **Flatness.** This is best tested by means of an optical flat brought into contact with each face in turn. Imperfections will be shown by a number of coloured interference bands on the surfaces, and the number and shape of these will indicate the degree of flatness present. The specified tolerance for flatness is 0.00005 in. and this is represented by a maximum number of five bands of similar colour on either of the faces.

NOTE: The bands are more distinct if the test is made in the light from a mercury vapour lamp, particularly if viewed through a green filter.

9.2.2 **Parallelism.** For 0–1 in. micrometers, this test may be made by utilising the same principle of optical interference. A number of optical flats of different thicknesses are used, the opposite faces being parallel as well as flat. These are positioned in turn between the measuring faces as if they were being measured and the number of interference bands on each face is noted. By careful manipulation between the measuring faces, the number of bands on one face is reduced to a minimum, and those on the opposite face are then counted. If this total number of bands of similar colour does not exceed ten, then the requirements of the Standard are satisfied.

9.2.3 In testing with optical flats of different thickness, the parallelism of the faces is checked in various angular positions. Generally, four flats are used with successive thickness variation of a quarter of 0·025 in., and the tests are made at four positions during a complete turn of the micrometer spindle.

9.2.4 Larger micrometers up to 4 in. may be tested by the same method. Two of the optical flats are wrung to the ends of a combination of slip gauges, and this combination is used as a parallel-ended test piece between the faces. The four-position check is made with changes in the length of gauge combination by 0·006 in. or 0·007 in. in succession.

9.2.5 For larger micrometers the optical test is too sensitive in relation to tolerances. It is usual for test pieces to be made up in suitable lengths for each size of instrument. Steel balls of ⅛ in. or $\frac{3}{16}$ in. dia. are often soldered to the ends of a ¼ in. dia. steel rod, and the test pieces are inserted between the measuring faces in various positions around their periphery. Variations in these measurements should not exceed the tolerance prescribed.

NOTE: Adjustable test pieces of this kind are often used to cover several sizes of micrometer.

9.2.6 **Calibration of the Micrometer Screw.** Reading accuracy of 0–1 in. or 0–25 mm micrometers is usually checked by various readings on a series of slip gauges. These are chosen to test the micrometer, not only at complete spindle turns but also at intermediate positions, to cover inaccuracies in thimble graduations. The following series of gauges are suitable for progressive and periodic errors in the micrometer ranges.

0–1 in. Micrometer: 0·105, 0·210, 0·315, 0·420, 0·500, 0·605, 0·710, 0·815, 0·920 and 1·000 in.

0–25 mm. Micrometer: 2·5, 5·1, 7·7, 10·3, 12·9, 15·0, 17·6, 20·2, 22·8 and 25·0 mm.

These series give readings around the thimble twice over, and so provide a double check on any periodic error which might exist.

NOTE: For very accurate readings during such calibrations, the thimble may be viewed under a microscope of low magnification.

9.2.7 In larger micrometers, the errors in traverse can be checked, using slip gauges as in paragraph 9.2.6, by carefully clamping the instrument to a surface table or plate and fixing a temporary anvil with rounded face close to the face of the spindle. Alternatively, an indicator with sensitivity of at least 0·00005 in. can be used as a temporary anvil.

BL/4-1

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BASIC

MATERIALS

CORROSION—ITS NATURE AND CONTROL

1 INTRODUCTION

1.1 This Leaflet gives general guidance on the causes, appearance and prevention of corrosion which, if not detected in its early stages, can have disastrous consequences. Information on corrosion theory is included where it has bearing on the practical aspect of the inspection and maintenance of aircraft and aircraft parts. The Leaflet should be read in conjunction with Leaflets **BL/4-2** and **BL/4-3** which deal with the removal and rectification of corrosion and with methods of protecting aircraft against corrosion. For guidance on methods of inspecting the more intricate parts of aircraft structures and for additional information on areas liable to corrosion, reference should be made to Leaflet **AL/7-13.**

1.2 All metals are subject to chemical and electro-chemical attack which converts them into metallic compounds such as oxides, hydroxides, carbonates, sulphates or other salts. Some metals resist attack better than others but the resistance of most metals may vary with such factors as physical environment, applied or internal stress, heat treatment state or working temperature. Although many of the metals used in aircraft construction have reasonable resistance to corrosion, it is essential that all possible action is taken to prevent its occurrence and to detect and remedy any corrosive attack, even if it appears to be insignificant.

1.3 As corrosion may arise from many different causes and can affect all kinds of metallic structures and components, it is beyond the scope of this Leaflet to enumerate all the defects that may result from it. It is also impracticable to enumerate every remedy as the treatment of each affected part must be determined by its nature and its function in the particular aircraft. Guidance on the repair and re-protection of corroded parts should be obtained from the appropriate Manufacturer's Publications, but whenever doubt exists the Manufacturer should be consulted.

2 TYPES OF CORROSION Corrosion is largely an electro-chemical phenomenon and is liable to occur whenever a difference in potential exists between two metals or a metal and substances in its vicinity in the presence of an electrolyte (see Figure 1). It can also occur when a difference in potential exists between separate regions of a single piece of metal or between the different constituents of an alloy. The degree of corrosion experienced will depend on external conditions and in some environments will be negligible; serious attack usually takes place only if moisture is present to act as an electrolyte between the poles created by any difference in potential. Two changes then occur, the metal that is attacked suffers a chemical change, some of it being converted into a metallic compound, whilst the cathodic pole of the circuit may be reduced.

2.1 **Direct Chemical Attack.** When metals combine with atmospheric oxygen or are attacked by acids, the anodic and cathodic changes occur at the same point. Impurities in the atmosphere can be responsible for this type of corrosion. Thus, aircraft operating near the sea are affected by airborne salt particles, whilst the high sulphur content of industrial atmospheres has a markedly deleterious effect on some exposed metallic surfaces. There is also the possibility of accidental contact with harmful substances. Where this form of attack occurs, the attacked metal is converted into a chemical compound by the corrosive agent, e.g. aluminium may be converted to aluminium sulphate by battery acids.

NOTE: On aircraft used for crop spraying, special care must be given to the inspection of the structure owing to the corrosive nature of some of the chemicals used. Guidance on the CAA's recommendations and requirements applicable to these aircraft is given in Leaflet AL/7-13.

2.2 **Electro-chemical Attack.** The close proximity of dissimilar metals in aircraft, aided by the presence of conductive media such as water, encourages the establishment of circuits and results in the metal which is anodic to the other being attacked. In some cases, such as when aluminium alloy and magnesium alloy are in contact, both metals may be corroded. Electro-chemical attack will be encouraged by the existence of stray currents from electrical apparatus or electrostatically-charged bodies (see Leaflet BL/4-3).

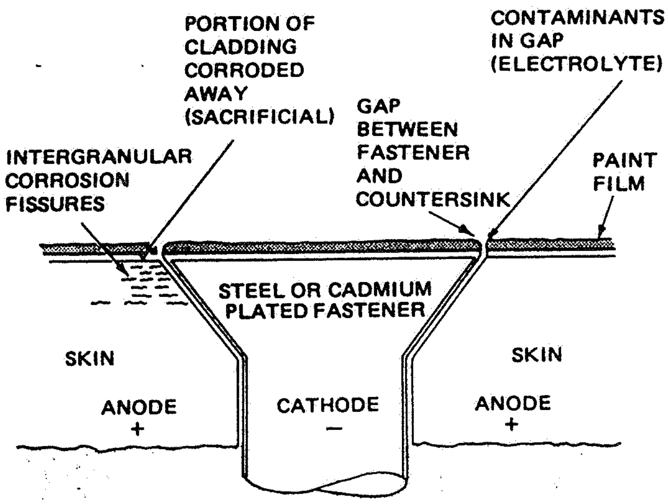

Figure 1 ELECTRICAL ASPECT OF CORROSION

2.3 **Evidence of Attack.** Both types of corrosive attack start on the surface of the metal but can work their way into the core if undetected. Evidence of corrosion will be indicated in the following manner:

(a) **Aluminium Alloy.** Corrosion of the aluminium surface is usually indicated by whitish powdery deposits with dulling of the surface on unpainted parts. The white powdery deposit also forms at discontinuities in protective coating and may spread beneath paint causing blistering or flaking. As the corrosion attack advances, the surface will appear mottled or etched with pitting. Swelling or bulging of skins, pulled or popped rivets are often visual indications of corrosion.

(b) **Alloy and Carbon Steels.** Corrosion is indicated by red rust deposits and pitting of the affected surfaces.

(c) **Corrosion Resistant Steels.** Corrosion is indicated by black pits or a uniform reddish-brown surface.

2.3.1 **Terminology.** The terminology used in describing corrosion is based on either the appearance of the corrosive attack or the mechanism associated with its formation. Frequently, several types of corrosion will occur simultaneously and it becomes difficult to determine the specific cause. The following types of corrosion are those most commonly experienced.

2.3.2 **Surface Corrosion.** This may take the form of a uniform etching of the surface, pitting or exfoliation of the surface grain boundaries. Light alloys are usually blotched by white or grey powdery deposits, whilst ferrous materials other than stainless steels become covered with reddish-brown rust, and a greenish powder forms on copper. Surface corrosion reduces the amount of sound material remaining and so weakens the structure but, since there is usually an indication of its existence, it is possible for it to be remedied by careful and systematic maintenance.

NOTE: In many instances the reduction in strength of a structure due to corrosion attack is out of all proportion to the reduction in thickness of the metal.

2.3.3 **Intergranular Corrosion.** The detection of this type of corrosion is difficult as the surface evidence may only be visible through a magnifying glass. Indications of the presence of corrosion can be obtained by anodising the part and examining for discoloration (black spots). Considerable experience is required for correct recognition, and often a metallurgical microsection examination will be necessary. The attack penetrates into the core of the material along the boundaries of the metal grains. As the material at the boundaries is usually anodic to the grain centres, the corrosion products often become concentrated at the boundaries, although sometimes the attack is transgranular and it is the material adjacent to the boundary which is attacked. The rate of attack is not limited by the lack of oxygen but is accelerated if applied or residual stress is present. Repeated tensile or fluctuating stresses encourage separation of the boundaries, so accelerating the spread of intergranular corrosion and giving rise to corrosion fatigue. As a result higher stress concentrations occur in the remaining sound material, cracks spread and complete failure follows. As there is no effective method of limiting or determining the loss of strength that occurs through this form of corrosion, material or parts showing any signs of it must be rejected immediately.

2.3.4 **Pitting.** Detected as a series of pits on the metal surface, usually in small, well defined local areas.

2.3.5 **Filiform and Exfoliation (or Laminar) Corrosion.** Filiform corrosion usually occurs under thin oil, grease or varnish films and is likely to be found on metal surfaces which have a protective film of any sort if there is evidence of a lack of adhesion of the protective film, and appears like 'worm-casts' on aluminium and magnesium alloys. Exfoliation appears as eruptions or flakiness on extruded alloys and can be a serious problem, although it is a relatively less harmful form of intergranular attack.

NOTE: Intergranular corrosion may occur without stress in the presence of acid chloride solutions or urine, etc., and the latter is often the cause of intergranular cracks which lead to component failure.

2.3.6 **Galvanic.** Galvanic corrosion is usually visible as pitting and is often referred to as dissimilar metal corrosion. However, it is not limited to just dissimilar metal couples. Various types of concentration cells, where electron flow occurs between areas or points of different electrical potential, are also examples of galvanic corrosion. Pitting results when, in the presence of a conducting solution, electron flow occurs between different metals or between different points or areas on a metal surface exhibiting different electrical potential.

2.3.7 **Microbial.** Microbial (microbiological) corrosion occurs in integral fuel tanks and is caused by the presence of bacteria and fungus in aviation kerosene. The fungus grows at the fuel/water interface, and the metabolic products formed corrode the metallic structure.

2.3.8 **Stress Corrosion.** This type of corrosion usually manifests itself as fine cracks. It occurs in alloys that are susceptible to cracking when exposed to a corrosive environment while under a tensile stress.

3 CONDITIONS CAUSING CORROSION Because of the stringent weight limitations of aircraft, structural parts and components cannot be designed so that they are heavier than is dictated by the requirements of mechanical strength. Thus, any loss of strength through corrosion damage is more critical than in other forms of transport. Aircraft parts should therefore be manufactured, protected and assembled so that corrosion is unlikely to occur and, after entering service, every precaution should be taken to preserve the original finish. Cleaning and inspection, and when necessary re-protection, are essential at frequent intervals throughout the working lives of all components and parts.

3.1 **Basic Factors of Material and Assembly.** The following factors are important as a guide to the prevention of corrosion:

3.1.1 **Selection of Materials.** As material specification used in initial construction or for subsequent repair are chosen by the Manufacturer, who should make resistance to corrosion a factor in selecting the appropriate specification, maintenance responsibility is normally limited to ensuring that all instructions for handling, storage, heat treatment, assembly and protection are correctly carried out and that a close watch is maintained for signs of incipient corrosion.

3.1.2 **Dissimilar Metals.** The contact of dissimilar metals, which occurs in many parts of aircraft structures and in most accessory components, is always likely to cause electro-chemical reaction, but in many instances such reaction can be prevented by maintaining protective or insulating layers between the metal surfaces. It should be remembered that parts to the same materials specification may have a relative difference in potential if their heat treatment states are different, and thus in some circumstances should be separated by jointing compound, etc., as though they were dissimilar metals. Some examples of dissimilar metal contacts are quoted:

(a) Steel bolts through aluminium alloy spars and structural members.

(b) Steel brake components secured to magnesium alloy wheels.

(c) Parts made of brass, steel, tungum, etc., such as clips or brackets, attached to aluminium alloy structural members.

(d) Aluminium alloy skin panels riveted to extruded stringers.

(e) Steel levers, shafts and gears housed in castings of light alloy.

3.1.3 **Heat Treatment.** Incorrect heat treatment may lower the corrosion resistance of the material treated, thus it is essential that all heat treatment should be applied strictly in accordance with approved specifications. The corrosion resistance of high-strength aluminium alloys is affected by their cooling rate; if this is rapid their susceptibility to intergranular corrosion is reduced, provided that locked-up quenching stresses are afterwards relieved.

NOTE: Heat is sometimes applied to structural parts for purposes other than the development of particular mechanical properties of the metal, e.g. when metal to metal joints are bonded by thermo-setting synthetic resins under the influence of heat and pressure. Since 'heat treatment' of this kind is not always covered by official specifications, close adherence to the aircraft Manufacturer's instructions is essential to ensure that the corrosion resistance and other properties of the metal are not impaired.

3.1.4 **Welding.** Welded joints are sometimes subject to corrosion because the heated strip has been rendered anodic to the surrounding metal but the danger can be greatly reduced by the exercise of skill and care. It should be remembered that the fluxes used in welding are often corrosive and hence all residues from fluxes should be thoroughly cleaned off immediately after welding. Some stainless steels are particularly susceptible to intergranular attack in the welded region (weld decay), although the likelihood of this can be reduced if the part is annealed after welding or if the steel contains stabilising elements such as titanium or niobium (Leaflet **BL/6-4**). Inert gas welding processes which do not require flux are sometimes used when the removal of flux would be difficult.

3.1.5 **Fretting.** This is a type of corrosion which can have serious consequences, as it reduces the fatigue strength of the structure; it occurs when parts are bolted tightly together and yet slip slightly on one another during flexing or other movements of aircraft parts. The heating caused by friction promotes oxidisation of steel parts and the oxide is then rubbed off to form dust frequently described as "cocoa". Fretting of aluminium alloys produces a black oxide. Structural assembly bolts should be inspected to ensure that the protective treatment plating is intact and should be assembled within the stipulated torque loading limits and in accordance with the Manufacturer's instructions.

3.1.6 **Stress.** Metals under stress generally corrode more rapidly than unstressed metals. The influence of stress on the development of intergranular corrosion is mentioned in paragraph 2.3.3. Corrosion that is continuing on parts under repeated stress is very much more harmful than corrosion for the same length of time without stress, and can lead to rapid failure of the part from fatigue. In many cases, stress corrosion cracks have resulted from initial pits in the surface.

3.1.7 **High Temperatures.** Parts which become heated in service, such as brake drums, combustion chambers and exhaust pipes, tend to oxidise more rapidly than unheated parts. This tendency is reduced if the parts are made from alloys containing nickel or chromium, although the corrosive effects of the sulphur present in exhaust gases may still do harm to heated engine parts.

3.1.8 **Electrical Equipment.** Faults in the insulation of electrical equipment which lead to current leakage can cause the equipment itself to corrode or can encourage electro-chemical attack in the surrounding structure. Insulation should therefore be carefully tested as outlined in Leaflet **EEL/1-6**. Sparking in confined spaces will produce nitric acid in the presence of moisture and this acid will then attack the surrounding material. Nitric acid attack can be prevented by ensuring that the vents of such equipment as magnetos are kept clean so as to permit the escape of the oxides of nitrogen evolved. Certain insulating materials give off vapours which are corrosive, e.g. phenolic resin-bonded insulating materials give off vapours which corrode cadmium plate.

3.2 **Factors Due to Environment and Operation.** Corrosion can arise from many circumstances, some of which are unavoidable but many of which can be anticipated and controlled. When conditions that create corrosion are an inevitable accompaniment of storage or operation, the only safeguard is adequate maintenance.

3.2.1 **Damage to Protective Coatings.** Metallic surfaces protected by chemical films, metal plating or organic coatings, may suffer severe attack if the protective coat is physically damaged. Some protective coatings are susceptible to attack from certain types of lubricants, de-icing fluids or hydraulic fluids, but this danger can be reduced by selecting protectives that are specially resistant for the items that are likely to be in contact with these fluids. Scratches caused by careless handling and abrasion from grit or water striking the aircraft at high speed can provide starting points for corrosion, but the seriousness of such defects depends on the materials affected. Thus aluminium alloy sheet clad with pure aluminium is not much harmed by minor scratches since the aluminium cladding provides 'sacrificial protection' (Leaflet **BL/4-3**). On the other hand, chromium plated steel will rust readily if the chromium is damaged.

3.2.2 **Surface Defects.** Corrosion may arise from particles of foreign matter, such as rolling-mill scale or emery particles, which are embedded in the surface. Particular care is necessary after such operation as filing, grinding or abrasive grit blasting to ensure that all particles are completely removed. A high polish is given to some components to enable them to resist attack, and this resistance will be lowered if polished surfaces are roughened or scored.

3.2.3 **Crevice Corrosion.** Intense corrosion is often found where non-conducting materials, such as plastics, glass-wool or upholstery, are in contact with metal. A similar effect may occur in inaccessible corners formed in metal parts. In such places, oxygen is replenished less quickly than elsewhere with the result that the crevice is rendered anodic to the surface outside and is therefore subject to electro-chemical attack. It follows that the contact of metals and non-conductors should be treated like the contact of dissimilar metals, and that all enclosed regions in aircraft structures should be vented and drained as adequately as possible. Ventilation also helps to prevent the accumulation of condensed moisture and discourages the growth of moulds and bacteria which can also promote corrosion.

3.2.4 **Marine Corrosion.** The salt present in sea water will attack many metals directly. Landplanes may be affected by airborne particles or spray droplets, whilst amphibians require constant attention to keep them free from the salt deposited by evaporated spray. If trapped in the aircraft structure, sea water will provide a particularly active electrolyte for electro-chemical action. Hulls are sometimes damaged because of the voluminous character of the corrosion products precipitated in crevices; as the material accumulates, plates may be bulged and rivets fractured. The inside of the chine members where the side sheeting joins the planing bottom is particularly vulnerable to corrosion because of its moisture trapping shape.

3.2.5 **Fuels, Oils and other Liquids.** Although petroleum products contain sulphur compounds and organic acids, they do not usually corrode fuel tanks, pipe-lines, etc., because of the resistant nature of the materials from which these items are made. The danger of corrosion chiefly arises from the water content of oils and fuels; the water acts as an electrolyte to promote combination with oxygen dissolved in the oil or fuel. This effect is most pronounced with leaded petrol, and light alloy tanks containing such fuels should be protected with inhibitor cartridges (Leaflet **BL/4-2**). Careful inspection of the external surfaces as well as the internal structure of the keel areas, particularly of pressurised aircraft, is necessary due to condensation and spillage from toilet and galley installations. Battery acids, de-icing fluids, disinfectants, water methanol spillage and urine can also cause extensive attack on structural parts and care should always be taken to wash off any of these fluids which may be spilt. Integral fuel tanks should be designed to give good water collection and drainage.

3.2.6 Water in aviation kerosene may cause serious corrosion within the fuel system. It may be saline or brackish, which with other contaminants such as iron oxide, micro-biological organisms, etc., may have very serious effects (see Leaflets **AL/3-15** and **AL/3-17**).

NOTE: All aviation fuels absorb moisture from the air and the amount of dissolved water contained varies with the temperature of the fuel. When the temperature of the fuel decreases, some of the dissolved water comes out of solution and falls to the bottom of the tank. When the temperature of the fuel increases, water is drawn from the atmosphere to maintain a saturation solution. Changes in temperature, therefore, result in a continuous accumulation of water.

4 THE CONTROL OF CORROSION Details of corrosion control during design and production are outside the scope of this Leaflet; the following paragraphs relate to care and maintenance under operating conditions.

4.1 **Cleaning.** It cannot be too strongly emphasised that frequent cleaning is essential for the prevention of corrosion. During take-off and landing, aircraft are splashed with mud and water; during flight, engine oil and exhaust products are deposited on parts of the structure, and at all times contamination by atmospheric dirt is likely to occur.

4.1.1 Metal-skinned structures should be washed down thoroughly using solutions, materials and equipment which are recommended by the aircraft manufacturer. Non-flammable degreasing cleaners for aluminium alloys are available in powder form; they should be applied with a bristle brush, care being taken to remove all dirt from odd corners, panel edges, screw and rivet heads, etc. If deterioration of protective treatments or signs of corrosion are revealed by cleaning, the affected parts should be treated as described in Leaflets **BL/4-2** and **BL/4-3**. Cleaning preparations should be washed off with cold water after they have loosened the dirt, and the parts should be dried thoroughly before restoring any protective treatments.

NOTE: There are certain proprietary cleaners which, although harmless to metals, are inclined to rot fabric and other textile materials. It follows that care should be taken to prevent them from wetting fabric or upholstery. Transparent plastics can also be damaged by cleaning chemicals and should therefore be suitably protected. (For guidance in cleaning and maintenance of transparent plastics panels, see Leaflet **AL/7-4**).

4.1.2 At the intervals specified in the Approved Maintenance Schedule, marine aircraft should be beached and hosed down with fresh water. The bilges should be drained and flushed through with fresh water at the same time. Care should be taken that all deposits of salt and marine growths are removed from both the inside and outside of the aircraft and that all damage to protective coatings is made good. All submerged parts of the hull and floats should then be sprayed with liquid lanolin, pigmented lanolin or seaplane varnish, the spraying being continued to approximately 0·6 m (2 ft) above the water line.

4.1.3 Where battery or other acids have been spilled, the surrounding area should be rinsed with generous quantities of clean water to dilute and remove the acid. The affected parts should then be brushed with a dilute solution of sodium bicarbonate for lead acid batteries, and diluted acetic acid for nickel cadmium batteries, to neutralise any remaining electrolyte. After this has remained on the surface for a few minutes, the area should again be washed with water, finally wiped dry, and the protective treatments restored.

NOTE: In cases where spillage of acid or heavy concentrations of battery fumes (e.g. due to a runaway battery) have occurred which are not contained within a known area, it may be necessary to dismantle parts of all the surrounding structure to ensure the effective removal of all traces of electrolyte.

4.1.4 High octane fuels, which are doped with tetra-ethyl-lead and ethylene dibromide, produce lead bromide when burnt. This is ejected in the exhaust gases and can do considerable harm if deposited on aluminium alloys. Such deposits should be removed by using detergents or emulsifiable cleaners which will not soften the underlying paint coat. Where possible all apertures at wing root joints, etc., should be sealed to exclude exhaust gases from the inside of the structure, but if the gases do penetrate, internal cleaning will also be necessary. If the deposits are so hardened that they will not yield to normal cleaning, a paint stripper should be applied. Using a high pressure jet of water or rubbing with a damp rag, the stripper and paint can then be removed together. Afterwards the cleaned area must be re-protected (see Leaflets **BL/4-2** and **BL/4-3**).

NOTE: Paint strippers containing methylene dichloride or ethylene dichloride can seriously reduce the strength of resin-bonded joints, and hence aircraft on which processes such as "Redux" bonding have been used should only be cleaned with strippers which are recommended for the purpose by the aircraft Manufacturer. Information on acceptable materials, if not in the appropriate Manual, is normally available in Service Bulletins published by the Manufacturer's Service Department.

4.1.5 Although accumulation of oil and grease may not in themselves be corrosive, they tend to retain dirt and metal particles, to damage surface finishes and prevent inspection for cracks, etc. They should be removed from such parts as the landing gear and engine nacelles by means of solvents or emulsifiable cleaners. The cleaning agents recommended by the aircraft Manufacturer should always be used.

NOTE: It is important that the cleaning fluids specified by the Manufacturer are used in the strengths recommended and in applications where their use has been specified. Cases have arisen where cleaning fluids in combination with kerosene have had a deleterious effect on aircraft structures, the penetrating qualities of kerosene promoting seepage into skin joints. Such cases are particularly troublesome and it becomes difficult to diagnose the cause of corrosion. Also, unspecified cleaning fluids might contaminate or destroy jointing compounds, bonding adhesives or sealing mediums.

4.1.6 Wrong methods of cleaning can do more harm than good. The following points should be noted:

(a) Steel wool should not be used on aluminium alloy or magnesium alloy surfaces as particles may be lodged in crevices or embedded on organic coatings and so provide starting points for electro-chemical attack.

(b) Aluminium-clad light alloy sheet should not normally be polished with mechanical buffing wheels, except under a carefully controlled technique, as this will remove the coating of pure aluminium and the unprotected alloy core will be subject to corrosion.

(c) Dirt and swarf should not be washed or brushed inside the structure where particles may be trapped behind stringers, frames, etc. (Trapped water can do more damage than the dirt.) Interior cleaning should be done with an efficient vacuum cleaner.

(d) Pressure cleaning should be used with caution, particularly where bearings are in use. Steam cleaning should only be used when specified, for it can penetrate joints and leave water residues.

4.2 **Inspection.** Every precaution must be taken to ensure that all corrosion is detected in its early stages. Corrosion cannot always be found by visual examination alone, and one of the methods of non-destructive examination such as radiological examination (Leaflet **BL/8-4**) may be of assistance. However, corrosion tends to blister paint and its presence can be suspected if the paint flakes off when pressed.

NOTE: Because of the rapid improvements that have been made in radiological techniques, the latest information on this subject should be sought from the aircraft Manufacturer.

4.2.1 At the time specified in the Approved Maintenance Schedule and whenever the aircraft has been subjected to especially corrosive conditions, the inside and outside of the structure should be thoroughly examined. The upholstery and floor coverings should be removed and all access panels should be opened to facilitate inspection. With a strong light, a detailed examination (see also Leaflet **AL/7-13**) should be made of the spars, ribs, frames, bulkheads, stringers, etc. Particular attention should be given to poorly vented regions and to places where dampness and condensation are apparent or suspected. Strontium chromate inhibitor pellets are sometimes used in areas where water accumulates and the condition of such inhibitors should be assessed. The satisfactory adhesion of sealant fillets and paintwork should also be verified.

(a) Special attention should be given to parts of the fuselage where condensation may tend to collect. Considerable condensation will occur on the inner surfaces of pressure cabin structures. Water will run down the cabin wall structure and this will tend to start corrosion in the lower parts of the structure.

(b) Inspection should give special attention to such areas and particularly to the faying surfaces between stringers and skin, where moisture may remain trapped and promote corrosion. In some cases it may be necessary to dismantle parts of the structure to ensure adequate inspection.

NOTE: On some types of aircraft operating under widely different conditions, recent investigations have revealed the presence of serious corrosion which had remained undetected in parts of the structure. In some instances it has been shown that normal methods of inspection and radiological examination were inadequate, and dismantling, particularly of pressurised skin structures, was therefore necessary.

4.2.2 Where evidence of surface corrosion exists, the extent of pitting or exfoliation should be tested by probing with a fine needle. Whenever possible, the strength of all suspect rivets should be tested by applying a moderate shear load to the rivet head. The remedial action to be taken will depend on the depth and extent of the attack and the thickness and function of the affected parts, but any areas where rivets fail must obviously be repaired in accordance with the appropriate Repair Manual. Elsewhere, if the attack is not serious, the corrosion can be cleaned off and the part re-protected (Leaflets **BL/4-2** and **BL/4-3**), but any intergranular or widespread surface corrosion will also necessitate repair by renewal of the damaged areas.

4.2.3 Assessment of the condition of parts subjected to high temperatures is not easy but, as a general rule, discoloration and light scaling are normally acceptable (light scale sometimes protects the metal from further attack) whilst heavy scale is an indication that the strength of the metal has been reduced. However, the majority of exhaust systems fitted to aero engines are manufactured from stainless steel or inconel and visual examination of these components is often misleading. This is because those parts of the system which are subjected to the highest temperatures will, after extensive periods in service, suffer from intergranular corrosion. If undetected this is obviously dangerous and may constitute a fire hazard, but detection is possible by measurement of magnetic permeability. A rough check for this condition can be made with a small horseshoe magnet, the component under examination being rejected if the magnet shows any tendency to adhere to it, but sensitive instruments which measure the relative magnetic permeability should be used whenever possible. The guidance of the Manufacturer should be followed when assessing the condition of particular exhaust systems.

4.2.4 It is a wise precaution to remove a sample number of key assembly bolts during major inspections, care being taken to ensure that different bolts are removed at each inspection. Bolts securing engine mountings, wing and empennage attachment bolts, and undercarriage assembly bolts should be examined for signs of fretting corrosion. The bolt holes and surrounding material should be inspected for intergranular penetration and fatigue cracks by the methods given in Leaflet **BL/4-2.**

NOTE: This should only be done by skilled personnel with the appropriate jigs and assembly equipment.

4.2.5 It should be remembered that metal tubes may corrode internally as well as externally. Sealed tubes, which have been protected internally before assembly should not cause concern, but open-ended tubes can accumulate moisture. Guidance on the inspection and protection of tubes is given in Leaflet **BL/4-2.**

4.2.6 Visual examination for corrosion is one of the most essential aspects of inspection and is necessary on all components, pipelines, control cables, electrical equipment, instruments, etc. For further information on the inspection of particular systems and components, reference should be made to the appropriate Manual and to other CAIP Leaflets dealing with the systems concerned.

4.3 **Storage.** Aircraft, engines and components will deteriorate rapidly when stored unless adequate precautions are taken to protect them from climatic conditions, damp, condensation and accumulations of dust. It should be remembered that conditions suitable for some materials may not suit others. The following information stresses some important factors of good storage.

4.3.1 The most suitable environment for storing complete aircraft is a cool, dry hangar with a relative humidity of less than 60% where the structure is protected from strong sunlight, rapid changes of temperature, atmospheric impurities of marine or industrial origin, and the erosive effect of blown dust. Before prolonged storage is contemplated it is advisable, where possible, to remove all sound insulating and textile materials of a hygroscopic nature. After storage, special attention should be given to parts of the structure which have remained in contact with material of a hygroscopic nature. It should also be noted that damp wood will evolve acids that can be harmful to adjacent metal even though the wood may not be in direct contact with it.

4.3.2 Aircraft should be stored in a dry, clean condition, all drains and vents should be clear and unobstructed, and blanks should be fitted to intakes and apertures in which condensation might occur. Colour indicator type of silica-gel may be used in enclosed spaces to absorb atmospheric moisture.

4.3.3 Temporary protectives such as rust inhibitors and lanolin should be applied to exposed metal surfaces which are likely to corrode. Guidance on the protection of particular aircraft should be obtained from the Manufacturer concerned.

4.3.4 If aircraft have to be stored for long periods in the open or under detrimental climatic conditions, they should be adequately covered and protected by a special process. Packaging by the spray application of a plastics film is a satisfactory method, provided every precaution is taken to control the humidity of air inside the protective covering and an externally visible moisture absorption indicator is used.

4.3.5 Some of the special precautions necessary to protect engines from corrosion are covered in Leaflet **EL/3-14.** There are numerous precautions, with variations in materials, equipment and methods of application, which are specific for various engine types and installations; these must be applied strictly in accordance with the appropriate Manual and related technical documents.

4.3.6 Metals held in stores should not only be stored under controlled conditions but should be protected by a method suitable to the specification and shape of the material. Thus a coating of lanolin is usually applied to light alloy castings, whilst sheet and strip light alloy are most effectively safeguarded by spraying them with an approved plastics film on to a pre-oiled surface. Plastics films, which can be peeled off before fabrication, have the added advantage of protecting them against mechanical damage.

4.3.7 Components such as instruments, hydraulic valves and electrical equipment are usually packaged by their Manufacturers and given a guaranteed shelf life. However, it should be remembered that the shelf life is only valid if the storage conditions are suitable; in humid conditions corrosion may occur even if the packaging appears to be undamaged. The only remedy is periodic inspection, cleaning and re-protection throughout the shelf life of the component.

4.3.8 Aircraft, engines and components which have been stored for any considerable period should be carefully examined and tested before being put into service. Temporary methods of protection should be removed, and all permanent protection should be inspected and rectified as necessary.

NOTE: For further information on storage conditions for aeronautical supplies see Leaflet **BL/1-7**.

BL/4-2

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BASIC

MATERIALS

CORROSION—REMOVAL AND RECTIFICATION

1 INTRODUCTION

1.1 This Leaflet gives general guidance on the removal of corrosion products and on the cleaning and pre-treatment of the metal parts of aircraft. It should be read in conjunction with Leaflets **BL/4-1** and **BL/4-3** and the appropriate Manufacturer's publications for the aircraft concerned.

1.2 Many of the processes recommended in this Leaflet are covered by specifications issued by the Ministry of Defence or the British Standards Institution. Since these specifications are frequently re-issued, the alphabetical suffix of each DTD Specification has been omitted, but the application of any particular process should always conform to the latest issue of the relevant specification. All processes should be approved by the aircraft Manufacturer.

2 TREATMENT OF STRUCTURAL PARTS Wherever corrosion is found in aircraft it is essential that the corrosion products should be completely removed. This is necessary for two reasons, firstly to permit the extent of the damage to be assessed and secondly because the presence of corrosion products assists in the continuation of the attack. The full value of protective treatments will only be achieved if the surfaces are thoroughly cleaned and the treatments are applied immediately after cleaning.

2.1 **Preliminary Cleaning of Corroded Areas.** Parts which cannot be removed for cleaning should have all oil, grease, moisture and surface dirt cleaned off before the application of corrosion-removing chemicals. Oil and grease should be wiped off with rags soaked in organic solvents such as trichloroethylene fluid (BS 580) (Type 2 or other suitable grade), or a mixture of equal volumes of white spirit (BS 245) and either (a) solvent naptha (BS 479) or (b) 3°xylon (BS 458), used at room temperature as recommended in DEF STAN 03-2. (Degreasing procedures are detailed in specification DEF 1234.) Surface dirt should be removed with detergent solutions, using hand brushes with non-metallic bristles such as nylon.

NOTE: Trichloroethylene degreasing processes and the precautions necessary when used with certain metals are described in Leaflet **BL/6-8**.

2.2 **Removal of Old Protective Coatings.** To facilitate the inspection and re-protection of corroded surfaces, the protective coatings in the vicinity of the damage should be removed. Whenever possible this should be done chemically, as mechanical methods such as wire brushing, grinding or rubbing with emery, may overheat the surface or remove an undesirable amount of material. There is also the danger that abrasive methods may drag surface metal over the corroded area or cause particles to become embedded which will cause further corrosion later.

2.3 Air-blast abrasive equipment has been proved satisfactory, particularly for relatively large areas of surface corrosion removal. The abrasive must in all cases be aluminium oxide or glass beads, never silicon carbide; for coarse and rapid removal the particle size should not exceed 180 mesh (0·08 mm) and for fine control the size should be 400-600 mesh (0·038-0·025 mm). Due to the possibility of cladding removal from aluminium skins and cadmium plating from steel fasteners, etc., abrasive blasting should only be considered if a complete organic finish is to be applied.

2.3.1 **Removing Organic Coatings.** Non-flammable paint strippers should be used to remove paints, varnishes, synthetic enamels, cellulose, etc., (see DEF STAN 80-16 and Manufacturer's recommendations). A number of proprietary solutions are available which are satisfactory for the majority of organic coatings; they are neutral and will not attack the underlying metal provided they are rinsed off after the paint has been removed. The strippers should be brushed over the paint, left on the surface for a few minutes and the loosened paint then wiped off with a cloth, aluminium wool or non-metallic material, e.g. wood, Tufnol or suitable plastics materials. Steel wool should not be used.

2.3.2 Where a paint coating is required to be repaired or renewed in localised areas only, surrounding areas should be masked by means of suitable tapes, and these should be removed at suitable stages during the painting process to prevent subsequent contamination of later stages, and as soon as practicable after completion of the painting operation.

2.3.3 Where damage or removal of pressure cabin sealants or other sealing or stopping materials has occurred, these should be renewed either before or at some convenient point during repainting operations. Where stoving materials have been used originally, these may be replaced with an approved air drying scheme compatible with the original.

NOTE: The effects of certain strippers on adhesive-bonded joints, plastics parts and windows should be borne in mind (see Leaflet **BL/4-1**), and care should be taken to avoid caustic strippers on aluminium alloys. Rubber gloves and goggles should be worn to prevent any contact between the stripper and the skin.

2.3.4 When the paint has been removed, all traces of the stripper and residue should be removed by one of the following methods (DEF STAN 03-7).

(a) **Water-miscible paint remover:** Washing with clean water and drying, followed by solvent cleaning.

(b) **Solvent-miscible paint remover:** Washing with the appropriate solvent only.

2.3.5 **Removing Chemical Coatings.** It is not always essential to remove chemical coatings such as anodic films from aluminium alloys or phosphate coats from steels. As it is generally impossible to restore chemical coatings without removing the part and immersing it in a suitable bath, it is sometimes advisable to retain as much as possible of the original coating and, after local cleaning of the corroded areas, to apply one of the brush-on processes mentioned in paragraph 3.2.1, followed by organic coatings for subsequent protection. If the affected parts can be removed it is preferable to clean them completely and then re-protect by the original method.

(a) **Anodic Film.** Anodic films may be removed from aluminium alloys by the application of a solution of 10% sulphuric acid by volume in water plus 4% by weight of potassium fluoride (Leaflet **BL/7-1**).

(b) **Chromate Films.** Magnesium alloy parts which can be immersed should be cleaned as recommended in Leaflet **BL/7-3.** Local cleaning where immersion is not justified can be effected by swabbing with a solution of 100 g of chromic anhydride in 1 litre of water, with 14 drops of concentrated sulphuric acid added (2 oz of chromic anhydride in 1 pint of water, with 8 drops of concentrated sulphuric acid added). Where parts are not machined to fine tolerances, abrasion with fine 'wet' glass paper is permissible. The glass paper should be well wetted before use and care should be taken to prevent abrasive particles from remaining embedded in the surface. After rubbing down, the chromic-sulphuric acid solution should be applied and left on the surface for 2 or 3 minutes. The surface should finally be washed off with generous quantities of water and thoroughly dried.

(c) **Phosphate Films.** Phosphate films on steel are generally tenacious and are not easy to remove without immersion in acid solutions. To clean a small area of a part in situ, mechanical cleaning is usually most satisfactory, but when complete stripping is required a dip in dilute hydrochloric acid is recommended (see paragraph 3.2.2 (a)).

2.3.6 **Removing Metallic Coatings.** Coatings of cadmium, zinc, nickel, copper and tin are frequently used to protect steel aircraft parts; light alloys are usually protected by other methods. Immersion in an acid solution is usually the most effective method of removing a metallic coating, but it should be remembered that the removal of original deposits before replating is necessary only if the thickness of the deposit is critical. Mechanical cleaning is also used on occasions, particularly if the old deposit is flaking or peeling, but whichever method is used care should always be taken to avoid removing too much material, especially on parts to close dimensional tolerances.

2.4 **Removal of Corrosion Products.** Although the cleaning methods outlined in paragraphs 2.1 and 2.2 will remove superficial corrosion, surfaces which have been seriously attacked may still retain powdered oxides, salt crystals, etc., in pits and surface cavities. Chemicals suitable for cleaning each of the principal materials used in aircraft construction are available, but in some cases the chemicals will themselves cause corrosion if they penetrate faying surfaces. There is also evidence that some pickling and electro-chemical polishing techniques have an adverse effect on fatigue life and this aspect should receive serious consideration when selecting cleaning processes for parts which are subjected to fluctuating stresses in service. When doubt exists regarding the corrosive nature of certain chemicals, they should be tested as recommended in the following paragraph.

2.4.1 **Test for Cleaning Chemicals:**

(a) Prepare two panels of approximately 900 cm^2 (1 ft^2) area from material of the same specification as that to be treated.

(b) Apply the chemical to be tested to one face of each test piece and clamp the treated faces together.

(c) Expose the sandwiched test panels to alternate humid and dry atmospheric conditions in temperature conditions of 38°C (100°F). About 16 hours a day in humid conditions and 8 hours a day in dry conditions is recommended.

(d) After approximately 10 days the panels should be separated, rinsed and scrubbed, and examined for corrosion.

(e) The chemical will be acceptable if the metal is only lightly etched, but should not be used on the aircraft if it has caused deep pitting or intergranular corrosion of the test panels.

2.4.2 **Chemical Cleaning of Steel.** The removal of rust from steel by pickling in acid is often recommended, but it is not a practical method for in situ parts or welded steel tubular structures. A variety of proprietary rust removing solutions is available; most of them are solutions containing phosphoric acid, which, in addition to dissolving oxide film, partly inhibit the steel surface from further rusting. These solutions should always be applied as directed by their Manufacturers and in accordance with DEF STAN 03-2.

NOTE: Where parts are removable, the use of alkaline de-rusting solutions (with chelating reagents) is recommended.

2.4.3 **Chemical Cleaning of Aluminium Alloys.** Cleaning methods will vary according to the extent and location of the corrosion and the specification of the alloy concerned. General guidance on some recommended methods of cleaning are given below:

(a) Light corrosion deposits on aluminium alloys can often be wiped off with solvents or detergents which will leave a clean surface ready for pre-treatment and re-protection. The use of non-flammable preparations which are free of caustic substances is recommended. Swabbing with trichloroethylene is not advised because concentration of the fumes can be harmful and, in any case, the function of this chemical is to remove grease and not corrosion products. When solid particles are held in suspension in surface grease, they will be removed if the parts can be immersed in boiling trichloroethylene liquor but this is seldom a practical method of cleaning aircraft structural parts during maintenance. The use of an inhibited phosphate chemical brightener is also recommended.

(b) Heavy deposits on clad aluminium alloys should be removed chemically because mechanical cleaning will take off the protective cladding and expose a greater area of the core to subsequent corrosion. Preparations of thickened phosphoric acid are recommended for this purpose. All other material, including non-clad aluminium alloys, should be masked to prevent them being attacked by the acid. The corroded surface should then be brushed with the acid and, after an interval of not more than 3 minutes, scrubbed with a stiff non-metallic brush until all corrosion products are removed from pits, rivet heads, etc. The surface should then be rinsed off with generous quantities of water to remove all traces of remaining acid, and should then be thoroughly dried.

(c) Heavy deposits on non-clad aluminium alloys can be removed mechanically, i.e. by scraping, wet sanding with fine sandpaper or by light abrasion with aluminium wool (steel wool should not be used), provided dimensional tolerances are not exceeded. A general purpose surface wash which will also form a base for painting can be made up as follows:

Butyl alcohol	40%	By volume
Isopropyl alcohol	30%	
Phosphoric acid (85% solution)	10%	
Water	20%	

The alcoholic-phosphate wash should not be used on high strength wrought aluminium alloys such as DTD 5024, 5044, 5114 and 5124. On other alloys it should not be allowed to remain on the surface for longer than 15 minutes; in fact shorter times are desirable, particularly if the temperature is high. It should be applied with a soft cloth or bristle brush, washed off with water and the surface dried. As an alternative the proprietary 'brush on' solutions mentioned in paragraph 3.2.1 (b) may be used.

(d) The use of phosphoric acid corrosion removers is usually followed by the application of a chromate bearing conversion coating treatment such as the Alocrom series. These remove the final traces of corrosion and provide an improved surface condition for painting. The application of a 10% chromic anhydride solution for a few minutes is also efficacious, particularly on polished skins.

2.4.4 **Chemical Cleaning of Magnesium Alloys.** A solution of 10% by weight of chromic acid in distilled water with 0·1% sulphuric acid added is a satisfactory chemical for removing corrosion products from magnesium alloys. The solution should be brushed over the corroded area, working it well into pits and crevices, and should be left for about 5 minutes. It should then be rinsed off with clean water. Reference should be made to the requirements of specification DTD 911. (See paragraph 2.4.5 (b).)

2.4.5 **Note on Mechanical Cleaning.** Although mechanical cleaning is often necessary when preparing fabricated parts for anticorrosive treatments, its use should be restricted during maintenance work on complete aircraft.

(a) Steel and non-clad aluminium parts should be rubbed down with fine 'wet' glass paper in preference to emery papers. Wet sanding methods are more efficient, as water acts as a lubricant and permits a finer grain to be used; the rubbing should be in the direction of the working stress.

(b) Castings, forgings and extruded members can be hand scraped to blend out corrosion pits. Steel carbide tipped scrapers are recommended and should be used so that pits are transformed into saucer-shaped depressions which relieve stress concentration. Afterwards the depth and area of the depressions, and the total number per unit area of surface, should be assessed to ensure that the material has not been unduly weakened.

(c) Light abrasion is sometimes helpful in removing heavy deposits from skin panels. Pumice powder applied with a solvent-moistened cloth is generally satisfactory. If clad aluminium alloy sheet is cleaned by this method, a simple test with caustic soda should be made afterwards to determine whether sufficient aluminium remains to protect the alloy core. If the surface layer of pure aluminium has been rubbed off, a spot of dilute caustic soda solution will turn the surface black. After making the test the caustic soda should be thoroughly washed off.

NOTE: After testing and washing, a 10% solution of chromic anhydride is recommended to neutralise any caustic soda and passivate the etched surface.

3 TREATMENT OF COMPONENTS The information in this paragraph relates to component parts which can be removed for immersion treatments.

3.1 **Degreasing.** The trichloroethylene vapour method (Leaflet BL/6–8) is satisfactory for most aircraft materials, but in cases of heavy contamination the following alternatives may be used:

3.1.1 **Aluminium Alloys.** Mild alkaline baths effectively remove grease from aluminium but the baths should be inhibited to limit attack on the metal. A satisfactory bath can be prepared from a 4-5% w/v (36 to 48g/litre (6 to 8oz/gal)) of a mixture of crystalline trisodium phosphate and sodium metasilicate in proportion between 2: 1 and 1 : 2 w/w (if anhydrous trisodium phosphate is used, the proportion will lie between 1 : 1 and 1 : 4) with or without a suitable wetting agent.

3.1.2 **Steels.** The immersion pickling processes described in paragraph 3.2 will remove residual grease as well as rust, scale and other surface dirt. However, cleaning with trichloroethylene or other solvents is necessary prior to pickling.

3.1.3 **Magnesium Alloys.** Instructions for cleaning by immersion in caustic soda or chromic acid are given in Leaflet **BL/7–3.** Sometimes pickling in a 5 to 10% solution of concentrated nitric acid in water is recommended for castings and parts which are not machined to close tolerances. The electrolytic-fluoride process mentioned in Leaflet **BL/4–3** will also remove corrosion products and has the further advantage that the fluoride film created on the surface is to a certain degree corrosion-resistant.

3.2 **Pickling Processes.** The following immersion processes are of value in preparing metal parts for subsequent protection treatment. Their action is generally twofold; they remove corrosion products and the residue of original treatments, and to some degree they etch the treated surfaces to provide a better key for organic protectives.

3.2.1 **Aluminium Alloys.** Treatments should be selected to suit the nature of the parts and to prepare them for the finish specified in the drawings or repair scheme. Some suitable processes for the preparation of clad sheet for painting are described in DEF STAN 03-2; they are for use as an alternative to etch primers. When proprietary processes are used the Manufacturer's instructions should be carefully followed to ensure that the fatigue resistance of the metal will not be lowered.

(a) **Chromic-sulphuric Acid Process.** After degreasing and rinsing the parts, they should be immersed for approximately 20 minutes in one of the alternative solutions given below. The temperature of the solutions should be maintained between 43 to 65°C (110 to 150°F). This process should not be used for spotwelded or riveted assemblies but is satisfactory for castings, forgings, extrusions, etc., provided they are thoroughly rinsed and dried afterwards.

Solution 1.	Sulphuric acid (Sp. Gr. 1·84)	15% by volume
	Chromic acid (CrO_3)	5% by weight
	Water	Remainder
Solution 2.	Sulphuric acid (Sp. Gr. 1·84)	15% by volume
	Sodium bichromate	7½% by weight
	Water	Remainder

(b) **Phosphoric Acid Processes.** The constituents of an alcoholic-phosphate wash are given in paragraph 2.4.3 (c); this solution can be used in a mild steel tank to pickle aluminium alloy components. A variety of proprietary solutions containing phosphoric acid are also available; some of these build up a thin phosphate film which provides a good base for painting. However, a distinction should be made between phosphoric acid processes which create phosphate films and those which only clean and etch. The proprietary cleaning processes listed in DTD 900 include Titanine metal degreasing paste, Jenolite AKSI etching compound and the ICI Deoxidine process 202. These are materials which can be brushed over aluminium assemblies including parts which are riveted together, but care must be taken to wash all surfaces thoroughly after treatment, drying carefully after washing. Deoxidine 170 is a hot dip process which is suitable for both steel and aluminium alloy; another treatment not covered by the specification is Deoxidine 125 which can be applied to both these metals by fold dipping or by brushing. If any of these treatments are applied by brush, all crevices and seams should be blown out with compressed air before proceeding to paint the treated area. Painting should follow promptly since none of these treatments builds a resistant film.

(c) **Chromic-phosphoric Acid Process.** After degreasing and rinsing the parts, if specified in the Maintenance Manual or other appropriate instructions, they should be immersed in a near-boiling aqueous solution as follows, for 20 minutes, if of sheet material, or up to 1 hour if cast.

Chromic acid (CrO_3)	0·75-1·0% w/v (7·4-9·9 g/ litre (1·2-1·6 oz/gal))
Phosphoric acid (Sp. Gr. 1·75)	0·5-0·75% v/v (5-7·4 cm³/ litre (0·8-1·2 fl.oz/gal))

NOTE: The use of Deoxidine 624 followed by Alocrom 1200 is recommended. Alocrom 1200 or other similar conversion coating treatment should be used after pickling processes (particularly phosphoric acid) prior to painting, except when etch or wash primers are to be used.

3.2.2 **Steels.** The chemical treatments for steel can be divided into two main groups. Pickling is a process in which acids are used to remove rust and scale so that a chemically clean surface is produced which requires immediate protection to safeguard it from further corrosion. In contrast, phosphoric acid processes, in addition to de-rusting, coat steel surfaces with insoluble phosphate films which confer a measure of corrosion protection and form a good base for paint.

NOTE: Phosphating processes should only be used on aircraft parts if cadmium plating is impracticable.

(a) **Pickling Solutions.** Information on the pickling of steels is given in DEF STAN 03-2, which specifies solutions of 10% hydrochloric acid in water or 10% sulphuric acid in water. Since immersion in these solutions causes hydrogen absorption, heat-treated steels of more than 1004 MN/m^2 (65 $tonf/in^2$) ultimate tensile stress (UTS) should only be pickled by the electrolytic method given in paragraph (b) below. The danger of blistering and embrittlement of other steels due to hydrogen entering the metal can be reduced by adding inhibitors (such as quinoline ethiodide) to the acid, but if inhibitors or wetting agents are used the parts should have a final dip for not more than 2 minutes in an acid solution free of such substances. After immersing parts in dilute acid solutions they should be rinsed in clean water and dried. Limited brittleness can be reduced by heat treating the steel at 150 to 200°C.

(b) **Electrolytic Pickling.** The advantages of this method are twofold. Chemical cleaning is assisted by the evolution of oxygen on the surface of the metal and, as hydrogen is only produced on the cathode, no embrittlement occurs. An electrical bath is required containing a solution of 30% by volume of concentrated sulphuric acid in water, to each litre of which can be added 18 g of potassium dichromate (3 oz/gal). With the part as the anode, a current density of 1000 amps/m² (100 amps/ft²) should be applied for approximately 5 minutes, after which the part should be rinsed in clean water and thoroughly dried.

(c) **Phosphating Processes.** Certain commercial phosphoric acid treatments, such as Waterisation, Jenolising and Bonderising, are approved for aircraft use by the provisions of DTD 900. These processes should be considered as foundation treatments for painting and not as reliable anti-corrosive measures in themselves. To obtain satisfactory phosphate films they should be applied in accordance with the instructions issued by their Manufacturers.

NOTE: Some laboratories state that electrolytic pickling of steels does produce embrittlement in high tensile steels, and that heat treatment is necessary afterwards for steels above 1004 MN/m² 65 tonf/in²) UTS. If plating is to be carried out, the heat treatment should follow that process as soon as possible and, in any event, within 2 hours.

4 ASSESSMENT OF CORROSION DAMAGE After removing paint, grease and corrosion products, the affected parts should be examined to determine whether their strength has been lessened beyond permissible limits. Pitting may cause local stress concentrations which may seriously impair both the static and the dynamic strength of thin sections whilst surface corrosion, without causing pitting, can lower the fatigue strength of load-bearing members. Cleaning operations often cause an appreciable reduction in cross-sectional area which must also be considered when evaluating the decrease of strength.

NOTE: A corrosive attack on a structural member will cause a reduction in strength out of all proportion to the reduction in thickness of the member; this should be borne in mind at all times when assessing corrosion damage and particularly when light gauge construction is involved such as a pressurised skin structure.

4.1 **Skin Panels.** Corrosion damage to aircraft skins should be classified as negligible or repairable according to the extent, depth, loading and location of the damage. It is not possible to give a general rule for classification based on the percentage reduction of skin gauge or the number of pits per unit area, as the load distribution through the affected panels must be considered. It is therefore essential to consult the approved repair scheme for the aircraft concerned. Some general guidance on the assessment and rectification of damage is given in the following paragraphs. It must be appreciated, however, that all previous corrosion rectifications must be taken into consideration.

4.1.1 If no pronounced pitting or roughening of the skin is evident after the removal of corrosion products, it is usually satisfactory to re-protect the part by applying the appropriate finishing scheme (see Leaflet **BL/4-3**).

4.1.2 Skin panels which have a rough and pitted surface after the corrosion products have been removed should be smoothed down with fine grade wetted sandpaper. The minimum reduction of cross-sectional area consistent with the blending out of jagged pits should be the aim. After smoothing, the minimum skin thickness in the affected region should be computed by measuring the depths of the deepest depressions; a method of mounting a dial test indicator for use as a depth gauge is illustrated in Figure 1.

NOTE: Where access is difficult, radiological and/or ultrasonic examination techniques (see Leaflets **BL/8-3** and **BL/8-4**) are often prescribed to determine the presence or extent of a corrosive attack. In some instances, however, such as at faying surfaces of stringers to skin panels, dismantling of specified parts of the structure has been found necessary as the only means of ensuring adequate inspection.

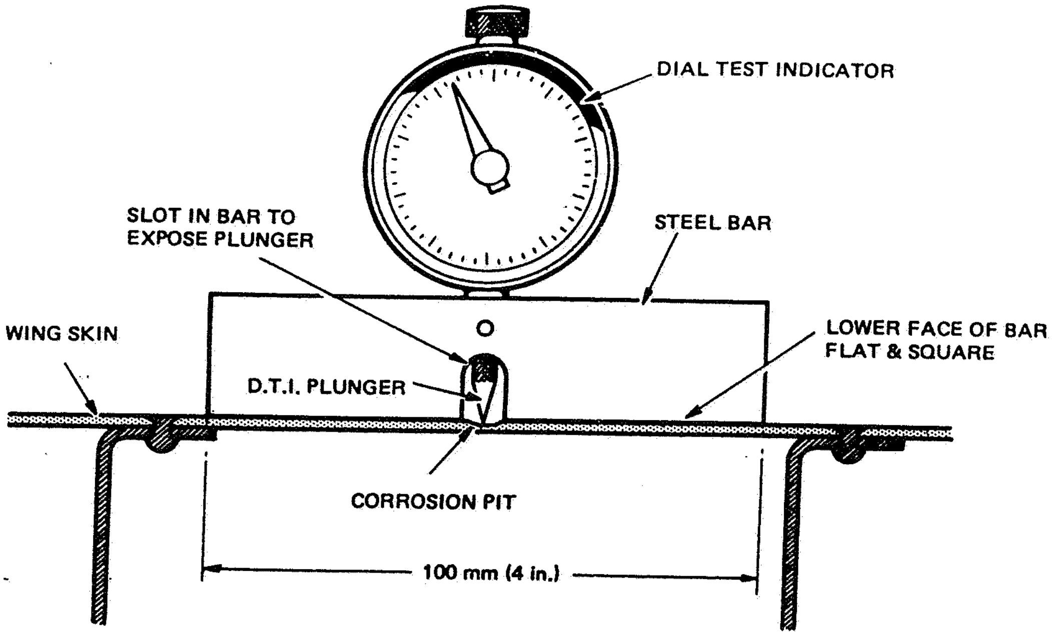

Figure 1 ASSESSMENT OF SKIN PANEL CORROSION

4.1.3 If the damage exceeds the general limits specified by the Manufacturer as negligible but is not thought to be of such a severe nature as to warrant renewal of the whole panel affected, the Manufacturer may, in some instances, issue a repair scheme whereby the original strength of the panel can be restored by the addition of local reinforcements.

4.1.4 If the smoothing down of corrosion damage would reduce the thickness of skin panels or similar components beyond permissible limits, they should be renewed. During removal the condition of rivets and faying surfaces should be examined. If these show signs of corrosion, repairs will be necessary over a wider area than that indicated by the extent of the surface damage.

NOTE: For guidance on repairs to metal aircraft structures reference should be made to Leaflet **AL/7-14.**

4.2 **Load-bearing Members.** The effects of corrosion on the strength of main load-bearing members can be serious. It has been clearly established that the fatigue life of wing spars can be drastically shortened by corrosive attack and these members should therefore receive the most careful attention during periodic inspections.

4.2.1 The inspection of spars is often rendered difficult because of limited access to the interior of the wing structure and because portions of the spar are obscured by electrical cable installations, fuel pipes, control mechanisms, etc. Special optical aids to facilitate inspection such as those outlined in Leaflet **AL/7-13** should be used to detect corrosion and, after its removal, to assess the damage it has caused. Areas affected by pitting should be checked for cracks by the penetrant dye method described in Leaflet **BL/8-2**.

4.2.2 Serious cases of spar corrosion should be reported to the Manufacturer of the aircraft. If minor corrosion is discovered, rectification should be possible in accordance with the approved repair manual for the aircraft.

4.2.3 When specified in the appropriate publication or at other times at the discretion of the inspector, a selection of the main assembly bolts should be removed and examined for signs of corrosion. The aircraft structure must be adequately supported to prevent strain and distortion before the bolts are removed. Before replacing assembly bolts they should be magna-flux tested (Leaflet **BL/8-5**) and the bolt holes should be carefully inspected for evidence of attack on the surrounding material. If cadmium has been removed from the bolts, they should be replated before replacement (Leaflet **BL/7-2**), and at all times jointing compound should be applied immediately before insertion, in accordance with the appropriate instructions (see also Leaflet **AL/7-8**).

NOTE: The inspection of bolt holes is a matter of great importance but often of unusual difficulty. Pits and cracks tend to be concealed by corrosion products, which are forced into them as the bolt is extracted. If the hole is reamed before inspection, the reaming action tends to close the edges of cracks; the hole should therefore be inspected both before and after reaming. In some cases satisfactory results may be obtained by cleaning the hole with a round bristle brush using the mixture of white spirit and naphtha recommended in paragraph 2.1. After cleaning it may be possible to adapt the penetrant dye or fluorescent method of detection (Leaflets **BL/8-2** and **BL/8-7**) to the particular job, using an endoscope or a light probe (Leaflet **AL/7-13**) in the bore of the hole. The eddy current method of examining bolt holes is effective and is often used where inspection by optical means is impracticable.

4.3 **Tubular Members.** Welded steel or aluminium alloy tubes used in aircraft construction are usually thin-walled and can therefore be seriously weakened by corrosion. Although external corrosion can be seen during inspection, internal corrosion may remain undetected until the tube is so weakened that failure occurs. For this reason it is essential that tubes are protected internally during assembly and sealed to prevent accumulation of moisture. Open-ended tubes should be protected internally and externally by the same method.

4.3.1 There is no completely reliable method of determining whether a sealed tube is corroded internally, short of cutting it open, but ultrasonic and radiological methods of examination will give an indication of reduction of thickness.

4.3.2 During assembly or after repair the interior of sealed tubes should be flushed with a protective material and reference should be made to the Manufacturer for the appropriate one to be used. Some such corrosion inhibitors are hot linseed oil, lanolin or zinc chromate pigmented lanolin to specification DTD 279 being particularly suitable. The flushing liquid is normally introduced through small holes, for which the appropriate design approval should first be obtained, drilled in the tubing. Surplus liquid should be drained off through suitable drain holes. It may be possible as an alternative, to remove an existing bolt or rivet ensuring that the hole is not enlarged. When sufficient liquid has been introduced to give a good coating, the holes should be plugged to exclude air or moisture.

NOTES: (1) If, for any reason, the above procedure cannot be carried out, the danger of corrosion will be greatly reduced if the enclosed air is dry and the tube is effectively sealed against the ingress of moisture. The interiors of steel tubes can be further safeguarded by the introduction of a Vapour Phase Inhibitor. Marketed in powder form, vapour inhibitors consist of stable organic nitric compounds which release corrosion-inhibiting vapour at a slow rate. The vapour will prevent corrosion even when oxygen and moisture are both present.

(2) During maintenance and overhaul, radiological methods of examination (Leaflet **BL/8-4**) are sometimes used for the detection of damage in tubes of relatively thin cross section. This method will show changes in sectional thickness when corrosion is present and, with the correct technique, some idea of the depth of the corrosive attack can be obtained. Similarly, in some instances where tubular members are made of heavy gauge, ultrasonic methods of examination will give an indication of local reductions in thickness (Leaflet **BL/8-3**).

4.4 **General.** Components which are not part of the structure can usually be removed for anti-corrosive treatment. If items such as pumps, valves and electrical equipment are found to be corroded, rectification appropriate to the particular material and its duty should be made. Reference to the relevant Manufacturer's publications for the aircraft concerned should be made at all times. Some points of special interest are listed below.

4.4.1 Doped fabrics in contact with painted metal surfaces sometimes cause the paint to deteriorate with the result that the metal is attacked. The metal should be protected by the application of a dope-resisting paint on top of the normal finish.

4.4.2 A method of protecting seaplane floats is to tie bags of potassium or sodium dichromate to the keelson so that the dichromate permeates the bilge water.

4.4.3 Light alloy tanks containing leaded fuels should normally be protected by corrosion inhibitor cartridges. Typically, these cartridges consist of strontium chromate or calcium chromate tablets contained in a linen bag. It is a requirement with such cartridges that the linen bag should be thoroughly wetted with water before installation, and after tank repair operations.

4.4.4 When locking wire is used, it should be of a material which will not cause electro-chemical reaction with the part locked.

4.4.5 Control cables should be protected after installation, and at intervals, by applications of rust-preventing compounds. Lanolin-resin compounds or preparations containing zinc chromates are sometimes recommended; these should be diluted and applied so as to ensure penetration of the compound between the strands of the cable whilst avoiding an excess accumulation which would cause stickiness of controls in fairleads and pulleys.

NOTE: British Standards W9 and W11 call for a lubricant to be applied during the spinning of cables. It is therefore important, when cleaning these cables, not to wash out the lubricant by saturating the cables with a grease solvent.

4.4.6 During assembly and repair, dissimilar metals should be insulated from each other unless there are overriding structural and functional considerations. Corrosion-inhibiting sealing compounds should be applied wet between all faying surfaces immediately prior to assembly: solutions containing zinc or barium chromate are generally used. Most of the proprietary materials and processes are to be found in specification DTD 900. The compound should be applied in sufficient quantities to cover all contacting faces and to cause a small quantity to be squeezed out at the boundaries to form sealing fillets. Where special compounds are used for particular purposes, e.g. to seal pressure cabins or integral fuel tanks, they should be used to insulate dissimilar metals in addition to forming a seal.

NOTE: Unsatisfactory results will be obtained if inhibiting jointing compounds are kept in open containers which allow the compound to become semi-dry before application. This trouble can be avoided if the compound is supplied in squeeze-tubes, from which it can be directly applied to the joint.

4.4.7 Metal parts in contact with wood should be treated with the prescribed compound before assembly, in order to prevent corrosion due to moisture in the wood.

4.5 **Protective Treatments.** Metal surfaces (on other than stainless steels and un-alloyed titanium) should never be left unprotected after cleaning or repair. Where practicable the original protective treatment should be restored. In other cases alternative treatments suitable for application during maintenance work may be authorised. General information on the corrosion-proofing and finishing of aircraft is given in Leaflet **BL/4-3**, whilst details of some of the particular protective treatments are given in the BL/7 series of Leaflets, and specifications DTD 900, 903, 904, 905, 909 and 911, DEF STAN 03-2 and 03-7, BS 2569 Part 1 and 2, BS 4921 and Specification DEF 151.

BL/4-3

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BASIC

MATERIALS

CORROSION—METHODS OF PROTECTION

1 INTRODUCTION

1.1 This Leaflet gives guidance on the selection and application of protective treatments to safeguard aircraft from corrosion. It should be read in conjunction with Leaflets **BL/4-1** and **BL/4-2,** which give general information on the control and rectification of corrosion, and with the relevant leaflets of Section BL/7, which give details of some of the treatments mentioned in this Leaflet.

1.2 When re-protecting aircraft, reference must be made to the appropriate Manufacturer's publications for guidance on the anti-corrosive treatments specified for the aircraft concerned. Reference should also be made to the latest issues of the relevant British Standards and Ministry of Defence DTD Specifications when these are quoted.

2 PREVENTION OF CORROSION Protection against corrosion can be provided in a number of ways. Some of the principles involved are briefly summarised in the following paragraphs.

2.1 **Choice of Metal.** Certain metals and alloys have a high natural resistance to corrosion. This applies to the noble metals because they have a low affinity for oxygen and other non-metallic elements, but the resistant materials which are used in aircraft construction, e.g. stainless steel and aluminium, owe their properties to thin films of oxides which protect the metal from further attack. However, because of strength or weight considerations, many aircraft parts cannot be made of 'self-protecting' material and hence require anti-corrosive treatment.

2.2 **Passivity.** In certain conditions metals and alloys commence to corrode and the initial products of corrosion form protective films which limit further attack. Natural passivity is sufficient protection for pure aluminium and the stainless steels, but passivity has to be produced under controlled conditions to be of value for aluminium alloys. The anodic treatment described in Leaflet **BL/7-1** is a form of artificial passivation.

2.3 **Surface Finish.** The oxide films on non-stainless steels do not become passive but corrosion-resistance can often be greatly increased by careful attention to mechanical finish. Thus some internal engine parts are highly polished but otherwise are only protected by a coat of clear varnish.

2.4 **Chemical Inhibition.** One of the most widely used methods of protection is to treat the metal with chemicals which inhibit or stifle corrosion and so artificially induce a form of passivity. The phosphate process for steels and the chromate and fluoride treatment for magnesium alloys are inhibiting treatments. Paints and primers usually contain inhibiting substances to increase the effectiveness of the protection they offer. It should be appreciated, however, that the inhibiting treatments are temporary and that the full treatment will include oil or paint films (paragraph 2.6).

2.5 **Sacrificial Protection.** When two metals of different electric potential are in close contact, the elements of a voltaic cell are established and the metal which is anodic to the other may be preferentially attacked. This principle is often deliberately applied to protect constructional materials. For example, cadmium and aluminium coatings protect steel because these metals are anodic to steel; at the same time the protection they render is long-lasting because they corrode at a much slower rate than steel. Similar protection is extended to aluminium-alloy sheet when it is clad by surface coats of pure aluminium; this protection is effective even at the sheared edges and where holes are drilled.

2.6 **Mechanical Protection.** Corrosion can be prevented by excluding water, oxygen and corrosive chemicals from the surface of the metal. This form of protection is the basis of most organic coatings, such as varnishes, paints and enamels, which are applied on top of inhibitive priming coats. To be effective the coats should be as watertight as possible, but, since even the best paint coats only delay rather than prevent the ingress of water, periodic re-protection is essential. Metallic coatings applied by spraying, dipping or electro-deposition may also give satisfactory mechanical protection.

3 TREATMENT OF AIRCRAFT PARTS It is the responsibility of Approved Design Organisations to specify the forms of protection to be used during the manufacture of each particular type of aircraft. During the operational life of the aircraft the original treatment should be renewed when necessary, but where this is impracticable a suitable alternative method should be specified.

3.1 **Chemical and Electro-chemical Treatments.** Treatments in this category are those which strengthen the natural oxide film of the base material or which convert the metal surface chemically to a protective coating of phosphate, chromate, etc. The most satisfactory results are usually obtained by immersion treatments but where these are impracticable brush-on applications can often be used. In the following paragraphs the standard immersion treatments for the principal aircraft constructional materials are given, together with brush-on substitutes which can be used for repair or in emergencies.

3.1.1 **Steel.** The majority of chemical treatments for steel involve the formation of phosphate films and to a certain degree are covered in Leaflet **BL/4-2.** Proprietary immersion and brush-on applications, if approved under the provision of the latest issue of DTD 900, can be used to inhibit corrosion and to form a base for painting steel parts which cannot be protected by metallic coatings. Certain processes can be followed by immersion in mineral oil to render them suitable for moving parts; the phosphate coating absorbs the oil and provides a wear-resisting surface. Chemical treatments do not provide adequate protection for steel if used alone; further corrosion-proofing, e.g. painting, is usually specified.

3.1.2 **Aluminium and Aluminium Alloys.** The most satisfactory chemical treatment for these materials is anodic oxidation (Leaflet **BL/7-1**). Unless clad with pure aluminium, the majority of aluminium alloy parts are anodised. Anodised structural components usually receive further protection from priming and paint coats.

(a) There are a number of proprietary processes which increase corrosion resistance and improve the adhesion of paint to aluminium and aluminium alloys. They are mostly simple chemical processes in which the parts are immersed in hot solutions of salts for periods of up to 10 minutes. It is not essential to apply paint immediately after the application of such processes as Alocrom or Walterisation L, as these render the surface passive; on the other hand it is undesirable to leave the treated surfaces so long that they become dirty before being painted.

NOTE: Processes which merely pickle the surface of aluminium-alloys, such as the Chromic-Sulphuric acid treatment of Specification DEF 130 and the Deoxidine treatments, do not protect against corrosion and should be followed immediately by priming and painting.

(b) Films can be produced by the application of pastes to parts in situ, e.g. Alocrom 1200; they are not as satisfactory as films produced by immersion treatments but are useful for items not exposed to weathering or abrasion.

3.1.3 **Magnesium Alloys.** Some chemical treatments for magnesium alloys are covered in Leaflet BL/7-3. The immersion processes given in that leaflet are all chromating processes but local repairs to protective films can be effected by the Alocrom 1200 chromate conversion by swab method. Another method of protecting these alloys is by the electrolytic fluoride method known as "Fluoridising". This involves anodising the components in a solution of ammonium fluoride. It is a particularly effective method for the removal of moulding contaminants and for restoring corrosion resistance which may have been reduced by processes such as shot or grit blasting. The process consists of applying a.c. current when the items are immersed in the solution, the voltage being gradually increased to a value of 100 volts. The current falls proportionately as impurities are removed from the surface of the magnesium alloy and a thin coating of magnesium fluoride is formed. This coating has a protective value about equal to that of a chromate film and forms a good paint base. To obtain satisfactory results, full details of the process should be obtained from the Manufacturer.

3.1.4 **Zinc Coated Components.** Metallic coatings of zinc are sometimes used to protect steel parts, but zinc coatings tend to corrode rapidly unless rendered passive. After plating with zinc, the chromate passivation process described in DTD 923 should be employed.

3.2 **Metallic Coatings.** The protection of one metal by the application of a surface coating of another of greater corrosion resistance is common practice. Thus, aluminium-alloy sheet used in aircraft construction is usually clad on both faces with thin layers of pure aluminium rolled on during manufacture. Steel is protected by a greater variety of methods, the more important of which are summarised below.

3.2.1 **Cadmium Plating.** The electro-deposition of cadmium (Leaflet BL/7-2) provides the most satisfactory form of protection for AGS and other parts of non-stainless steel. It is the standard anti-corrosive treatment for streamline wires, tie-rods and similar parts which are not usually painted. Where steel bolts and other parts are in close contact with light alloys, cadmium plating greatly reduces the danger of corrosion resulting from the proximity of dissimilar metals; it has been found that this is so even when the cadmium coat is scored or partially rubbed off. Cadmium plating can be applied to close dimensional limits and is suitable for the protection of closely fitting attachment bolts. The relevant British Standards for cadmium plated bolts with close tolerance shanks are A59 and A111, and for shear bolts A60 and A112.

NOTES: (1) It should not be assumed that stainless steels in contact with aluminium alloys are unlikely to promote intergranular corrosion or corrosion fatigue. For this reason it is advisable that they too should be cadmium plated, but a special technique is essential to ensure good adhesion of the cadmium. A plating technique that is suitable for some specifications of stainless steel involves degreasing, anodic pickling in dilute sulphuric acid (Leaflet **BL/4-2**), the deposition of a preliminary coating of nickel and, finally, cadmium plating by the usual method.

(2) Further protection by painting is not usually necessary on interior cadmium plated parts but, if it is specified, the cadmium coating should first be passivated by the process given in Specification DEF 130 or an etch primer should be used.

3.2.2 **Nickel and Chromium Plating.** These two metals are electrically deposited in a similar manner to cadmium; nickel-plating is cathodic to steel but will give good corrosion resistance if the coating is uniform and free from discontinuities. It is used for some turbine parts which are subjected to fairly high temperatures, and for the protection of many springs. Chromium is sometimes applied directly to the steel parts of aircraft as an anti-corrosive treatment and sometimes is deposited on top of nickel plating to improve appearance. Chromium plating is also used to resist wear in some engine cylinders, landing-gear shock-struts, jack rods, etc.

3.2.3 **Metallising.** Aluminium, zinc, cadmium and certain other metals can be sprayed directly on to steel from special pistols. The metal is fed into the pistol as a wire or a powder and is melted by an oxy-acetylene flame. Compressed air then blows it in the form of tiny molten globules on to the surface to be coated, where it solidifies. Spray coats of aluminium are applied to engine bearers, steel tube assemblies, combustion chambers, etc. Some of these items are afterwards painted but this is not always necessary.

3.2.4 **Flame Plating.** This process, similar to some metallising, is carried out on many aircraft parts which are subject to wear by fretting, particularly engine components such as compressor and impeller blades, combustion chamber parts and seals. It is sometimes applied to hydraulic pumps and motors. Briefly, the process consists of a charge of powdered tungsten carbide, chromium carbide or similar hard material, suspended in an oxygen/acetylene mixture in the breech of a special gun. The mixture is detonated and the particles become plastic; they are then blasted on to the areas being coated. This is repeated until the entire surface is coated to the required depth. Stripping of worn coatings can be carried out and new coatings applied, and thus the life of expensive components is considerably extended.

3.2.5 **Powder Processes.** Metal coatings of zinc and aluminium can be produced by packing steel parts, after sand blasting, in suitable mixtures containing the appropriate metal and heating them in sealed containers to specified temperatures. The application of aluminium by this method is known as Calorising. Sheradising, covered by BS 4921, creates a coat of zinc-iron alloy on steel parts.

3.2.6 **Replating Local Areas.** Local repairs to damaged metallic plating, and the deposition of metals in places where accessibility is limited, can be accomplished by certain plating processes without immersion in a plating bath. The part to be plated should be made the cathode by connecting it to a d.c. power unit. The electrolyte is brushed over the metal surface by an absorbent pad attached to the end of a graphite anode; the anode, which is called a "tampon", is air or water-cooled according to size. Plating solutions and current densities should be selected according to the Manufacturer's recommendations. Cadmium, copper, zinc, tin, etc., can be deposited very rapidly by this method.

3.3 **Organic Coatings.** Paints, varnishes and enamels protect metals by inhibition, by mechanical exclusion of corrosion influence, or by a combination of both these methods. Before application, the metal surfaces should be cleaned and pre-treated to provide a good key for the paint. General guidance on pre-treatment is given in Leaflet **BL/4-2**; mechanical roughening, chemical etching, chemical film formation or preliminary deposition of metal coating should be in accordance with approved practice for the materials concerned. Reference should always be made to the relevant aircraft Manufacturer for details of the organic coating scheme to be applied to a particular aircraft.

3.3.1 **Priming Coats.** Most aircraft painting schemes commence with the application of a primer containing an inhibiting chemical such as zinc chromate. The majority of primers are air drying, but when a stove enamel finish is specified the priming coat is also stoved (BS X31). Primers can be directly applied by brush or spray to aircraft parts in situ, but dipping is sometimes preferred for detachable items. Primers to suit the wide range of finishing schemes covered by the Ministry of Defence Process Specifications are supplied as proprietary products; care should be taken to ensure that the Specification selected is appropriate to the particular job. When painting certain aluminium alloy structures it is sometimes advantageous to use etching primers which obviate the need for preliminary etching by Deoxidine and similar chemicals. General guidance on finishing schemes is given in paragraphs 5 and 6.

3.3.2 **Cellulose Finishes.** Cellulose finishes are specified for many individual components of civil aircraft as well as for the exterior finishing of metal-skinned aircraft, as they give finishes which have good adhesion and resistance to weathering. Although the best results are obtained by spraying on top of a suitable primer, one-coat applications direct to pre-treated aluminium or aluminium-clad alloys have sometimes been used.

3.3.3 **Synthetic Finishes.** A number of external finishing schemes for the metal surfaces of aircraft are based on the use of pigmented oil varnishes or pigmented synthetic resin finishes. The relevant British Standard is BS X28 and the Ministry of Defence Specification is DEF 1044. The majority of finishing schemes are two-coat treatments; the pre-treated metal surface is given a brush or spray coat of the primer applicable to the scheme and, after the primer has dried, the finishing coat is applied by spray. Synthetic finishes should only be thinned with approved thinners (DTD 96); thinners for cellulose paints and dopes are generally unsuitable. As a general rule priming coats require a longer drying period for synthetic finishes than for cellulose finishes.

3.3.4 **Lanolin-resin Finishes.** Lanolin-resin preparations to Specifications DTD 279 and 633 are brush, spray or dip treatments which remain soft for considerable periods and are only occasionally applied to parts of aircraft in service. They have a limited application for the protection of marine aircraft.

DTD 420 covers a range of matt pigmented lanolin-resin finishes suitable for use on metal surfaces exposed to sea water. Generally, two-coat finishes applied by brush or spray are recommended.

3.3.5 **Stoving Finishes.** Stoving enamels generally have a much higher degree of resistance to abrasion than air-drying finishes and are therefore used for some power-plant components and certain airframe parts which are not adversely affected by stoving temperatures. For maximum durability, two-coat schemes are recommended. High temperature stoving finishes, such as those covered by DTD 56, generally consist of two coats of enamel, each of which is baked separately; low temperature finishes, whether proprietary or to BS X31, usually consist of a preliminary priming coat which is baked first, followed by application of the enamel and further stoving.

NOTE: There are some kinds of enamel, e.g. the synthetic glossy black enamel specified in DEF 1044, which can be either air dried or stoved. The principal advantage of stoving is that it shortens the drying time.

3.3.6 **Epoxide Finishes.** Interior and exterior protective finishing schemes of the cold curing epoxide type are now frequently used. There are three schemes: Scheme 1 consists of etch primer and finish; Scheme 2 consists of etch primer, filler and finish or epoxy primer, filler and finish; Scheme 3 consists of etch primer, epoxy primer and finish. Details of the schemes are covered in Specification DTD 5555 whilst the requirements for the materials are detailed in Specification DTD 5567.

3.4 **Special Fuel Tank Treatments.** Special sealing and anti-corrosion treatments are often given to fuel tanks and integral fuel tank structures. In certain instances where there are undrainable areas, these are filled with a light 'void' filler, to prevent the formation of stagnant water pockets in which micro-biological growths can form. Basic structural components are chemically treated, e.g. Alocrom 1200, etc., and in assembly all joints are inter-layed with a sealant such as Thiokol PR 1422. After assembly, all joints are brush-treated with rubber sealant compound such as Buna-N (EC 776) and PR 1005L, and some tanks are then given a final 'slushing' treatment with Buna-N in the tank, to impart a uniform protective film on all inner surfaces. The tank (or structural assembly) is slowly rotated in a special rig, and this ensures that the protective film is free from pinholes. Reference should always be made to the relevant aircraft Manufacturer for the appropriate treatment for any particular aircraft.

4 TESTING PROTECTIVE TREATMENTS The efficacy of a protective treatment depends on its nature, its adhesion to the surface of the basis metal, its thickness, its uniformity and its chemical stability. In many cases the only guarantee of satisfactory protection lies in close control of pre-treatment and application of finish plus the general appearance of the completed treatment, but sometimes it is necessary to test the treated part, or an equivalent test piece, to ensure that the specified properties have been obtained. It is, therefore, advisable to consult the relevant aircraft Manufacturer for the preferred methods.

4.1 **Chemical Treatments.** There is no simple and reliable test for chemically produced films, since they are usually too thin to permit measurement of the thickness of deposits by checking the gauge. Parts on which phosphate films have been produced should be inspected for colour; a finely crystalline grey surface is required, as coarse or sparkling films indicate inadequate cleaning or wrong bath composition. Chromate films on magnesium alloys are judged by their colour, as explained in Leaflet BL 7-3.

4.2 **Anodic Treatment for Aluminium Alloys.** Leaflet **BL/7-1** gives two practical methods of testing anodic films, i.e. the methyl violet test for sealing and the electrical potential test. The average thickness of anodic films can be checked by the method given in British Standard 1615, in which a test piece with a surface area of not less than 32 cm^2 (5 in^2) is anodised and then stripped in a boiling solution of phosphoric acid and chromic acid in distilled water. The test piece should be immersed until constant weight is obtained, the loss of weight being taken as the weight of the anodic film.

NOTE: Eddy current instruments are available and can be utilised to gauge anodic films.

4.3 **Coating Thickness Measurement.** The thickness of conducting or non-conducting coating on ferrous or non-ferrous bases can be measured using basic eddy current methods (see Leaflet **BL/8-8**), although measurement becomes difficult where the conductivity of the coating and base metal are similar. When measuring thin coatings it is recommended that equipment designed specially for coating thickness measurement should be used.

4.4 **Electro-plated Coatings.** The British Non-Ferrous Metal Research Association has devised a standard test for the inspection of electro-deposited metallic coatings; the BNF Jet Test is for local thickness measurements and has the advantage over other chemical methods in that it gives the thickness at any desired point. An adhesion test for the detection of local non-adherence of metallic coatings is given in BS 1224, Appendix C, and is summarised in paragraph 4.4.2.

4.4.1 **The BNF Jet Test.** The apparatus for conducting this test is illustrated in Figure 1. The separating funnel should be filled with a reagent solution appropriate to the nature of the metal; suitable solutions for testing cadmium and zinc coatings are given below. The test should be made as follows:

(a) The article to be tested should be clamped so that the surface under test is at an angle of about 45° to the horizontal and about 6 mm (¼ in) below the tip of the jet.

(b) Jet Test solutions for cadmium and zinc coatings are:

	Cadmium	**Zinc**
Ammonium nitrate	17·5 g	70 g
N/1 Hydrochloric acid..	17·5 ml	70 ml
Distilled water to produce	1 litre	1 litre

(c) The tap should be opened and, simultaneously, a stop-clock should be started. At the end of 5 to 10 seconds, the tap should be closed and the clock stopped simultaneously and, without moving the specimen, the test piece should be examined for penetration.

(d) The process in (c) should be repeated until the first sign of penetration is seen below the jet. The total time of impingement is taken as a guide for a further test in which the reagent is allowed to run continuously until the end-point is nearly reached.

(e) The temperature of the solution and the total time for penetration are the data from which the thickness is calculated. The time required for a particular penetration at the temperature of the test should be obtained from curves supplied by the Manufacturer of the test apparatus and the total time of penetration should be divided by this time.

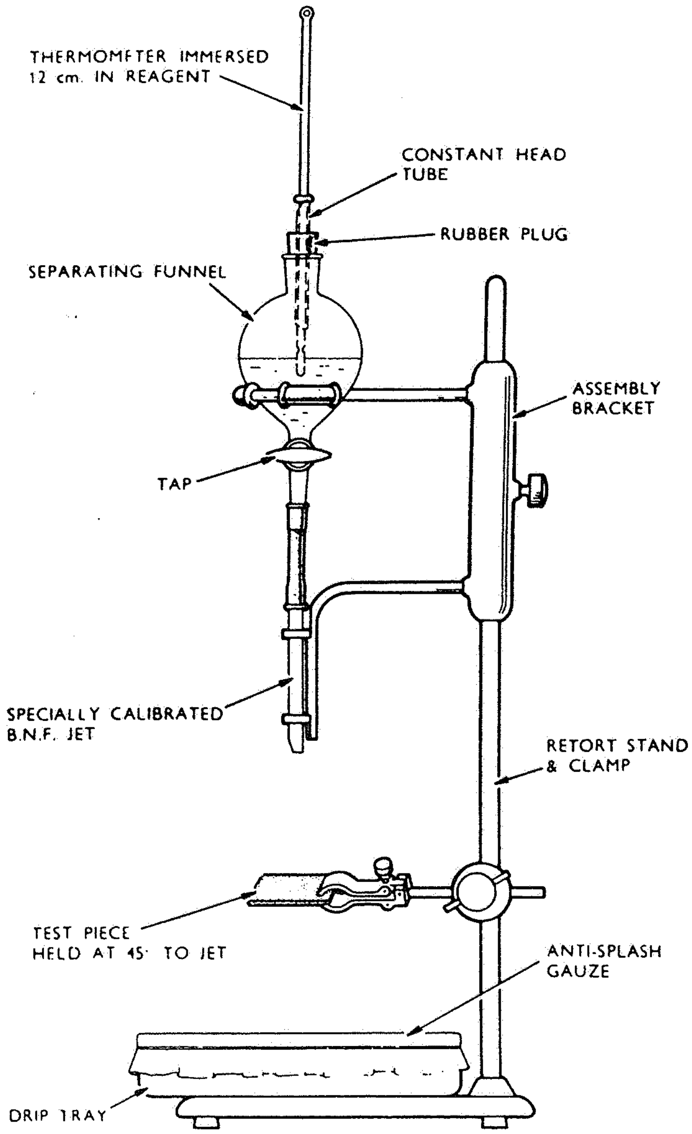

Figure 1 APPARATUS FOR BNF JET TEST

4.4.2 **Test for Determination of Adhesion.** An area of 6 cm^2 (1 in^2) of the plated surface should be rapidly and firmly rubbed for 15 seconds with the smooth edge of a metal implement such as a copper coin, the pressure being sufficient to burnish the film at every stroke without cutting into it. If inspection then shows no detachment of the deposit, the adhesion is satisfactory. A blister which grows with the rubbing indicates poor adhesion; splitting and peeling of the deposit shows it to be of inferior quality.

4.5 **Organic Finishes.** The standard method of testing the corrosion-resistant properties of paint, varnish, lacquer and related products is by means of the salt spray test specified in Method No. 24 of Ministry of Defence Specification DEF 1053. The apparatus for making this test is shown in Figure 2. It consists of a glass tank with a close fitting lid in which a salt mist is produced by spraying the test solution through an atomiser. Test panels, the preparation of which is given in detail in Method No. 2 of the Specification, are painted with the finish under test and are then supported on non-metallic supports with their test faces upwards. They should be at approximately 15° to the vertical in the tank so that they will be evenly coated with droplets of solution, but the spray must be prevented by a baffle from impinging directly on to the test faces. The salt solution drained from the panels should not be recirculated. The composition of the solution should be as follows:

Calcium sulphate ($CaSO_4$)	1·3 g
Magnesium chloride ($MgCl_2$)	2·6 g
Magnesium sulphate ($MgSO_4$)	1·7 g
Sodium chloride (NaCl)	21·4 g
Water (distilled)	to 1000 ml

Test panels are normally exposed for periods of 10 days, at the end of which period they should be removed, washed in running water and dried with absorbent paper. Any deterioration in the paint film should then be noted, after which a strip 150 mm × 50 mm (6 in by 2 in) should be cleaned off with a suitable paint remover to permit inspection of the underlying metal for corrosion.

NOTE: When required, the thickness of paint coats can be gauged by using the electrodes of a capacitance-type proximity meter. This method is applicable whether the base is ferrous or non-ferrous. Eddy current (for non-ferrous bases) and magnetic (for ferrous bases) thickness meters are now in use. They are not greatly affected by permeability or curvature of the base material and may be used on organic or metallic coatings.

5 EXTERNAL FINISHING OF AIRCRAFT Finishing schemes for metal-skinned aircraft are selected to provide the maximum of corrosion protection with the minimum weight of paint. Adherence of finish, effect on aircraft performance and appearance are also important; therefore, verification of the scheme used should be obtained from the relevant aircraft Manufacturer.

5.1 **Surface Finishes.** Cellulose or synthetic finishes give satisfactory protection if applied on top of suitable primers. After pre-treatment the metal surface should be finished in accordance with a recognised scheme; for the best results it is advisable to use compatible primers, undercoats and finishing coats from the same Manufacturer. Polyurethane and acrylic finishes are now widely used in some modern aircraft, whilst others utilise epoxy paint and epoxide primers.

5.2 **Retouching Local Areas.** It is not always necessary to clean down to the bare metal before touching up a damaged finish but this is advisable if there is any evidence of flaking or blistering. The area should be flattened down with 'wet' sandpaper or with pumice powder applied with a damp cloth. The edges of the area should be feather-edged. If stopping is required, the stoppers should be applied with a knife. The priming coat should then be sprayed on using a round instead of a fan spray and spraying from the feather-edge inwards. The same technique should be used for the finishing coat, for which it is advisable to adjust the spray gun to give a finer spray than usual.

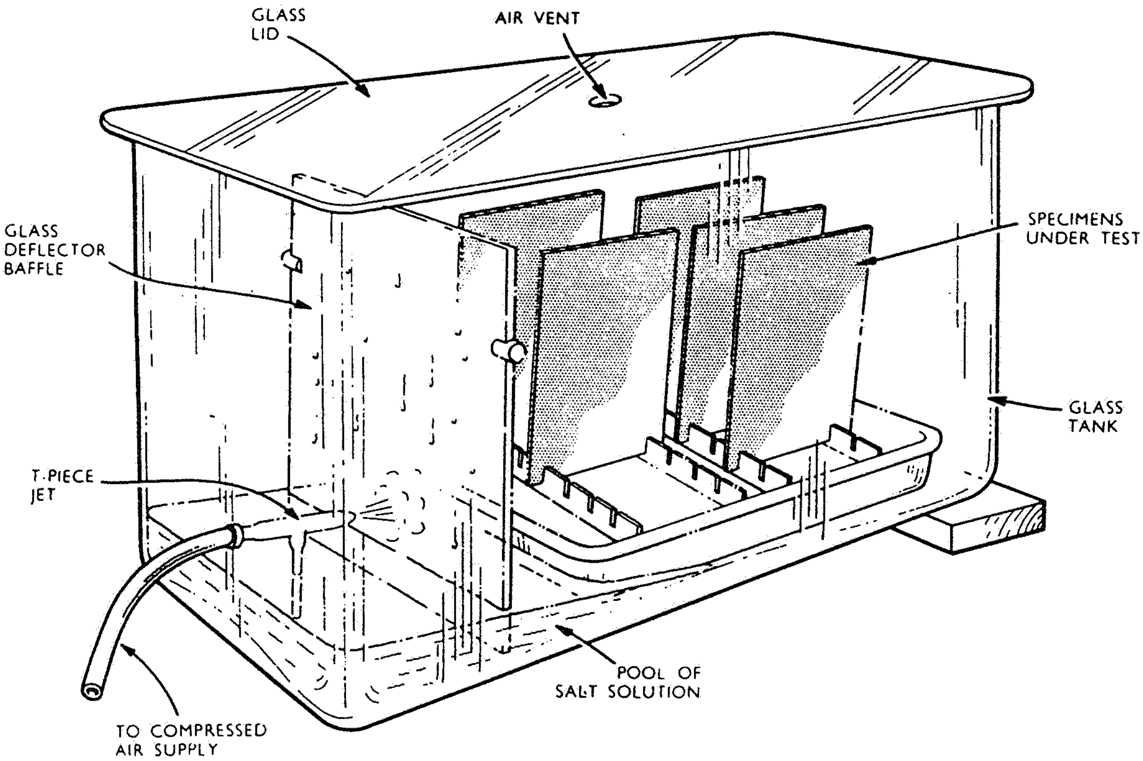

Figure 2 APPARATUS FOR SALT SPRAY TEST

5.3 Experience has shown that external paint schemes reduce maintenance labour and enhance the appearance of an aircraft. Stoving is carried out where practicable, but the paint materials used, including the latest epoxy/polyamide, will be suited to air-drying touch-up operations which might be necessary from time to time. Most paint materials are described in Ministry of Defence Specifications DTD 827, 5555, 5567, 5580 and 5599.

6 INTERNAL FINISHING OF AIRCRAFT The interiors of wings, fuselage, etc., are usually protected by at least one coat of zinc-chromate or general purpose primer. This should be applied by spray, care being taken to ensure that all corners and enclosed spaces are adequately covered. Where greater resistance to abrasion is required, a cellulose or synthetic finish is applied on top of the primer. Special additional treatments are given to areas subject to excessive contamination.

6.1 Some aircraft Manufacturers ensure that every component receives a full protective treatment, including painting, at the detail stage. Paint is applied to clean pre-treated metal surfaces and stoved to ensure the best adhesion and durability. This finish has good resistance to knocks and abrasives, and the parts are thus protected from damage during assembly. In assembly, paint and interfaying compound is present in all joints, giving enhanced protection from corrosion and fretting.

6.2 Aluminium-alloy parts are often protected by the Alocrom 1200 process which has no deleterious effect on the fatigue properties of the metal, and gives a good bond for paint adhesion. Steel components are cadmium plated and then given chromate passivation, which improves the paint adhesion and provides increased corrosion resistance. The paint treatment is often an epoxy/polyamide system using a chromate pigmented primer and a gloss finish which is suited to air-drying touch-up operations. Areas subject to slight contamination may receive chemical cleaning, chemical protection and primer painting only, whilst areas contaminated by water, oil, etc., may receive an additional process of hard gloss finishing paint. Those areas subject to attack from acid or corrosive fluids are given a further treatment of epoxy nylon lacquer.

6.3 Some Manufacturers apply a water displacing corrosion inhibitor to supplement the finishing scheme, and similar material may also be used, where permitted, in cases where interior paintwork has been damaged. These inhibitors are volatile liquids which are sprayed or brushed on the surfaces to be treated; the liquid carrier then evaporates leaving a waxy film on the surface. The inhibitor penetrates small cavities and between faying surfaces and thus prevents the ingress of moisture.

6.3.1 These inhibitors are usually slightly toxic and the appropriate precautions should be observed during their application. In addition, corrosion inhibitors may contain flammable components and may present a fire hazard when mixed with oxygen or subjected to high temperatures. All safety precautions recommended by the Manufacturer should therefore be observed.

BASIC MATERIALS

MERCURY CONTAMINATION OF AIRCRAFT STRUCTURES

1 INTRODUCTION This Leaflet describes the possible effects of the spillage of metallic or mercury salts and solutions on aircraft structures, and the methods by which these substances may be removed.

1.1 Contact between mercury and aircraft structures is, fortunately, infrequent, but on those occasions when it does occur, immediate action is necessary to prevent serious loss of strength in the contaminated components, since the effects of spilt mercury are potentially more dangerous than those of spilt battery acid. The aircraft must not be moved, and no action must be taken which might disturb the mercury and increase the area of contamination. The area must be isolated, and decontamination must be carried out as quickly as possible. Metallic structural members, exposed wires, electrical cables, terminal blocks, and other metallic parts susceptible to mercury attack, must be carefully examined, and replaced or repaired if evidence of corrosion is found.

2 GENERAL If mercury is spilled (by breakage of a container, mercury vapour lamp, thermometer or similar instrument) the mercury will split into small globules, which will quickly disperse over a wide area, and attack many of the metals with which they come into contact. If the spillage occurs in the passenger or freight compartments of an aircraft, some of these globules are likely to find their way through joins in the floor panels and insulation blankets, and come to rest on the aircraft skin and structure, where corrosion and embrittlement of the aluminium may start. A film of oxide, paint, grease or oil, will delay the onset of mercury attack, but where the mercury is in contact with bare metal, and moisture is present, the attack will progress rapidly and cannot be arrested by any normal cleaning process.

2.1 **Amalgamation.** If metallic mercury, or mercury salts or solutions come into contact with any of a number of materials, they combine with the basic material, and form an amalgam which has no appreciable structural strength. This process is very rapid, particularly in moist conditions, and the affected component may be completely destroyed.

2.2 **Embrittlement.** Intergranular penetration by the mercury results in embrittlement, which will initiate cracks, and accelerate crack propagation. Degradation of the structural strength of the material may be complete, and will be accelerated if the material is under stress.

2.3 **Recognition of Mercury Attack.** Evidence that corrosion and embrittlement have commenced, may be recognised visually, as follows:—

(i) On aluminium or aluminium alloys; a greyish powder, fuzzy deposit, or whiskery growth.

(ii) On copper, brass or gold; a silvery stain or coating.

(iii) On silver, cadmium or zinc; the surface of the affected area will appear slightly brighter than that of the surrounding metal. This may be very difficult to see.

2.3.1 In all cases where visual signs of mercury attack are found or suspected, the affected part must be replaced, or repaired by the insertion of new material.

3 HEALTH HAZARDS Both mercury and its vapour are toxic, and at normal room temperatures a toxic concentration will be present in the air above spilled mercury. Care must be taken to prevent mercury and its vapour from being inhaled or swallowed, or from coming into contact with the skin or eyes. If a person finds that his hands have come into contact with mercury, he should not eat, smoke or blow his nose without first washing carefully with soap and hot water. Protective clothing and rubber gloves must be worn by personnel engaged in decontamination, and adequate ventilation must be provided in the working area. After decontamination has been carried out, the protective clothing should be discarded, and the hands, and any tools used, thoroughly washed with soap and hot water.

4 DETECTION Large globules or pools of mercury are normally easily visible, but small particles may be difficult to locate. Fortunately, even minute particles of mercury show up well on an X-ray radiograph, appearing as white dots, while corrosion and embrittlement appear as tree-like forms in the aluminium structure.

4.1 An electronic device known as a 'sniffer' is commercially available, which can be used to detect mercury vapour. This device will also indicate the presence of liquid mercury which is not visible to the naked eye.

5 CLEANING METHODS There is no satisfactory method of removing mercury corrosion, but a number of methods have been developed for picking-up spilled mercury, and these may be broadly classified as mechanical or chemical. On no account should normal methods of cleaning such as washing, wiping with a cloth, or using an air-jet, be employed, as these will merely increase the area of contamination. When collecting loose mercury, care must be taken not to scratch the metal surface, as this could result in mercury attack on a previously unaffected area.

NOTE: Jars containing mercury or other corrosive fluids should always be contained within an unbreakable case, so that accidental demage to, or spillage from, the jar will not introduce additional problems.

5.1 **Mechanical Methods**

5.1.1 **Suction.** A powerful vacuum-cleaner, or vacuum pump, may be used to pick up pools or large globules of mercury. However, since mercury or mercury vapour may have an adverse effect upon their mechanisms, a glass trap should be used to collect the spilled mercury, and should be located near to the free end of the suction pipe. By using suction, rubber pipes of small bore may be adapted to remove mercury from otherwise inaccessible corners. A medicine dropper, or a rubber battery-water syringe, may be used for picking up large globules if no mechanical suction device is available.

5.1.2 **Brush.** A tool developed specifically for picking up spilled mercury, consists of a brush with nickel-plated carbon fibre bristles. When the brush is drawn lightly over the contaminated surface, mercury is picked up by capillary action. The brush should be carefully shaken into a suitable container after each stroke.

5.1.3 **Foam Pad.** A commercially made plastic foam collector may be used on flat surfaces to pick up small globules of mercury. The pad should be pressed onto the mercury, and, when pressure is released the globules will be drawn into the pad. Mercury may then be expelled into a suitable container by squeezing the pad in a special holder.

5.1.4 **Adhesive Tape.** Small globules of mercury may be picked up by pressing adhesive tape or medical plaster onto them, but care is necessary to prevent spreading the contamination during removal of the tape.

5.2 **Chemical Methods.** If calcium polysulphide is brought into contact with mercury, an inert solid (mercuric sulphide) is formed, and this can be easily removed. The normal method of application is to make a thin slurry of calcium polysulphide in water, and to brush this onto the contaminated area. When the mixture is thoroughly dry (after approximately two hours), it may be removed by brushing and vacuum cleaning. An alternative, but less effective method, is outlined in paragraph 5.2.1.

5.2.1 **Chemical Recovery.** In this method a length of flexible electrical cable, comprising fine strands of bare copper wire, is used, together with glass jars or test tubes containing separately, dilute nitric acid (5% by volume in water), distilled water, methylated spirits, and a small quantity of mercury. The recovery process is as follows:—

(i) Bare the cable for 2·5 cm (1 inch) approximately, untwist the wire to form a brush, and immerse the bared wires in the nitric acid for a few seconds to remove any staining.

(ii) Wash the brush quickly in the distilled water to remove the acid, and then in the methylated spirits.

(iii) After shaking off excess liquid, dip the brush in the jar of mercury. An amalgam should form on the bared wires.

(iv) Insert the brush into the spilled mercury to pick up a small quantity, then shake off this mercury into the mercury jar. Repeat this step until all spilled mercury is recovered.

NOTES: (1) Over exposure to air between steps (iii) and (iv), may result in oxidation of the copper wire and failure to form an amalgam.

(2) The active life of the brush after step (iii) may be a few minutes only, and the process will have to be repeated as necessary.

(3) The brush must be discarded if the copper strands show signs of breaking away as a result of amalgamation with the mercury.

DECONTAMINATION PROCEDURE Whenever spillage of mercury has been reported or discovered, the area should immediately be isolated to prevent the spread of contamination through transfer by footwear and clothing. If radiographic facilities are available, the following actions should be taken:—

(i) Locate and remove the source of contamination, taking care to prevent further spillage.

(ii) Carry out a radiographic examination to ascertain the extent of contamination at floor level.

(iii) Remove all mercury from the floor panels, paying particular attention to the joins, and using an appropriate cleaning method (paragraph 5).

(iv) Remove the floor panels, and carry out a further radiographic examination of the underfloor skin and structure, including electrical cables and terminals, and any components of a material which is likely to be affected by mercury attack.

(v) Remove any mercury indicated on the radiographs.

NOTE: If mercury has penetrated between riveted or bolted joints, it will be necessary either to separate the joints, or to completely remove the panels or structure concerned, in order to clean the contaminated surfaces. Drill bits used on contaminated structure should be discarded.

(vi) Carry out a careful visual examination of the area, using a lens of 10× magnification, and renew or repair any components which show signs of mercury attack.

(vii) Carry out a final radiographic inspection to ensure that all traces of mercury have been removed, and re-assemble the skin and structure, using approved repair schemes where necessary.

(viii) Apply a film of oil to the area so as to prevent any minute particles of mercury, which may have been overlooked, from causing future corrosion.

6.1 If contamination is discovered at an airfield without radiographic facilities, the source should be carefully removed and the affected area progressively stripped to the metallic structure. A thorough examination for mercury should be carried out before removing any item, and any mercury found should be removed by a suitable method before proceeding with the stripping. Material exhibiting signs of mercury attack must be renewed or repaired, and the suspect area should be marked with chalk or grease crayon. The aircraft must be routed to a base with radiographic facilities, for complete decontamination and inspection as outlined in paragraph 6.

6.2 Details of the occurrence, including the exact area affected and the action taken, should be entered in the appropriate records.

6.3 After the aircraft has been in service for a short time, a further inspection of the previously contaminated area should be carried out, to ensure that no further corrosion or embrittlement cracking has occurred.

BASIC
ENGINEERING PRACTICES AND PROCESSES
SOFT SOLDERING

1 INTRODUCTION This Leaflet gives guidance on the manufacturing processes involving the use of soft solders. Soft soldering is a method of joining metals without intentional fusion of the basis metal, the solders having a lower melting point than the metals being joined. The term "soft soldering" is used to distinguish the process from brazing, which is performed at higher temperatures.

1.1 Information on brazing is contained in Leaflet **BL/6-2**, on oxy-acetylene welding in Leaflet **BL/6-4**, on arc-welding in Leaflet **BL/6-5**, and on spot welding in Leaflet **BL/6-12.**

2 STRENGTH OF SOLDERED JOINTS The strength of a soldered joint is dependent on the continuity and adhesion of the solder film and the mechanical properties of the solder, and can only be verified by the destruction of the joint. In order to ensure satisfactory joints it is essential that adequate inspection is carried out at various stages throughout the process. In addition, where a large number of similar articles are being soldered, periodic tests can be made by sectioning, or by pulling surfaces apart. In the majority of applications, the solders used are considerably weaker than the materials they join; where the film of solder is too thin the joint will be brittle; conversely, if the film is too thick, the shear strength of the joint will be low. (See paragraph 7.5.)

3 SCOPE OF PROCESS Most metals, with the exception of some aluminium alloys, magnesium alloys and zinc-base die-castings, can be soldered, but before applying the process it should be verified that the relevant specifications permit its use. For example, because of the danger of intercrystalline penetration by the molten solder, the soldering of high tensile steel tubes, complying with specifications such as British Standards T57, T58, T59 and T60, is prohibited, both for jointing and for the attachment of identification labels. The soldering of aluminium with aluminium solder and a suitable flux is possible and is sometimes used for radio and instrument assemblies, but is not normally permitted for other aircraft purposes.

4 MATERIALS The solders and fluxes used for aircraft purposes must comply with British Standards or DTD specifications. Relevant specifications are given in Table 1.

TABLE 1
SOLDERING SPECIFICATIONS

Specification	Description
BS 219	Soft Solders.
BS 441	Rosin-Cored Solder Wire.
DTD 599	Non-corrosive Flux for Soft-Soldering (except high-pressure oxygen equipment).
DEF 34/1	Tinning and Soldering Solution.

4.1 **Solders.** Solder is available in two forms, i.e. stick solder with which a separate flux is used, and solder in wire from having a rosin flux core. BS 219 covers a range of antimonial and non-antimonial stick solders, whilst BS 441 is concerned with wire solders having non-corrosive, activated and non-activated flux cores. (See paragraphs 4.2.2 and 4.2.3.)

4.1.1 **General Purpose Solders.** The solders which may be used for general soldering work are designated in BS 219 and listed in order of tin content in Table 2. Solder manufactured to other specifications may be recommended for particular applications, and an approved proprietary brand of tin/lead solder containing a small percentage of copper is also available for electrical circuit bit-soldering. It is claimed that the copper content reduces bit erosion without impairing the efficiency of the solder.

TABLE 2

GENERAL PURPOSE SOLDERS

Grade	Alloy (%)			Melting Range (°C)	Typical Uses
	Tin	Antimony	Lead		
A K	64 to 65 59 to 60	max. 0·6 max. 0·5	remainder remainder	183 to 185 183 to 188	Components liable to damage by heat, e.g. electrical and instrument assemblies. Nickel and high nickel alloys.
B* F M* R	49 to 50 49 to 50 44 to 45 44 to 45	2·5 to 3·0 max. 0·5 2·2 to 2·7 max. 0·4	remainder remainder remainder remainder	185 to 204 183 to 212 185 to 215 183 to 224	General coppersmiths and tinsmiths bit-soldering and machine work.
C* G	39 to 40 39 to 40	2·0 to 2·4 max. 0·4	remainder remainder	185 to 227 183 to 234	Blowpipe soldering and general fine work.
H L* D* J	34 to 35 31 to 32 29 to 30 29 to 30	max. 0·3 1·6 to 1·9 1·5 to 1·8 max. 0·3	remainder remainder remainder remainder	183 to 244 185 to 243 185 to 248 183 to 255	Dipping baths. General plumbers' work.
V N*	19 to 20 18 to 18·5	max. 0·2 0·9 to 1·1	remainder remainder	183 to 276 185 to 275	Electric lamps, dipping solder.

NOTES: (1) Grades marked with an asterisk are known as antimonial solders, the antimony being added to increase strength. They should not be used on zinc or galvanised work.
(2) The two figures quoted in the melting range column represent the completely solid and completely liquid states.

4.1.2 **High Temperature Solders.** Three types of solders which may be used in high temperature applications are also specified in BS 219. They are used in the manufacture of oil coolers, radiators, etc., where operating temperatures would adversely affect solders with lower melting temperatures. High temperature solders may be applied by soldering iron or torch flame.

TABLE 3

HIGH TEMPERATURE SOLDERS

Grade	Alloy (%)				Melting Range (°C)
	Tin	Antimony	Lead	Silver	
95A	94·5 to 95·5	4·75 to 5·25	max. 0·7	—	236 to 243
5S	4·75 to 5·25	max. 0·1	remainder	1·4 to 1·6	296 to 301
1S	1·0 to 1·5	max. 0·1	remainder	1·4 to 1·6	309 to 310

4.1.3 **Wire Solder.** Solders of this type, complying with the requirements of BS 441, are of circular cross-section, having one or more continuous cores of activated or non-activated flux. Because wire solders release flux and solder simultaneously when the appropriate temperature is applied, they are generally considered to be more efficient than stick solders. These solders are available in five grades. Information on their properties and uses is given in Table 4.

TABLE 4

WIRE SOLDERS

Alloy (%)		Melting Range (°C)	Typical Uses
Tin	Lead		
65 max. 60 max.	remainder remainder	183 to 185 183 to 188	Electrical, radio and instrument assemblies liable to damage by heat or requiring free running solder.
50 max.	remainder	183 to 212	Electrical, radio and instrument work where slightly higher temperature and some slight loss of penetrating power are permissible. General hand soldering and medium coppersmiths' work.
40 max.	remainder	183 to 234	Tagging components less liable to damage by heat. Tinsmiths' and coppersmiths' light gauge handwork.
20 max.	remainder	183 to 276	Blobbing electric lamp contacts.

4.1.4 **General.** Care must be taken to ensure that the solder used is of the type specified on the drawing and is the correct type for the work in hand. Apart from the effect on the strength of the joint, the use of incorrect solder may result in other damage, e.g. if solder with too high a melting point is used, damage may result to the surrounding structure from the heat required to melt the solder.

4.2 **Fluxes.** Since solder will only adhere to clean metal, all surfaces to be soldered must be thoroughly cleaned (paragraph 5). However, even after cleaning, the oxidation occasioned by heating will prevent the satisfactory adhesion of solder. The use of flux reduces the effect of oxidation, removes oxides and other impurities, helps the molten solder to run freely and results in the production of a stronger joint.

4.2.1 Fluxes complying with Specification DTD 599 are available in rosin, liquid and paste forms, are non-corrosive, and either activated or non-activated. Rosin to this specification is used for the flux in wire solders.

4.2.2 **Activated Fluxes.** Activated fluxes consist of wood or gum rosin, and contain a small proportion of an agent intended to facilitate the soldering process; such fluxes are usually selected when a more active cleaning agent is required.

4.2.3 **Non-Activated Fluxes.** These fluxes consist of wood or gum rosin only and are usually selected for the soldering of surfaces where active cleaning is unnecessary.

4.2.4 **Test to Distinguish Activated from Non-Activated Flux in Wire Solder.** The method of conducting this test is described in BS 441. The principle of the test is that a specimen of the solder is melted on a prepared nickel plate. It is essential that the solder should be melted within a period of from two to six seconds, and if the solder on melting wets the nickel and spreads upon its surface, the flux is judged to be activated.

4.2.5 **Fluxes for Stainless Steel Soldering.** Suitable fluxes, which are all corrosive, are as follows:—

(i) A liquid flux made by dissolving zinc chloride in a solution of equal volumes of hydrochloric acid and water. The solution may be applied with a brush or, if more convenient, the parts may be dipped into the solution.

(ii) Ortho-phosphoric acid, in its commercial form, which should be applied undiluted.

(iii) Phosphate-base flux pastes.

4.2.6 **Oxygen Equipment.** Rosinous fluxes, such as those complying with Specification DTD 599, must not be used for soldering oxygen equipment. A flux complying with DEF 34/1 is suitable.

4.2.7 **Miscellaneous Applications**

(i) For Monel and nickel the rosin types of fluxes are suitable, but for Inconel and the Nimonic alloys, a more vigorous flux, such as killed spirits of salts or lactic acid, is necessary.

(ii) Parts which cannot be washed after soldering, e.g. radio, electrical and instrument equipment, should be soldered in conjunction with a flux complying with DTD 599.

(iii) Zinc-plated steel parts, including galvanised wire ropes, should be soldered in conjunction with a flux complying with DTD 599 or with a triethanolamine oleate flux.

(iv) Where such action is permissible (see paragraph 3) the soldering of identification labels to steel tubes should be in conjunction with a flux complying with DTD 599.

4.2.8 **General.** Care must be taken to ensure that the flux used is of the type specified on the drawing and is of the correct type for the work in hand. The use of the wrong type of flux may not prevent oxidation of the surfaces to be joined, nor act as an efficient cleaning agent. In addition, it is imperative that a corrosive flux such as that complying with DEF 34/1 is only used on work from which its residues can be readily removed. (See paragraph 8.6.)

4.3 **Flux Baths.** Where a flux bath is used, the bath should be kept in a clean condition, and the contents checked at regular intervals. The acidity of fluxes of the DEF 34/1 type must be carefully controlled.

5 SURFACE CLEANING The following methods of cleaning surfaces should be adapted to the material and type of joint.

5.1 A high polish is not desirable, since a slightly roughened surface provides the best base for a good joint. Best results will be obtained by mechanical cleaning of the surface with a suitable abrasive, such as a file, sandpaper, or emery cloth; this, however, does not apply to stainless steel (see paragraph 5.3). Care should be taken to remove only the surface film and not to reduce the thickness of the material. After such preparation it is necessary to degrease the surface using one of the solvents described in paragraph 5.2.

5.2 Trichloroethane and trichloroethylene are good liquid cleaners and the latter may also be used in a vapour degreasing bath (Leaflet **BL/6-8**). Neither petrol nor paraffin should be used, since both will leave a film on the metal surface.

5.3 **Cleaning Stainless Steel.** After degreasing, stainless steel may be cleaned by a pickling process followed by washing; suitable processes are given in the following paragraphs.

5.3.1 Anodic treatment in an aqueous solution containing one-third (by volume) of concentrated sulphuric acid and 2·5 per cent (by weight) of potassium dichromate. Current density should be at least 1100 amps per square metre of surface area, and the treatment should be continued until the surface has acquired a light grey colour.

5.3.2 Immersion for not more than five minutes in an aqueous solution containing 50 per cent (by volume) of concentrated hydrochloric acid.

5.3.3 After pickling, the parts should be washed in clean water.

5.4 **General.** In order to minimise the detrimental effects of the oxide film which forms rapidly on the surfaces of the parts after cleaning, the interval between the cleaning and soldering operations should be kept to a minimum.

6 SOLDERING EQUIPMENT For normal small soldering operations, such as fixing a tag to an electrical cable, a hand soldering iron is the most convenient method of melting the solder. In cases such as fixing identification tags to pipes, where dissipation of heat may prevent the solder from flowing properly, the use of a large iron or blow-lamp may be necessary. Some soldering operations require much more sophisticated heating equipment, however, and in these cases dipping baths (paragraph 9), ovens, pre-heating equipment and automated handling methods are often used.

6.1 **Hand Soldering Irons.** A soldering iron consists of a copper 'bit' attached to a suitable handle, and may be heated either by a self-contained device (electrical elements or gas flame), or by an external source such as a fire or blow-lamp. Irons should be used at a temperature of approximately 60°C above the melting point of the solder, and should not reach a temperature which will result in rapid oxidation. Electric irons are often fitted with a thermostat to maintain ideal working conditions.

6.1.1 **Tinning.** Before an iron can be used for soldering the bit must be tinned, i.e. a coating of tin or solder applied to all faces. A suitable method of tinning an iron is described below.

(i) The faces at the tip of the bit should be filed to remove dirt and rough edges, after which the bit should be heated to a temperature sufficient to melt solder. One face of the bit should then be coated with flux and rubbed against a stick of solder until a thin film of solder adheres to it. The operation should be repeated until all faces are suitably tinned.

6.2 **Resistance Tools.** With these tools a low voltage electric current is passed into the work to be soldered, by means of a metal or carbon electrode. The resistance between the electrode and the work area causes a rapid local increase in heat which is used to perform soldering functions. The main advantages of this method are that electrical power is only used during the soldering operation and that the electrodes are nearly cold during approach to, and removal from, the work area.

6.3 **Induction Heating.** If a high frequency current is passed through a coil which is held adjacent to a workpiece, the workpiece will be heated by induction. This method is often used for soldering on a production line basis, but, since a large high frequency generation is required, is not suitable for occasional use.

6.4 **Ultrasonic Soldering Equipment.** Ultrasonic soldering equipment can be used for the jointing of aluminium. Further information on the process and equipment is given in paragraph 14.

7 PREPARATION FOR SOLDERING Before the actual soldering operation is begun, preparations should be made taking into account the factors given in the following paragraphs.

7.1 The size of a soldering iron should be adequate for the job in hand, and should provide sufficient heat to prevent the solder from solidifying before it has completely melted in a joint. If a large soldering operation is contemplated using a common hand iron, two irons should be available, and used alternately, so that the materials being soldered will not lose heat while one iron is being re-heated.

7.2 The parts to be soldered should not be in contact with a material which will cause rapid dissipation of heat, e.g. if the parts are held in a vice, wood should be used for insulation purposes.

7.3 When pins are used with soldered joints, the holes should be drilled and the pins inserted before the joint is soldered. Oil must not be used when drilling unless the articles can be degreased before soldering.

7.4 Aircraft batteries should be disconnected, as a precaution against fire, when soldering is carried out adjacent to wiring looms or cables.

7.5 The clearance between the parts should be in accordance with drawing requirements, a gap of between 0·08 mm to 0·25 mm (0·003 inch to 0·010 inch) before tinning usually being specified for all materials except aluminium (paragraph 14.1.1).

8 GENERAL APPLICATION OF SOLDER After the surfaces have been cleaned, an adequate, but not excessive, amount of the appropriate flux should be applied; the surfaces should then be tinned by hot tinning, dipping in molten solder, or by electrolytic deposition. When a dipping process is used, surplus solder should be removed from the surface by wiping or other convenient means before assembly and final soldering.

NOTE: Electro-tinned surfaces, if allowed to age, may present difficulty in soldering unless the tinning is at least 0·008 mm (0·0003 inch) thick.

8.1 Where a common soldering iron is used, the bit should be heated in a blue flame. The use of a red or luminous flame is not recommended, since this would result in a deposit of soot on the bit. The bit should not be heated to such an extent that it displays a "rainbow" effect, as this will cause rapid oxidation necessitating re-tinning. In addition, overheating the bit may cause the solder to sputter and detrimentally affect adjacent parts.

8.2 Irrespective of the nature of the flame used for heating, some oxides will form on the bit; these should be removed by dipping the tip into a cleaning solution each time it is removed from the flame. A suitable cleaning solution can be made by mixing one pound of melted sal ammoniac with one pint of distilled water.

8.3 A mass of material tends to dissipate the heat from the surfaces to be joined, and to obviate this effect it is usually necessary to pre-heat the metal. Care must be taken to prevent the overheating or burning of the parts, since, apart from possible detrimental effects on the material, this will cause the solder to run out of the joint. However, if insufficient heat is applied, the solder will not run evenly into and fill the small space between the faces of the joint, and lack of strength will result.

8.4 The use of an excessive amount of solder is undesirable; if the process is correctly applied, a little solder, thoroughly melted, will cover a considerable surface.

8.5 When the solder is solidifying, any movement will produce internal fractures in the solder; such fractures are not readily discernible and will considerably weaken the joint. To prevent any such movement, the parts should be firmly clamped during the soldering process.

8.6 After soldering, the joints should be wiped clean and thoroughly washed in hot water. Joints soldered with the aid of paste fluxes should, before washing, be cleaned with a spirit solvent such as petrol or industrial methylated spirit. Joints soldered with the aid of zinc-chloride fluxes (e.g. DEF 34/1) should, before washing, be cleaned with a 1 to 2 per cent (by volume) hydrochloric acid solution, preferably with a suitable wetting agent additive.

NOTE: A wetting agent is a substance added to a liquid in order to reduce its surface tension.

8.7 Unless otherwise specified, joints which cannot be examined visually, e.g. such as may occur inside containers, etc., should be thoroughly washed with a 2 per cent (by volume) solution of hydrochloric acid, and subsequently swilled for at least two minutes with water. Where paste fluxes are used for such applications, a thorough washing in spirit solvent should precede the acid wash.

9 BATH SOLDERING There are a number of methods by which parts may be joined by dipping in molten solder. The simplest method is to dip items into a heated container after fluxing; this method may be suitable for occasional use where attention can be given to the removal of scum or dross immediately before dipping. The presence of dross is a serious matter in production line soldering and the two methods described below have been adopted to overcome this problem.

9.1 **Rotary Baths.** In this method the solder bath is rotated slowly, and dross flows under centrifugal force to the periphery, where it may be easily skimmed off. By this means soldering may be carried out at temperatures of up to 500°C, at which temperature normal bath operation would not be practical.

9.2 **Standing Wave Baths.** In this method a pump is used to pump molten solder from the bottom of the bath through a slot-shaped hole so that a standing wave of solder appears across the surface. Dross forming on the surface is swept to a catchment area where it can be periodically removed. This method is frequently used in the manufacture of printed circuit boards, which are pre-fluxed and drawn across the standing wave. One advantage of this method is that the size of the work is limited only by the width of the bath and not by its length.

9.3 **General Recommendations**

9.3.1 The composition of a bath should be checked at frequent intervals. Particular attention should be given to the copper pick-up, which should not be allowed to exceed 0·4 per cent.

9.3.2 The temperature of the bath should not be allowed to rise too high, as the solubility of copper in the solder increases rapidly with temperature. The formation of a blue film on solder with a high tin content is indicative of an excessive temperature, but this indication will not be found in solders containing less than approximately 40 per cent tin. Pyrometric control of solder baths is strongly recommended.

9.3.3 The bath used should be of adequate size for the work in hand, so that placing a large item in the bath does not result in undue cooling of the solder.

10 SOLDERING SHEET METAL The following method of soldering seams in sheet metal is usually employed, to comply with the tinning process referred to in paragraph 8.

10.1 The surface should be cleaned and a suitable flux applied. A heated bit should then be held on the surface until the material reaches the melting point of the solder. Solder should then be applied to the bit so that it will flow from the bit to the surface of the material and spread evenly. The solder may also be applied by dipping or by electrolytic deposition.

10.2 The tinned surfaces to be joined should be fluxed, placed together and heated by a bit held on the outside of the joint. The heat transference will be quicker if the bit is applied to the material with a firm steady pressure and moved along the seam slowly. When the materials become sufficiently hot, the solder on the tinned surfaces will melt and flow together to make the joint. Wherever possible, the seams should be soldered in the horizontal position.

10.3 The above process is sometimes known as "sweating" and other methods include the use of solder creams, and solder paints, which contain flux and solder, and which are applied to the surfaces of the joint either with a brush, or by dipping, before assembly. The parts are made a close fit, and are manufactured so that they remain in position during heating, or may be held together by a jig.

NOTE: When proprietary types of solder creams or solder paints are used, it is essential that they should be of a type approved for use on aircraft.

11 SOLDERED ASSEMBLIES MADE OF TINNED STRIP The methods of soldering described in the following paragraphs are used mainly for the manufacture of heat exchange equipment. Repairs must be strictly in accordance with the manufacturers' instructions.

11.1 **Honeycomb Structures.** The assembly is made up of strip material previously coated with solder, and the component parts are tacked by local heating to hold them in position, after which the completed assembly is placed in a jig. The assembly is then degreased, preferably by trichloroethylene, and allowed to drain, after which it is dipped into a flux bath and again allowed to drain.

11.1.1 Hot air is then blown through the assembly so that the coating melts and forms a soldered joint where the parts are in contact. After soldering, the flow of heated air is replaced by a flow of cold air, which is maintained until the temperature of the assembly drops to room temperature, when the assembly is removed from the jig and washed thoroughly.

11.1.2 As it is not possible visually to check assemblies produced by this method, it is essential that a schedule of operations should be compiled for each type of assembly, the suitability of which has been proved by sectioning and examination of trial assemblies.

11.1.3 A suitable schedule, subject to necessary variations, should include the following:—

(i) Each component should be thoroughly degreased.

(ii) After degreasing the assembly should be drained in such a manner as to preclude the formation of pockets of condensate.

(iii) The assembly should be adequately fluxed and thoroughly drained.

(iv) The assembly should be positioned in its jig so as to ensure that it is evenly heated or cooled.

(v) The temperature of the air and the time of blowing should be in accordance with drawing or schedule requirements.

(vi) After cooling, the assembly should be washed as detailed in paragraph 8.7, then thoroughly dried.

11.2 **Fin and Tube Structures.** In the production of fin and tube type heat exchangers, thin brass strip is formed into rectangular tubes with a rigid locked seam along one edge. The strip can be pre-tinned with solder, or the tube can be continuously tinned after forming by fluxing and dipping in a solder bath, after which it is cut to the required length.

11.2.1 The tubes are assembled into copper gill-plates punched with rectangular holes to space the tubes evenly apart. The assembly is placed in a jig and is dipped into a bath of flux, usually of the hydrazine type.

11.2.2 After draining, the assembly is baked in an oven, and during this process the solder on the tubes melts and joins the tubes to the gill-plates at their points of contact; at the same time the seam along the edge of each tube is permanently sealed with solder.

11.2.3 Oven temperature must be carefully controlled during the soldering process, and the assembly should be tested with compressed air at the test pressure stated on the drawing to ensure that the solder has effected a perfect seal. A flow test is also essential to ensure that the tubes are not blocked.

12 CABLE NIPPLES Nipples and other types of end fittings are normally swaged on to stranded cables, but on some types of aircraft soldered nipples may be used in systems where safety considerations are not of prime importance. To ensure satisfactory attachment of a soldered nipple the following procedure should be adopted (see Figure 1).

(i) Thread the cable through the nipple sufficiently to enable the strands to be splayed apart; the strands should be evenly spaced around the countersink in the nipple and project beyond it.

(ii) Clean the cable strands and the nipple (paragraph 5).

(iii) After cleaning, pull the cable back so that the splayed strands lie on the countersink.

(iv) Hold the nipple securely in a vice and ensure that the cable is straight and concentric with the hole in the nipple.

(v) Heat the joint with the soldering bit.

(vi) Apply a suitable flux and solder; the solder should fill the hole in the nipple and envelop the cable and splayed ends. When the solder is set, any projecting ends should be clipped off and filed flush with the surface of the nipple.

(vii) Examine the cable at the point where it enters the nipple, to ensure that there is a clean run of solder on and between the strands.

(viii) Remove all traces of flux from the nipple and cable (paragraph 8.6) and apply a coating of rust preventative. When required by the drawing, the assembly should be proof loaded.

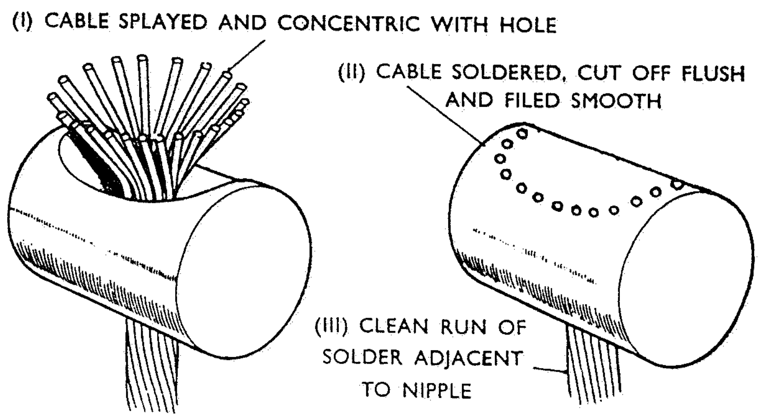

Figure 1 SOLDERING NIPPLES TO STRANDED CABLES

13 SOLDERED ELECTRICAL CONNECTIONS Electrical cables are usually attached to a terminal or plug by means of a crimped end connector, but, on some aircraft, connections may be made by soldering. Crimped end connectors are considered essential in some circuits, e.g. fire detectors, and in locations where high ambient temperatures may be expected; these connections should not be replaced by soldered connections.

13.1 **General Considerations**

13.1.1 Cored wire solder complying with BS 441 is generally used for making electrical connections for use in temperatures up to 100°C, but BS 219 Grade A or K solder and flux complying with DTD 599 are often recommended as an alternative. Grade 5S solder may be used for working temperatures up to 200°C. Corrosive fluxes are not generally permitted for use on electrical equipment because of the difficulty of removing the residue, and activated fluxes are not recommended for use on very thin wire (i.e. less than 43 s.w.g.) because of the relatively high erosion by the hot flux.

13.1.2 Heat applied by a soldering iron may be conducted along the wire and cause damage to cable insulation or to heat-sensitive components such as transistors. Damage may be prevented by using a "heat sink", which usually takes the form of close fitting pliers attached to the wire, to conduct heat away from the insulation or component. A heat sink may also be used to minimise "wicking" (i.e. the run of solder along the strands by capillary action), when soldering stranded or braided wire.

13.1.3 When soldering a number of connections in close proximity, a heat shield should be placed between the joint being soldered and adjacent connections. In similar locations the use of neoprene sleeves over completed joints is often specified to prevent short-circuiting.

13.2 **Soldering Process.** A soldered electrical connection must be strong enough to withstand normal handling and vibration, and must also provide the minimum resistance to the flow of electric current. The following procedure should ensure a satisfactory connection.

13.2.1 The cable should be cut to length and the insulation cut back sufficiently to make the connection, care being taken not to nick or damage the wire and to ensure that the remaining insulation does not touch the soldered joint. It is recommended that properly adjusted mechanical strippers or thermal strippers are used for removing unwanted insulation. If the cable is stranded it should be lightly twisted in the direction of lay to eliminate sharp projections.

13.2.2 The end fitting and exposed wire should be cleaned over their contact areas, using a light abrasive paper, then washed in a suitable solvent. The solvent must be compatible with the insulation material, so that any contact between the two will not cause the insulation to deteriorate.

13.2.3 Parts which are not pre-tinned or plated should be tinned by applying flux and solder with a heated iron. The tinning of flexible wires should be restricted to the minimum necessary for making the connection; over-tinning will reduce the flexibility of the wire and may lead to fracture in service.

13.2.4 The wire should be positioned in the end fitting and heat applied by means of a soldering iron until the solder flows through the joint, additional solder or flux being added as necessary. The connection should be made quickly, and held securely in place while the solder solidifies. The wire should be attached in such a way as to provide additional security to the joint, but must not prevent removal if the solder is melted in a future disconnection; if the tag has a hole the wire may be bent 90° through the hole, but if the tag does not have a hole the wire should be bent 180° to hook round the tag.

13.2.5 After soldering, the soldered parts should be cleaned with an approved solvent.

13.3 **Inspection.** Inspection of completed soldered connections should include the following:—

(i) Joints should be clean, smooth, bright and free from sharp projections, and the wire easily discernible through the solder.

(ii) As far as can be detected visually, the joint should be filled with adhering solder.

(iii) Insulation should be undamaged (i.e. not burned or affected by solvent).

(iv) There should be no pitting, corrosion, scale or other evidence of poor workmanship.

(v) Where electrical tests are specified, the results obtained should be within the prescribed limits.

14 SOLDERING OF ALUMINIUM Proprietary brands of cored wire solder are available, which may be used for soldering aluminium and many aluminium alloys, and a method of ultrasonic soldering may also be used.

14.1 The normal soldering technique is similar to that used with other materials but, because of the material's high specific heat and thermal conductivity, a greater heat input is required. An advantage of these properties is that uneven expansion and contraction are avoided, and heating of complex structures is simpler than with other materials. A soldering temperature of 280°C to 370°C is required, and may be obtained using a hand iron, gas torch, furnace or induction coil. Solder should be pre-positioned or hand-fed to the edge of the joint, and heat applied adjacent to the joint to bring it quickly to the soldering temperature, so that the solder melts by indirect heating.

14.1.1 As aluminium expands more than most materials, light jigging, which will allow the parts to expand and contract, should be used when necessary. A joint clearance of 0·05 mm to 0·1 mm (0·002 inch to 0·004 inch) will allow the solder to fill the gap by capillary action, and give maximum strength.

14.1.2 Pungent fumes are given off by the flux, and soldering should be carried out in a well-ventilated working area.

14.2 Ultrasonic soldering equipment is available in the form of an iron, for normal joints, or a bath, for the quick dip-turning of aluminium wire and small parts.

14.2.1 The working principle of the equipment is that ultrasonic vibrations are imparted to the bit of the iron or, where baths are used, to the vessel containing the solder. When the vibrations are applied to the molten solder on the surface of the material, the effect of the ultrasonic energy is to produce imploding cavitation bubbles in the solder, which remove the oxide film and permit a wetting action by the solder to take place. No flux is required for the process and the solder used should contain 90 per cent tin and 10 per cent zinc.

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BASIC

ENGINEERING PRACTICES AND PROCESSES

BRAZING

1 INTRODUCTION This Leaflet gives guidance on the brazing processes applicable to ferrous and non-ferrous metals. For the purpose of this Leaflet 'brazing' means the joining of materials by a process in which a molten filler alloy is drawn by capillary attraction into the space between the adjacent surfaces of the parts to be joined. The parts to be joined are known as the basis, or parent, metals.

1.1 Low temperature brazing, also known as silver soldering or hard soldering, is a brazing process which uses filler alloys based mainly on the metals silver and copper, with a melting temperature within the range 600°C to 850°C. The strength of a joint brazed with silver brazing alloy, if properly designed, is often equal to the strength of the materials joined.

1.2 When brazing is carried out with filler alloys of high melting temperature, grain growth and softening of the parent metal often occur, thus necessitating further heat treatment to restore the required properties.

1.3 Where special techniques of brazing are applicable to certain materials, these are described under the heading of the material concerned.

1.4 Information on soft soldering processes is given in Leaflet **BL/6-1,** on oxy-acetylene welding in Leaflet **BL/6-4,** on arc-welding in Leaflet **BL/6-5,** and on spot welding in Leaflet **BL/6-12.**

2 STRENGTH OF JOINTS The strength and efficiency of brazed joints depend on a number of factors, including the design of the joint, cleanliness of the surfaces to be joined, the method of applying the process, the composition of the materials to be brazed, use of the brazing method and materials specified on the drawing or manual, and the competency of the operator. Primarily the strength of the joint depends on the area of the film which unites the surfaces of the parts forming the joint and, to a lesser extent, on the thickness of the film, a thin film usually producing the strongest joint.

2.1 Specific values for the strength of joints can be misleading, since so many factors are involved. For example, most joints made in normal workshop or mass-production conditions contain voids resulting from gas or flux entrapment, or from the formation of shrinkage cavities in the filler alloy during its transition from the liquid to the solid state. Although it is seldom possible to eliminate such faults completely, they can be minimised by careful attention to cleanliness, joint gaps, heating methods and the method of feeding the filler alloy into the joint.

2.2 Overheating during brazing can have a serious adverse effect on the strength of a joint. Care is necessary, when using a hand torch, to ensure that the flame is suitable for the work in hand, otherwise grain growth, burning, distortion or melting of the parent metal may result. Particular care is necessary when using oxy-acetylene gas, which has a flame temperature in excess of 3000°C. Overheating of the parent metal may also result from the use of incorrect brazing alloys.

2.3 Strength at elevated temperatures depends largely on the type of filler alloy used, and in general terms the silver brazing alloys having the lowest melting temperature are suitable for continuous service at temperatures up to about 250°C.

2.4 When dissimilar metals having different rates of thermal expansion are brazed, the possibility of stresses resulting from differential contraction during cooling is reduced by the use of low temperature filler alloys.

2.5 Flux should be removed from parts by washing in hot water but, with assemblies consisting of parts of dissimilar metals or with sudden changes in section, washing should not be carried out while the parts are still hot from brazing. This practice could result in stress cracking or the production of high residual stresses in the component.

3 SCOPE OF PROCESS All brazing operations should be performed strictly in accordance with the requirements of the relevant drawings. Materials suitable for brazing are listed in BS 1723, and various combinations of these materials may also be joined provided that a suitable technique has been established.

4 COMPETENCY OF OPERATORS As stated in paragraph 2, the strength and efficiency of brazed joints depend, amongst other factors, on the competency of the operators. It is recommended that the competency of operators responsible for the hand torch brazing of important parts, should be checked regularly by a testing programme such as that described below.

4.1 A sample should be selected for testing from the operator's production work wherever possible, but where this is not practicable, a butt, fillet, tube-to-tube, or sheet-to-sheet test piece, as appropriate to the type of work in hand, should be prepared.

4.2 The test piece should be submitted for microscopical examination to a laboratory approved for the examination of welded joints, and should show satisfactory penetration into the joint, adhesion and freedom from porosity, freedom from overheating of the parent metal, absence of coarse grain, etc. Further test pieces, to ensure continued competency, should be submitted at intervals not exceeding six months. When an operator fails a competency test he should undergo further practice and/or training before resubmitting a test piece.

4.3 An additional competency test should be submitted whenever there is a marked change in the material or types of joints being brazed.

5 MATERIALS FOR BRAZING The filler alloys and fluxes used for brazing aircraft parts must conform to the appropriate British Standards or to DTD 900.

5.1 **Filler Alloys.** Details of the composition and melting range of filler alloys or metals which may be used for brazing are contained in BS 1845 in a series of Tables. The basic alloying elements listed in each of Tables 1 to 8 in BS 1845, provide the prefix for the filler type (i.e. AL, aluminium; AG, silver; CP, copper-phosphorous; CU, copper; CZ, brass; NI, nickel; PD, silver-copper-palladium; AU, gold) and a numerical suffix signifies the particular alloy within a group; Table 9 lists the maximum permissible content of impurities in the alloys specified for vacuum brazing.

5.1.1 Filler alloys are generally available in rod, wire and strip, and in some instances in granular form, the choice depending on the brazing method used. Whilst the majority of hand torch operations require the filler alloy to be fed by hand from a rod, wire or strip, better results can sometimes be obtained by placing the brazing alloy in a predetermined position in the joint, and heating the assembly by means of a fixed torch, furnace, or electrical induction or resistance methods. Filler alloy inserts for this purpose usually take the form of wire rings, but, in some cases, foil, washers, or pressings of special shape are used.

5.1.2 A silver brazing alloy in the form of a paste or paint is also available, and consists of finely divided filler alloy, flux and a volatile liquid medium. The proportions of the constituents are so arranged that the paste can be used with any of the various heating methods described in this Leaflet.

5.2 **Fluxes.** The function of a flux is to dissolve oxides; it also has the effect of reducing the surface tension of the molten filler alloy, thus assisting the alloy to flow readily between the surfaces of a joint.

5.2.1 It is recommended that the flux used in any brazing operations should be agreed with the supplier of the filler alloy, since in certain instances a flux suitable for one filler alloy may not be suitable for another of similar composition, for example, because of the melting range of the alloy. An example of this is borax, which has a higher melting temperature than some of the filler alloys, and, in this case, its use may result in flux entrapment.

5.2.2 Fluxes are normally supplied in powder form, and should be made up in accordance with the manufacturers' instructions. The application of the flux for the various processes is described in the appropriate paragraphs.

6 BRAZING JIGS Components which are to be joined by a brazing process are normally specially designed to ensure correct location and filler penetration. In the majority of cases the parts fit naturally together or may be lightly supported in such a way as to permit natural expansion and contraction to take place, but in some instances the use of locating jigs is unavoidable.

6.1 Jigs should be so constructed that contact with the parts to be joined is as light as possible, and should be shaped to avoid contact with areas where brazing alloy is required to flow. Jigs should also be designed so that, whenever possible, the capillary flow of filler metal is assisted by gravity.

6.2 Where large jigs are necessary, because of the weight of the component, for instance, care should be taken to prevent the absorption of heat from the brazing area. This may be largely avoided by facing the jig with asbestos, fireclay or other ceramic material, and by limiting the size of the areas in contact with the component.

7 PREPARATION OF JOINTS FOR BRAZING All scale, grease, dirt, paint, moisture and other foreign matter must be removed from the area to be brazed. Components should first be degreased with trichloroethylene or similar solvent, then cleaned by one of the processes described in the following paragraphs, immediately prior to brazing.

7.1 **Steels.** The methods of cleaning steels vary with the chemical composition of the steel. In general, however, steels may be divided into two main groups, i.e. low alloy steels having a carbon content not in excess of 0·2 per cent, and non-corrodible steels or heat-resisting austenitic stainless steels.

7.1.1 **Low Alloy Steels.** The area to be brazed may be prepared by sand, shot or alumina-blasting or by brushing with a wire brush. When a blasting process is used, the materials should be brazed as soon as possible after blasting. If a pickling process is required, a solution of 7·5 per cent (by volume) Sulphuric Acid (S.G. 1·84), maintained at a temperature of 70°C in a lead or rubber-lined tank, is suitable. An inhibitor should be added to the solution at the rate of 1 oz. per gallon of concentrated acid.

7.1.2 **Non-Corrodible and Heat-Resisting Austenitic Stainless Steels.** The area to be brazed may be prepared by an alumina-blasting process or by brushing with a brush having stainless steel bristles. The materials should not be prepared for brazing by blasting with crushed steel shot. If a pickling process is required, a solution of the following composition is suitable:–

Hydrofluoric Acid	3·4 to 4·0 per cent (by weight)
Ferric Sulphate	10 to 15 per cent (by weight)
Water	Remainder

The solution should be contained in a lead-lined tank and should be maintained at a temperature of 60°C.

7.2 **Nickel Base Materials.** The areas to be brazed may be prepared by an alumina-blasting process or by brushing with a brush having stainless steel bristles. After mechanical cleaning, the edges to be brazed should be wiped with a suitable solvent. These materials should not be prepared by blasting with crushed steel shot. If pickling is necessary, it must be ascertained that the process used is satisfactory for the material in question, since an intercrystalline attack may result from the use of an incorrect solution.

7.3 **Aluminium and Aluminium Alloys.** The surfaces to be brazed should be prepared either by abrasive blasting with alumina grit or by brushing with a brush having nylon bristles. The use of brushes having copper alloy bristles should be avoided, since, should pieces of bristle become embedded in the surface, there is a danger of bi-metallic corrosion.

7.3.1 If an etching process is required, a solution of the following composition is recommended:—

Sulphuric acid (d = 1·84)	150 ml/l
Chromic acid	50 g/l
De-mineralised water	Remainder

The solution should be maintained at 60°C. Components should be immersed in the solution for 30 minutes, then thoroughly washed in cold water and dried.

7.4 **Copper and Copper-Based Alloys.** The surface may be cleaned by mechanical means such as alumina abrasive blasting or the application of abrasive cloths. Care should be taken to remove only the surface film and not to reduce the thickness of the material when cleaning is effected with abrasive cloth, final cleaning with a solvent being recommended in either case. The parts may also be etched by immersion for two minutes in an aqueous solution containing sulphuric acid (40 ml/l) and sodium dichromate (200 g/l).

8 BRAZING METHODS Capillary attraction is the major factor in making a brazed joint, and although, in theory, there is no limit to the extent of penetration by capillary attraction, in practice this is dependent on the dimensions of the joint. The best results are obtained where a joint gap of 0·05 mm to 0·1 mm (0·002 inch to 0·004 inch) is used.

8.1 If the optimum joint gap is to be maintained during the heating operation, allowance must be made for the different expansion coefficients of the component metal used in the assembly. However, if the joint gap varies from the ideal, and is, for example, up to 0·2 mm (0·008 inch), an alloy which remains plastic over a greater temperature range should be used, but such an alloy will not have the penetrating power of those normally used for standard gaps.

8.2 **Heat Application.** The methods of applying heat most commonly used in brazing may be classified into four categories, i.e. induction, resistance, furnace and torch, and are described in paragraphs 9 to 12 respectively; flux dip brazing is described in paragraph 15.4.3.

9 INDUCTION BRAZING In this type of heating the parts to be brazed are placed within the influence of the magnetic field of a coil which carries high frequency alternating current. The heating effect is rapid and, by careful design of the induction coil, the heat can be closely localised to minimise distortion, grain growth and oxidation. Since the heating effect is influenced by the thermal conductivity and electrical resistance of the component, copper and similar materials will take longer to heat up than materials such as iron or nickel. This method is particularly suitable for high speed brazing of ferrous materials in production line quantities but, because of the high cost of the equipment and the need to design special coils for each particular job, it is not often used for small quantity work.

9.1 Induction machines often employ a valve type generator with outputs of up to 15 kVA at frequencies ranging from 100 kHz to 3 MHz, and are usually fitted with timing mechanisms to control the actual heating time. The coils are usually made from copper tube through which water is passed for cooling purposes but solid copper coils may also be used.

9.2 In order to take advantage of the speed of induction brazing, paste flux and pre-placed filler alloy are often used, but, in some instances, e.g. when brazing titanium pipe fittings, brazing may be carried out in an argon atmosphere, and no flux is required.

10 RESISTANCE BRAZING Resistance brazing is often used where precisely localised heating is required to prevent loss of mechanical properties throughout the parent metal. A high electrical current of low voltage is passed through a resistive circuit so that the heat developed in the circuit raises the temperature in the joint area to the brazing temperature. There are two main methods in use, carbon resistance heating and interface heating.

10.1 In carbon resistance heating the electrodes are made from carbon, which has very high resistivity and heats up quickly. The electrodes are in direct contact with the area to be brazed and heat is conducted into the workpiece where the temperature is raised sufficiently to melt the brazing alloy and form the joint. Since the temperature of the electrodes is very high, some marking of the surface of the workpiece may result, but this can often be alleviated by the use of pulsed current.

10.2 In interface resistance heating the electrodes are made from, or faced with, a material of relatively low resistivity. Most of the heat is developed through the resistance to the passage of current at the electrode/work interface, and some is also developed in the work itself because of its resistivity. The amount of heat in the workpiece itself is substantially higher than in the carbon electrode method.

10.3 With resistance brazing direct heating is often used, the workpiece being gripped between the electrodes at the position where heating is required. In some cases, however, indirect heating may be used, both electrodes being located on one side of the largest component and the smallest component being heated by conduction.

11 FURNACE BRAZING The main advantages of using a furnace for brazing are that high rates of output can be achieved, uniform results obtained and an inert or reducing atmosphere used to prevent oxidation. This method is particularly suitable for large batches of small articles which are self-locating or easily jigged, or for parts likely to distort through uneven heating.

11.1 Steel or nickel alloys can be successfully furnace brazed using a copper or bronze filler alloy. Brazing is usually carried out in a controlled atmosphere of cracked ammonia, town gas or hydrogen, and flux is not normally required although it may be recommended in some cases.

11.2 Furnace brazing of aluminium and aluminium alloys is widely used. Brazed joints may be made between aluminium and aluminium alloy parts either by the use of inserts of aluminium brazing alloy, or by using sheets with an integral coating of brazing alloy. The use of a suitable flux is essential. Since the difference in melting temperature between the filler and the basis metal is very small, close control of the furnace temperature is most important.

12 TORCH BRAZING The brazing methods previously mentioned all require a high initial outlay or are only suitable for specialised tasks; they are, therefore, mainly used for large quantity brazing. Brazing by means of a hand torch, although requiring a skilled operator, is inexpensive and is widely used for all types of work.

12.1 A wide variety of gas mixtures is suitable for torch brazing. Oxygen may be combined with acetylene, hydrogen, propane or coal gas; air with propane, butane or methane; or compressed air with coal gas. Of these the most commonly used are oxygen/acetylene and compressed air/coal gas.

12.1.1 The selection of a gas for a particular job depends on the size of the component, the temperature required and the rate of heating required, but account must also be taken of the likelihood of overheating, with consequent excessive oxidation and the possible loss of physical properties in the component.

12.1.2 A mixture of compressed air and coal gas burns at approximately 1000°C and is especially suitable for preheating components and for brazing components of light construction, while an oxygen/acetylene mixture burns at temperatures up to 3000°C, and is used where high rates of heating are required.

12.2 **Brazing Process.** It is recommended that before heating is commenced, flux should be applied in the form of an aqueous paste, both to the joint area of the assembly and to the filler alloy. Where the duration of heating or the size of the joint makes it necessary to add flux during the brazing operation, such additions are best made by dipping the hot end of the filler rod or strip into dry flux. If the overlap of a joint exceeds 4¾ mm ($\frac{3}{16}$ inch) the surfaces should be coated with flux prior to assembly.

12.2.1 In all cases rapid heating of the joint is essential, and the flame must be adequate for this purpose, but care must be taken to avoid overheating. When an oxy-acetylene flame is used, a larger jet should be employed than that used for the welding of similar material of similar thicknesses. The envelope of the flame should be kept constantly on the move over as large a portion of the joint as possible, since a static flame is likely to cause local overheating and loss of heat control.

12.2.2 Heating should be started with the torch held several inches from the work so that the outer flame envelope spreads over a large area of the joint. Where parts of unequal thickness are brazed, the flame should be concentrated on the heavier part to ensure uniform heating.

(i) As heating is continued, the flux first bubbles then settles down to a thin clear liquid. When this stage is reached, the work is approaching the correct temperature for application of the brazing alloy.

(ii) The brazing filler strip or rod should then be placed in contact with the joint, but if the filler does not melt on contact with the work, it should be removed and the heating continued until the correct temperature is reached. The filler must not be melted by the flame and so allowed to drop on the work; heat should be applied to the work, and the heat from the work used to melt the filler.

12.2.3 When the brazing alloy melts in contact with the assembly, the feeding in of the strip should be continued until the joint is slightly overfilled to allow for shrinkage on solidification. When this stage is reached and the molten filler has had time to penetrate the joint fully, heating should be discontinued. Unless the work has sudden changes of section, or is an assembly of metals of widely different expansion characteristics, and if there is no specific instruction on the drawing, it is usual to quench in water after the filler has set. (See paragraph 2.4).

12.2.4 **Oxy-acetylene Flame.** A neutral flame should be used in all instances, except when copper-zinc, copper-zinc-silicon or copper-zinc-nickel-silicon filler alloys are employed, when a slightly oxidising flame is necessary.

(i) An oxidising flame is produced by excess oxygen giving a considerably smaller inner flame than that obtained in the neutral condition.

(ii) A neutral flame is composed of an equal amount of both oxygen and acetylene, giving a clearly-defined inner flame.

(iii) A reducing, or carburizing, flame is produced by an excess of acetylene in proportion to oxygen, giving a furry edge to the inner flame.

12.2.5 The appearance of the various flames is shown in Figure 1.

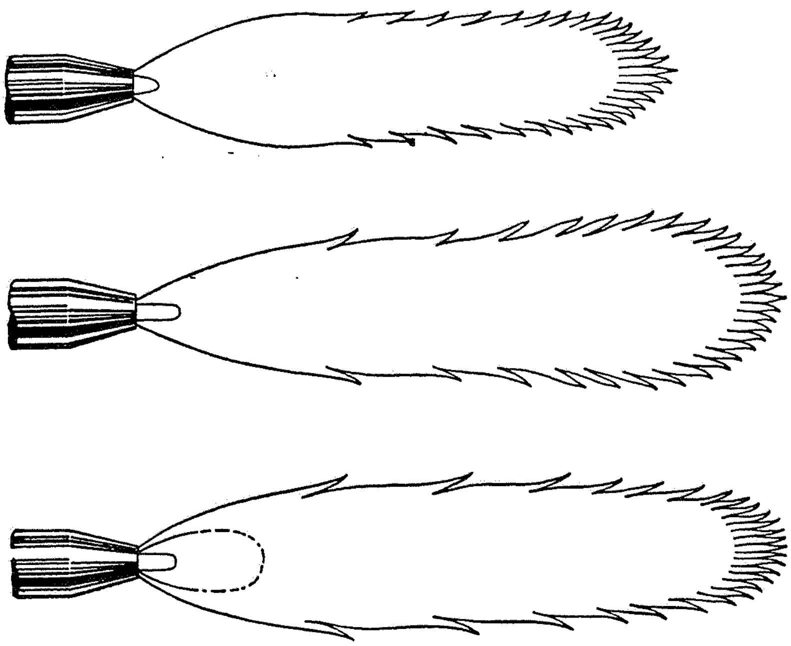

Figure 1 FLAME ADJUSTMENT

12.3 **Torches.** Brazing torches vary in design according to the gas used. When oxy-acetylene is employed, a welding torch, together with the normal welding equipment, is used, the flame being adjusted to suit the brazing work in hand. Information on this equipment will be found in Leaflet **BL/6–4,** Oxy-acetylene Welding.

12.3.1 There are several types of torches available for brazing with coal gas and air. Brazing torches are designed for lightness and balance to avoid physical strain on the operator. Flame control is obtained by various means, such as two adjustable levers, knurled knobs or, in some instances, a spring-loaded trigger-type of lever.

12.3.2 A typical brazing or braze welding hand torch embodies the following features: (a) quick action valves with conveniently placed thumb control for the gas and air supplies; (b) a built-in economiser that cuts off the gas and air supply when the operator's grip is relaxed, and restores the flame when the torch is again grasped; this same control enables a soft warming-up flame to be obtained by partial operation of the lever; (c) a pilot flame adjustable to suit different gas pressures; (d) several interchangeable flame units to provide various flame characteristics to suit a wide range of work and gas combinations.

12.3.3 Air is supplied by an electric blower, a foot operated bellows, a compressed air bottle, or the normal factory supply suitably regulated to the required pressure.

12.3.4 **Fixed Torches.** A logical development of the hand torch is to use fixed burners stationed around a turntable, conveyor belt or similar equipment. Conventional torches are used, but special burners have been developed for this purpose. Compressed air and coal gas are fed to the burner, which comprises a series of fine jets. This produces a flame which does not 'bounce' and has a good depth of heating. These arrangements are commonly fitted with electric timers.

13 BRAZE WELDING Braze welding, also known as bronze welding, is a process suitable for use with metals of high melting temperature, in which the main strength of the joint is obtained by building up a fillet of filler alloy. No fusion of the basis metal takes place, but some penetration of the filler alloy into the joint gaps may occur through capillary action.

13.1 Filler rods for braze welding are specified in BS 1724, and are basically a copper/zinc alloy, but may contain quantities of nickel, manganese, silicon or tin, depending on the metals being joined.

13.2 **Fluxes.** Proprietary types of fluxes are used, usually on the recommendation of the manufacturer of the braze welding rod. Fluxes should only be applied after the joint has been suitably prepared as detailed in paragraph 7.

13.3 **Torches.** Because of the high temperatures required for braze welding, an oxy-acetylene torch is normally used.

14 FLUX REMOVAL Flux residue is likely to promote corrosion when exposed to atmospheric moisture. The residue cannot be neutralised and should be removed from brazed joints by either chemical or mechanical means, removal being facilitated by the use of adequate amounts of flux and by the avoidance of overheating or prolonged heating during the brazing operation.

14.1 **Aluminium and Aluminium Alloys.** The following procedure may be used for removing flux residue from joints in aluminium or aluminium alloy assemblies:—

(i) Wash in boiling water for 10 to 60 minutes according to the complexity of the assembly, preferably in a bath through which there is a continuous flow of water.

(ii) Rinse in clean hot water.

(iii) Wash in a solution of 10 per cent nitric acid in water at a temperature of 65°C for 20 minutes.

(iv) Rinse in water and inspect visually for signs of flux residue.

If flux residue is still present, continue as follows:—

(v) Immerse for up to 30 minutes in a second nitric acid bath to which 1 to 5 per cent sodium dichromate may be added.

(vi) Rinse in clean hot water, drain and dry.

(vii) Inspect for flux residue and, if necessary, repeat operations (v) and (vi).

14.2 **Materials Other than Aluminium.** Where no harmful effects can occur, flux removal is assisted by quenching the work in water as soon as the filler has solidified, but where the component parts of an assembly are of dissimilar materials or have sudden changes in section, they should be allowed to cool before washing. (See paragraph 2.4). The parts should then be thoroughly dried to avoid the possibility of corrosion.

14.2.1 **Fluoride Fluxes.** Washing in water, followed by brushing with a wire brush, will generally remove the residue of fluoride fluxes, especially if hot or boiling water is used. In difficult cases, soaking in a cold solution of 5 per cent (by volume) of sulphuric acid (SG 1·84) in water, followed by a thorough washing in water and subsequent brushing, will facilitate flux removal, but it will be necessary first to ensure that such an operation will not prove harmful to the finished work, e.g. by entrapment of the solution.

14.2.2 **Borax Fluxes.** Residues of these fluxes are only slowly soluble in water; they may be removable by the methods specified in paragraph 14.2.1 but mechanical methods such as shot or grit blasting are sometimes necessary. In instances where mechanical methods are impractical the manufacturer may recommend that residues be dissolved in a hot caustic soda solution.

15 BRAZING ALUMINIUM AND ITS ALLOYS There is a distinction between brazing aluminium and brazing of other metals. For aluminium and its alloys, the filler metal is of the aluminium-silicon type with a melting point only slightly lower than that of the basis metal. Consequently there is a much smaller margin (compared with the brazing of other materials) between the melting point of the filler and the temperature at which overheating and collapse of the basis metal can occur; accurate control of temperature is therefore most important.

15.1 BS 1845 gives a list of the filler materials which are suitable for brazing aluminium and its alloys. Some of the basis metals which can be brazed easily are the various grades of pure aluminium, and some of the alloys of aluminium and magnesium or aluminium, magnesium and silicon. The brazing of alloys containing more than 2 per cent magnesium is not recommended because of the difficulty of removing the oxide film.

15.2 Many types of proprietary fluxes are available for brazing aluminium and its alloys; these are generally of the alkali halide type, and the recommendations of the manufacturer of the filler material, regarding their use, should be observed. A standard aluminium brazing flux containing chlorides of sodium, potassium and lithium gives satisfactory results when used with aluminium which has been chemically cleaned. (See paragraph 7.3).

15.3 Most fluxes for aluminium and its alloys absorb moisture very rapidly, and their efficiency is reduced accordingly. It is essential, therefore, that fluxes should be stored in airtight containers. Containers manufactured from aluminium or glass are suitable for this purpose, but steel or brass should not be used, since these materials cause contamination.

15.4 **Brazing Process.** The three main methods of brazing aluminium and aluminium alloys are: torch or flame brazing, furnace brazing and flux dip brazing.

15.4.1 **Torch Brazing.** In torch brazing, acetylene and hydrogen are the preferred fuel gases, although other gases, e.g. coal gas, are used; all these gases are often used with oxygen.

(i) A brazing torch, which is often a standard welding torch, is suitable for most aluminium brazing work. The flame must be maintained in a neutral condition, but should this prove difficult, a slightly reducing flame is preferable to an oxidising flame (see Figure 1).

(ii) When using oxy-acetylene the possibility of overheating must be kept in mind. The melting point of the filler alloy must occur before the temperature of the joint causes sagging or plasticity of the basis metal.

15.4.2 **Furnace Brazing.** Furnace brazing requires a temperature control of $^{+5°C}_{-0°C}$ over a range of 540°C to 650°C, according to the material being brazed. The general requirements for brazing aluminium are, a rapid rise in temperature, a short period at the brazing temperature, and a rapid cooling to below the solidifying temperature of the brazing alloy. Any heat-treatment furnace giving such conditions, and having its linings protected from attack by flux, is suitable.

(i) A high rate of heat input ensures that the work is raised to the brazing temperature rapidly and so prevents excessive alloying between the filler metal and the basis metal. An even distribution of the heat throughout the chamber is a definite advantage. No useful purpose is served by having an inert or reducing atmosphere in the furnace.

(ii) As a general guide to timing, light gauge sheets take 2 to 6 minutes from the time the brazing temperature is reached until the filler metal has filled the joint area, and 4 to 15 minutes for complete furnace treatment; heavier sections may take up to half-an-hour for the complete furnace treatment.

(iii) Heat-treatable alloys must be reheated and quenched at the appropriate temperature to restore their properties, although quenching from the brazing temperature results in partial restoration. Quenching also loosens and partly removes the residual flux, thereby simplifying the final cleaning process. Thin gauge materials may become distorted if quenched by immersion, and water sprays may be used to minimise this by ensuring that all parts are cooled simultaneously.

15.4.3 **Flux Dip Brazing.** Flux dip brazing is used largely in the quantity production of assemblies having a large area of jointing in relation to their size, for example, heat exchangers or radiators, and is useful for the brazing of parts in an inaccessible position which cannot be brazed by other methods. This process is suitable for any aluminium alloy that is suitable for furnace brazing.

(i) Components should be cleaned, assembled with pre-placed filler material and heated in a furnace to a temperature just below the melting point of the filler alloy.

(ii) Assemblies should then be transferred to a bath containing molten flux at a temperature high enough to melt the filler, but not the parent metal; they should be removed as soon as the filler has had time to flow freely through the joints. Overlong immersion may result in flux attack and allow excessive diffusion between the filler and parent metal.

(iii) Heat-treatable assemblies should then be quenched or re-heated as described in paragraph 15.4.2 (iii).

15.5 **Flux Removal.** The quick removal of flux after brazing is essential; immediately the assembly can be handled, it should be treated as described in paragraph 14.

15.6 **Properties of Brazed Aluminium Joints.** As the brazing temperature is higher than the recrystallisation temperature of aluminium and aluminium alloys, annealing takes place during brazing.

15.6.1 Brazed assemblies made of non heat-treatable alloy have their design strength based on the strength of the annealed material.

15.6.2 Suitable assemblies made of heat-treated alloy of the aluminium-magnesium-silicon type may be strengthened after brazing by quenching, followed by natural or artificial ageing according to the requirements of the specification. Alternatively, assemblies may be re-heat-treated to restore the full strength of the basis material.

15.6.3 Aluminium filler alloy does not show a significant increase in strength after heat-treatment and limits the design strength of a brazed assembly.

16 HIGH NICKEL ALLOYS These alloys are usually specified for their heat and corrosion resistant properties.

16.1 Most of the high nickel alloys can be readily joined by silver brazing, but may be subject to intercrystalline penetration by the filler alloy if brazed in a state of stress. When high melting point filler alloys are used all stresses are relieved during the brazing process but, if low melting point filler alloys are used on heavily worked components, stress cracking may result if the components are not stress-relieved prior to brazing. Nickel alloys should normally be brazed in the annealed condition.

16.2 **Cleanliness.** Cleanliness is essential, and it is particularly important that all foreign matter which might contain sulphur or lead is removed before any heating takes place, as all nickel alloys are subject to some degree of attack by intercrystalline penetration by these elements, resulting in embrittlement. Possible sources of such contamination are: oil, grease, paint, marking pencils and cutting lubricants. Cleaning should be carried out just before the actual brazing operation. The tenacious oxide film requires vigorous treatment for its removal, particularly on the chromium-containing alloys, and especially after long storage. Mechanical methods, such as grinding, buffing, etc., are generally used, but chemical cleaning may also be employed. (See paragraph 7.2).

16.3 **Brazing Materials.** Silver brazing alloys complying with the AG series of filler alloys in BS 1845 are readily available and are recommended for use with nickel alloys. The flux should be of a type recommended by the manufacturer of the filler alloy; borax is not a satisfactory flux for this material. The flux is generally mixed with water and applied with a brush but, alternatively, the parts may be coated with flux and assembled whilst wet. Flux residue must be removed as described in paragraph 14.2.

16.4 **Heating.** Any of the methods of heating previously described may be used with nickel alloys. The hand torch method may be applied to most work, but particular care is necessary when using an oxy-acetylene torch, as the flame can easily produce temperatures well above those required for silver soldering and may overheat the basis metal.

17 HIGH TEMPERATURE BRAZING Where joints are required to retain their strength and corrosion resistance at elevated temperatures, high temperature brazing may be used.

17.1 Brazing alloys containing palladium or nickel are widely used for joining the Nimonic and Inconel types of alloys; these brazing alloys make joints which combine good mechanical properties at high temperatures with a high resistance to oxidation.

17.2 **Brazing Methods.** Brazing is usually carried out in a vacuum furnace or in a furnace containing an atmosphere of cracked ammonia or hydrogen, but salt bath or induction heating may also be used. Except when vacuum brazing, a flux should normally be used, but if, because of the difficulty of removing the residue, the use of a flux is undesirable, components are sometimes electro-plated with nickel before being brazed.

18 BRAZING STAINLESS STEEL Stainless steel parts are often joined by brazing. The method is adaptable to repetitive techniques and provides a simple means of making joints which are often as strong as the parent metal.

18.1 The success of the brazing operation depends on the use of a suitable stainless steel alloy and on the selection of a suitable filler and flux.

18.1.1 When stainless steels are heated, the formation of chromium carbide within the metal reduces the amount of chromium available and may decrease its resistance to corrosion. This effect is known as weld decay and has been largely overcome by the use of 'stabilised' steels containing titanium or niobium. If it becomes necessary to braze unstabilised stainless steels the effects of carbide precipitation may be minimised by keeping the brazing temperature and heating time to a minimum.

18.1.2 Joints in nickel-free stainless steel often suffer from a defect known as crevice corrosion when subjected to conditions of high humidity. Silver brazing alloys are generally employed where this type of corrosion is likely.

18.1.3 Nickel brazing alloys and alloys containing palladium and gold have been found particularly suitable for furnace brazing in a protective atmosphere, the resulting joints being resistant to chemical attack and crevice corrosion. Bronze filler alloys may also be used but are less resistant to chemical attack.

18.1.4 Fluoride fluxes are normally used when brazing with silver brazing alloys, but special fluxes with improved wetting properties are often recommended for use with stainless steel because of the formation, during brazing, of a thin film of residue which is insoluble in normal flux.

18.1.5 Flux residues should be removed as described in paragraph 14.2.

19 SAFETY PRECAUTIONS All brazing operations involve the use of flame or heat and the handling of metals at high temperatures; it is necessary, therefore, that certain simple safety precautions are observed. Additional precautions are necessary because of the use of alloys or fluxes, which may have toxic properties under certain conditions.

19.1 **General Precautions.** Components may retain their heat for a considerable period after brazing and should always be handled with care. Unless asbestos gloves are worn, unquenched parts should always be handled with pliers or tongs.

19.1.1 Torches should always be pointed away from the operator when being lit and should be lit either from the side or from below. If possible, hand torches should be fitted with a switch hook, in which a pilot jet and hook are connected to a valve in the gas supply. When the torch is hung from the hook, its weight cuts off the main gas supply but when it is picked up the flame relights.

19.1.2 Controlled atmosphere furnaces often have a curtain of burning gases at the entry and exit doors. These flames are often nearly invisible under certain light conditions and particular care may be necessary when inserting or removing components.

19.1.3 Hand torch brazing should always be carried out in a location shielded from flammable materials by refractory bricks or asbestos.

19.2 **Induction Brazing.** Metal articles heat up very quickly when placed within an induction coil. For this reason the hands should not be placed in a coil if a ring, watch or bracelet is worn, as severe burns could result.

19.3 **Salt Baths.** Molten salts splashed from a salt bath may cause very severe burns; protective clothing, including overall, gloves and goggles, should always be worn when working with a salt bath. Components must be completely dry before being immersed in the bath and must be lowered very slowly into the salts to prevent splashing. Salt residue should always be scrubbed from the hands before handling food.

19.4 **Brazing Alloys.** Most silver brazing alloys contain zinc or cadmium which, if overheated, give off fumes which may be irritating and injurious to health. Adequate ventilation must be provided when brazing with these alloys and overheating must be avoided.

19.5 **Fluxes.** Most brazing fluxes cause skin irritation, and physical contact should be avoided whenever possible. The hands should be washed frequently and a barrier cream used. In the event of flux being swallowed, medical attention should be sought immediately.

20 INSPECTION In order to obtain the most successful brazed joints, close control of all operations is essential. The design, manufacture and cleaning of the component parts of the joint, the brazing alloy and flux used, the heating process selected, the method of removing flux residues and the application of any necessary heat treatment, should all be in accordance with proven methods and substantiated by the manufacture and testing of sample joints.

20.1 Adequate control of the heating method is essential, particularly for induction heating, resistance heating and furnace heating, and staff should be competent to ensure that consistent results are obtained. Hand torch operators should have their work checked at frequent intervals. (See paragraph 4).

20.2 At specified intervals a completed assembly should be selected and subjected to strength tests and sectioning to ensure that the complete brazing operation remains satisfactory.

20.3 The following points should be checked when visually inspecting a finished joint:—

(i) The joint and surrounding surfaces should be free from pitting, corrosion, scale, flux residue and other evidence of bad workmanship.

(ii) The filler alloy must have penetrated throughout the joint. In the case of pipe joints an examination should be made for excessive penetration which may partially obstruct the pipe bore.

(iii) Fillets of filler alloy should be smooth and continuous.

(iv) The dimensions of the assembly should be in accordance with the appropriate drawing.

20.4 A visual examination may sometimes be insufficient to establish that the filler alloy has penetrated through the joint. In these cases, X-ray, ultrasonic or eddy current inspections may be required.

20.5 In some instances, brazed joints which have been found unsatisfactory, may be re-brazed under suitably controlled conditions. Care is necessary to prevent the build up of an excessive amount of filler alloys, particularly in the case of pipe joints (paragraph 20.3 (ii)).

BL/6-4

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BASIC

ENGINEERING PRACTICES AND PROCESSES

OXY-ACETYLENE WELDING

1 INTRODUCTION This Leaflet gives general guidance on the welding of ferrous and non-ferrous metals by the oxy-acetylene process. It should be read in conjunction with the approved drawings and any related instructions for the welding operation(s) concerned.

NOTE: The term 'welding' is used to describe the joining of metals in which local fusing of the metals is a basic process.

1.1 Information on other welding processes will be found in the following Leaflets:—

BL/6-5 Arc Welding

BL/6-12 Resistance Welding—Spot Welding

BL/6-16 Resistance Welding—Seam Welding

BL/6-17 Resistance Butt and Flash Welding

NOTE: Information on Bronze Welding (sometimes known as Braze Welding) will be found in Leaflet BL/6-2.

1.2 The CAA requirements for the approval of welders are prescribed in Section A of British Civil Airworthiness Requirements.

2 THE WELDING PROCESS In the oxy-acetylene welding process, oxygen and acetylene gases are fed through a welding 'blowpipe', the pressures and quantities of each being separately adjustable. The jet of mixed gas is ignited, and produces a flame with a temperature of approximately 3100°C (5600°F), which is used to melt the adjacent material of the parts to be joined. Filler rods are normally used for materials of 0·9 mm (20 s.w.g.) and thicker, and a flux is generally used to remove oxides from the surface of the metals and to ensure a sound weld; different materials require different filler rods and/or fluxes.

2.1 The oxy-acetylene welding process should not normally be used for welding magnesium or high-nickel alloys, and is not recommended for stainless steel; inert gas or plasma arc welding are more suitable for these materials.

2.1.1 The relevant approved drawings and any related instructions on the welding operations should be closely followed. The following details are generally provided on the drawing(s):—

(a) Specification of the material(s) to be welded.

(b) Specification of filler rod.

(c) Type of flux.

(d) Details of joint preparation and cleaning procedure.

(e) Welding instructions (e.g. tack weld, clamp, starting position).

(f) Heat treatment and removal of flux.

(g) Inspection and any related tests.

3 WELDING EQUIPMENT Paragraphs 3.1 to 3.6 contain information of a general nature on the control, use and care of welding equipment.

3.1 **Gas Cylinders.** Special precautions are taken with oxygen and acetylene cylinders to ensure that confusion of identity cannot occur. Oxygen cylinders are painted black and have a right-handed valve thread, whilst acetylene cylinders are maroon in colour and have a left-handed valve thread. In addition, the cylinders are produced in distinctive shapes as shown in Figure 1.

Figure 1 CYLINDER IDENTIFICATION

3.1.1 Gas cylinders should be stored in the upright position in well ventilated rooms. Those standing in the open should be protected from extremes of temperature and should not be placed on wet soil.

3.1.2 Oxygen cylinders, valves, etc., should not be handled with greasy hands or greasy gloves, neither should any part of the welding equipment be lubricated with oil or grease, since these materials ignite spontaneously when in contact with oxygen under pressure.

3.1.3 Acetylene can form explosive compounds when in contact with certain metals and alloys (e.g. copper and silver), it is, therefore, important that all fittings through which acetylene is to flow have been designed specially for that purpose.

3.2 **Gas Generators.** Where acetylene gas generators are in use, a daily check for gas purity is necessary. Blotting paper soaked in a 10% aqueous solution of silver nitrate should show no darkening when placed in the gas stream.

3.3 **Gas Feeding System**

3.3.1 Oxygen vigorously supports combustion, but since it has no smell it is difficult to detect. Conversely, acetylene has an unmistakable smell and will ignite and burn instantly from a spark or even a piece of heated metal. It is clear that a dangerous condition could arise as a result of leakage in equipment, particularly in confined spaces, and the feed system should be checked periodically to ensure freedom from leaks. Tests for leaks should be made with soapy water and a brush, and not with a naked flame.

3.3.2 Pressure gauges should be checked periodically against a master instrument to ensure accuracy, and a record should be kept of these checks.

3.3.3 To avoid any possibility of confusion, it is usual for black hoses fitted with right-hand threaded connections to be used with oxygen equipment and red hoses fitted with left-hand threaded connections to be used with acetylene equipment.

3.4 **Blowpipes.** The selection of the proper blowpipe nozzle for the work in hand is largely a matter of experience. The various factors which govern the size of the nozzle include the nature of the work, the thickness and type of material and the skill of the welder. The instructions issued by the manufacturer of the equipment give the best guidance in this respect, but it is recommended that nozzles be checked periodically to ensure that they continue to conform to nominal dimensions.

3.5 **Lighting the Blowpipe.** Before lighting the blowpipe the regulators must be set to the correct pressures and the light must be applied only when a flow of gas is properly established, otherwise a flash-back may occur. The use of a spark lighter is recommended.

3.5.1 It is important that the instructions given by the manufacturer regarding the correct procedure for lighting up and operating the equipment, and the safety precautions to be taken in the event of a cylinder becoming heated due to a flash-back or other incident, should be followed. Failure to comply with such instructions and precautions may cause the cylinder to heat up and burst.

3.5.2 If the flame goes out when the blowpipe is in use, it may be caused by the regulator pressure and/or the gas flow being incorrect, obstruction of the nozzle, the nozzle being held too close to the work or to overheating of the nozzle. When this occurs both blowpipe valves should be closed. Only when the condition has been rectified should the blowpipe be re-lit. However, if the blowpipe nozzle has become overheated it should be plunged into cold water with the oxygen valve slightly open prior to re-lighting.

3.6 **Manipulation of the Blowpipe.** The essential factors in the manipulation of the blowpipe are careful adjustment to give the required types of flame and holding the blowpipe and welding rod at the most suitable angles for the work in hand. Other factors to be observed are the control of the heating period to obtain a neat and uniform weld bead, adequate penetration without excess heating or burning (especially with thin sheets of non-ferrous metals) and good fusion of the materials being joined.

4 MATERIALS Because of the wide choice of available materials it is impracticable within the scope of this leaflet to give a list of weldable metals. It is always essential to ensure that the material to be welded and the welding procedure used are those specified on the drawing.

4.1 **Filler Rods.** In general, filler rods are made of the same material composition as the metal to be welded but there are exceptions, thus the welding of aluminium alloys complying with different specifications with filler rods of the same composition could lead to cracking. Unless otherwise stated filler rods should comply with BS 1453 entitled 'Filler Materials for Gas Welding'.

4.1.1 Filler rods should be stored in a warm, dry atmosphere, to prevent the pick-up of moisture which can cause porosity in welds.

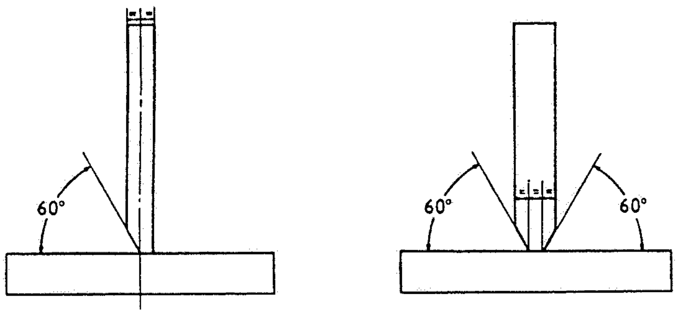
4.2 **Fluxes.** With most metals, except steel, the melting temperature of the metal is much below the melting point of the oxides formed by heating and therefore the oxides remain as solid particles. Flux reduces the effects of oxidation, floats oxides and other impurities to the surface of the weld where they do no harm, and produces a stronger weld. Fluxes are not used for the welding of carbon steels because the oxides of the various elements unite and form a slag at a temperature lower than that of the molten metal, the slag floating to the surface of the weld.

4.2.1 The oxides of different materials vary considerably in physical and chemical properties and no one type of flux is suitable for use with all materials. Unless otherwise specified, it is usual to use the flux recommended by the filler rod manufacturer.

4.2.2 Most welding fluxes absorb moisture readily and their efficiency is reduced accordingly; damp flux will also cause porosity in the weld. It is essential therefore that fluxes are kept in airtight containers. Containers made of aluminium or glass are suitable but steel or brass should not be used as these materials cause contamination of the flux.

5 JOINT PREPARATION It is usual for joints to be designed as simply as possible. Applications requiring the joining of metals of vastly dissimilar thickness are seldom specified since the heat required to bring the thicker material to the molten state may burn or melt away the thinner material.

5.1 **Fillet Welds.** To ensure adequate strength and weld penetration, chamfered edges, prepared as shown in Figure 2, are usually required for materials of 1·6 mm (16 s.w.g.) and thicker. For materials in the thickness range of 1·6 to 2·5 mm (16 to 12 s.w.g.) a single chamfer, as shown in Figure 2(A), can be used to ensure satisfactory penetration in instances where welding from both sides is not possible, but for materials thicker than 2·5 mm (12 s.w.g.) a double chamfer, as shown in Figure 2(B), is usually required to provide the necessary strength. Materials thinner than 1·6 mm (16 s.w.g.) should be welded from one side only to avoid burning and weakening the material. Fillet welding of aluminium and aluminium alloys is not normally recommended because of the danger of flux entrapment which could lead to serious corrosion. However, if fillet welding of these materials is essential then the joint should be completely sealed.



(A) SINGLE FILLET WELD (B) DOUBLE FILLET WELD

Figure 2 PREPARATION FOR FILLET WELDS

5.2 **Butt Welds in Materials other than Aluminium Alloys.** Prepared edges are not usually required for materials thinner than 1·6 mm (16 s.w.g.) but to ensure weld penetration and adequate strength in thicknesses up to 3·2 mm (10 s.w.g.) it is usual to chamfer the two adjacent edges thus forming a 'V' with an included angle of say 120°, as shown in Figure 3(A). For thicker materials the edge preparation is usually as shown in Figure 3(B).

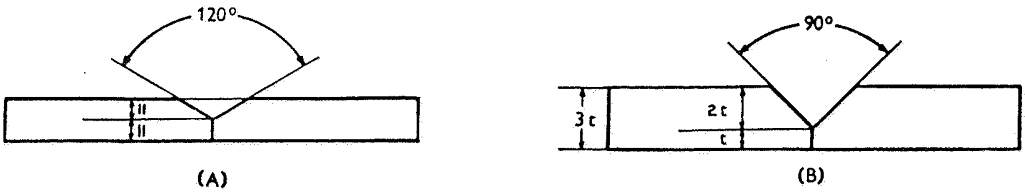


Figure 3 BUTT WELDS

5.2.1 In butt welding flat sheet due allowance should be made for distortion. If the edges are placed together for their entire length, as welding proceeds they will first diverge then gradually pull together again until one edge will tend to ride over the other and make welding impossible; this can be avoided by tack welding at suitable intervals before starting the welding run.

5.3 **Butt Welds in Aluminium Alloys.** For materials thinner than 2·0 mm (14 s.w.g.) no edge preparation is necessary but it is usual to leave a gap equal to the thickness of the material between the edges of the two sheets. For materials thicker than 2·0 mm (14 s.w.g.) the edges are usually prepared as shown in Figure 3(B), except that the angle is smaller (say 60 to 70°) and a gap not exceeding one-third the thickness of the material should be left between the sheets.

5.4 **Welds in Tubular Sections.** The preparation of tube ends for welding will depend mainly on the gauge of the material and the design of the joint. Where tubes intersect, special instructions will be given on the drawings regarding the fit of the tubes.

5.4.1 The clustering of several tubes at a given point is normally avoided, as the large amount of welding and the resultant heat in a restricted space may cause cracks in the welds and may weaken the basic metal. Where weld concentrations of this kind are unavoidable the instructions often stipulate a stress relieving treatment.

5.4.2 Where a tube or a tubular structure is completely sealed (e.g. to prevent internal corrosion), a hole should be drilled in a specified position to allow the expanded hot air to escape. When welding has been completed and the work has cooled down, the hole should be plugged (e.g. by welding) to avoid ingress of moisture.

NOTE: Some tubular structures, such as engine bearers, are protected internally by the introduction of a corrosion inhibiting fluid after welding has been completed.

5.5 **Cleaning Surfaces for Welding.** All scale, grease, dirt, paint or other extraneous matter should be removed for a minimum distance of 25 mm (1 in) each side of the edges to be welded. The methods of cleaning will vary with the material concerned. Some typical cleaning methods are given in paragraphs 5.5.1 and 5.5.2.

NOTES: (1) When a pickling process is required for cleaning purposes, it is essential that the process to be used is approved by the Design Organisation concerned.
(2) It is imperative that suitable safety precautions are observed when handling the types of acid used in the pickling processes described in 5.5.1 and 5.5.2.

5.5.1 **Aluminium and Aluminium Alloys.** The edges to be welded should be prepared either by vacuum blasting or by brushing with a brush with stainless steel or nickel bristles. The use of brushes with copper alloy bristles should be avoided because of the corrosion hazard which could result from pieces of bristle becoming enbedded in the surface. Chemical cleaning methods may also be used as follows:—

(a) **Brush Application.** A typical solution for brush application would consist of de-mineralised water containing:—

Sulphuric Acid (d = 1·84)	5% (V/V)
Hydrofluosilicic Acid	2·5% (V/V)
Aluminium Sulphate	3 g/litre

(i) This solution must be kept in a rubber lined tank.

(ii) The pickling solution should be removed by thoroughly rinsing the part in cold water, and it is recommended that a jet of water is used for this purpose. The part should then be dipped in hot water to assist drying.

(b) **Bath Treatment.** To remove an anodic film the treatment specified in DEF 03-2/1 should be used as follows:—

(i) The parts should be immersed in a solution consisting of de-mineralised water containing:—

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

(ii) The solution, which should be kept in a lead-lined tank, should be maintained at approximately 60°C.

(iii) The etched parts should be washed as quickly as possible in cold water, and thoroughly dried.

5.5.2 **Steels.** The methods of cleaning steels vary with the type of steel concerned. In general, steels may be divided into two main groups: (a) low carbon and alloy steels, (b) corrosion-resisting or heat-resisting austenitic steels.

(a) **Low Carbon and Alloy Steels.** The edges to be welded may be prepared by sand, shot or alumina blasting or by brushing with a wire brush. Where a blasting process is used, the material should be welded as soon as possible to prevent corrosion.

(b) **Corrosion-Resisting and Heat-Resisting Austenitic Stainless Steels.** The edges to be welded can be prepared by an alumina blasting process or by brushing with a brush with stainless steel bristles. Blasting with crushed steel shot should not be used. A typical pickling solution for brush application would consist of:—

Hydrofluoric Acid	3·0 to 4·2% (W/V)
Ferric Sulphate	10 to 15% (W/V)
Water	Remainder

(i) The solution should be contained in a lead-lined tank and maintained at a temperature of 60°C.

(ii) The pickling solution should be removed by thoroughly rinsing the part in cold water, and it is recommended that a jet of water is used for this purpose. The part should then be dipped in hot water to assist drying.

6 WELDING JIGS The accurate assembly of welded parts may necessitate the use of special jigs which will be unaffected by changes in temperature.

6.1 The type of joint, the nature of metal to be welded, and accessibility are factors which influence the design of jigs. The jigs should permit free access to the area to be welded. The jig assembly should be fairly rigid, but not so rigid that the parts become stressed during cooling, and clearance should, therefore, be allowed for the expansion and contraction of the parts.

6.2 Where clamping or locking devices are incorporated in the jigs to control distortion, they should align the components to a degree of accuracy which does not permit the overall distortion to exceed the following:—

(a) 0·075 mm (0·003 in) in material thinner than 0·7 mm (22 s.w.g.).

(b) 0·125 mm (0·005 in) in material of thickness 0·7 to 1·2 mm (22 to 18 s.w.g.).

(c) 0·25 mm (0·010 in) in materials thicker than 1·2 mm (18 s.w.g.).

6.3 When tubular sections are to be welded, the parts should be correctly fitted into the jig in relation to one another. The jig should be so constructed that there is no possibility of misplacing the tubes from the intended position, otherwise uneven joints and unequal distribution of stresses may result.

7 STRESS AND DISTORTION During welding operations the parts are in varying conditions of expansion and contraction, and the adaptation of the sequence of welding operations to each particular application is important if stress concentrations are to be kept to a minimum.

7.1 The heat necessary to perform the welding operation can be reduced if the weld metal is run in thin layers and the welding speed is reduced by using the smallest flame consistent with correct penetration and fusion. (For aluminium welding see paragraph 8.3.6).

7.2 Reduction of localised heat can also be effected by welding in short lengths, either with each length ending where the previous one began, or with each length as far apart from the previous one as possible. With fillet welding, when welding is to be done on both sides, the metal may be deposited in short lengths on alternate sides.

7.3 When butt welding sheets, particularly when jigs are not available, distortion can be considerably reduced if the joint is 'tack' welded at suitable intervals prior to commencing the finishing weld.

8 WELDING ALUMINIUM ALLOYS The oxy-acetylene welding process is used mainly for aluminium alloy sheet which is less than approximately 2·0 mm (14 s.w.g.) thick; sheets of greater thickness are normally welded by the inert gas arc welding process (Leaflet **BL/6-5**).

8.1 The melting point of aluminium is low and heat is conducted rapidly through the material. There is very little indication, by physical or colour change, that the material is approaching the melting point and when this stage is reached the material suddenly collapses. The material is very weak at temperatures near the melting point and adequate support should be provided. However, rigid clamping should be avoided whenever possible, to reduce the risk of cracking due to contraction on cooling. Where rigid clamping cannot be avoided, a welding technique must be employed which will keep the stresses to a minimum.

8.2 **Application of Flux.** The flux may be prepared for application by mixing it with methylated spirit to a free-flowing consistency, and then applying it with a brush or dipping the filler rod into the mixture. The methylated spirit will dry off rapidly and will have no deleterious effects.

8.2.1 When it is necessary to apply dry flux to the filler rod, the end of the rod should be heated and dipped into the powder. The deposit of powder adhering to the rod should be melted and allowed to run over the rod surface for about 150 mm (6 in) of its length.

8.2.2 When welding alloys containing magnesium, it is recommended that, in addition to applying flux to the rod, a layer of flux paste should be applied to the edges of the work before welding is commenced. If possible, the flux should be applied to the underside also to ensure a smooth, oxide-free, penetrating bead.

8.3 **The Welding Process.** A slightly carbonising flame should be used since an excess of oxygen will cause the rapid formation of aluminium oxide. However, the excess of acetylene should not be too great as it will be absorbed into the molten metal and result in a weakening of the joint. A low gas velocity giving off a quiet hissing sound should be used. Frequent checks should be made to ensure that the correct type of flame is maintained.

8.3.1 The blowpipe nozzle is usually comparable to that used for steel of similar thickness, any increase or decrease in nozzle size being determined by the gauge and bulk of material involved.

8.3.2 To minimise the possibility of cracking and to reduce the effects of expansion, sheet material should be pre-heated by playing the flame over the joint area before welding. With thin sheets it is advisable to start the weld inside one edge of the work and to weld the short unwelded portion in the opposite direction later.

8.3.3 When starting to weld, the two joint edges should begin to melt before the filler rod is added. The work must be watched carefully for signs of melting, experience determining the proper time for adding the filler metal. The filler rod should be held in a direct line with the weld, with the flame near the material being welded. Both edges of the weld should receive an equal amount of heat, and the metal from the filler rod should fuse with the parent metal.

8.3.4 The blowpipe should be held at an angle of about 30° to the plane of the weld, the angle being decreased as the end of the weld is approached. The tip of the inner cone of the flame should be held closely over the weld and should not be moved up and down. This practice results in heating a smaller area of the joint and minimises the possibility of 'blowing' through, especially when welding thin sheets.

8.3.5 Any tendency to partial collapse or excessive penetration should be rectified by instantly lifting the flame well clear of the material and not by a gradual withdrawal, since this will only worsen the condition.

8.3.6 One of the main differences between aluminium welding and steel welding is in the speed of working. With aluminium welding, as the weld progresses and the metal becomes hotter, the rate of welding should be increased, but in any case the welding speed should be as fast as possible. Where practicable it is better to complete the weld in one operation.

8.3.7 When welding long seams, the material should be tack welded at frequent intervals, e.g. for material of 1·6 mm (16 s.w.g.) and thinner at 25 to 38 mm (1 to 1·5 in) intervals, and for materials between 1·6 and 2·5 mm (16 and 12 s.w.g.) at 75 mm (3 in) intervals. Tack welds should fully fuse the metal.

9 WELDING PLAIN CARBON AND LOW ALLOY STEELS

9.1 A neutral flame should be used (see Figure 4) and the inner cone should be held close to the material being welded. The blowpipe and welding rod should be held at angles of about 60° and 30°, respectively, to the plane of the weld.

NOTE: A completely neutral flame is difficult to recognise, and in order to avoid the detrimental effects of an oxidising flame, a flame carrying the slightest trace of excess acetylene should be used. This condition is obtained when the blue cone nearest the jet has a slight fringe or 'haze' of white flame.

9.2 Good fusion should be obtained evenly on each side of the weld; the rod should be fed into the molten metal and not melted off by the flame itself, otherwise too much material may be run and this will result in a reduction of temperature in the weld with consequent unsatisfactory fusion.

9.3 The welding rod should be of the correct size for the work in hand; if too large it will melt too slowly and produce excessive build up and poor penetration; if too small the rod will melt too quickly and cause difficulty in building up the weld.

10 WELDING CORROSION-RESISTING AND HEAT-RESISTING STEELS

10.1 The heat conductivity of corrosion-resisting steel is approximately 50% less than that of mild steel, whilst its coefficient of expansion is approximately 50% greater. Therefore, correspondingly greater allowance should be made during welding to prevent distortion.

10.2 A welding flame showing a faint haze of excess acetylene around the cone should be used to ensure non-oxidising conditions (see Figure 4) and frequent checks should be made to ensure that this condition is maintained. Excessive oxygen will produce a porous weld, while excessive acetylene will produce a brittle weld. A blowpipe nozzle comparable to that used for mild steel is recommended for light gauge sheet, and up to two sizes smaller than that used for comparable mild steel when welding thicker sections.

10.3 As the rate of heat conduction through the material is less than that of mild steel, the heat is localised and, to minimise the possibility of burning the material, the flame should be played over a larger area than usual. The tip of the inner cone of the flame should be kept very close to the surface but 'puddling' should be avoided. Care is necessary to prevent the flame penetrating thin gauge sheets. The welding rod should be kept in the flame throughout the welding operation, and on completion of the weld the flame should be withdrawn slowly to avoid cracking of the material.

11 REMOVAL OF FLUX Unless the flux is specifically approved as being non-corrosive, it is essential that all traces should be removed.

11.1 **Ferrous Metals.** Where size permits, flux can be removed from ferrous parts by immersing them in boiling water for a period of not less than 30 minutes, the water being changed frequently to avoid contamination. Where immersion is not practical, the parts should be washed until all traces of flux are removed. If the flux residue is brittle its removal is sometimes made possible by lightly tapping it with a hammer.

11.2 **Aluminium Alloys.** The fluxes used in welding aluminium alloys are highly corrosive, and the products of corrosion are also actively corrosive. The action is therefore progressive, and any trapped flux will continue to act until the material is penetrated.

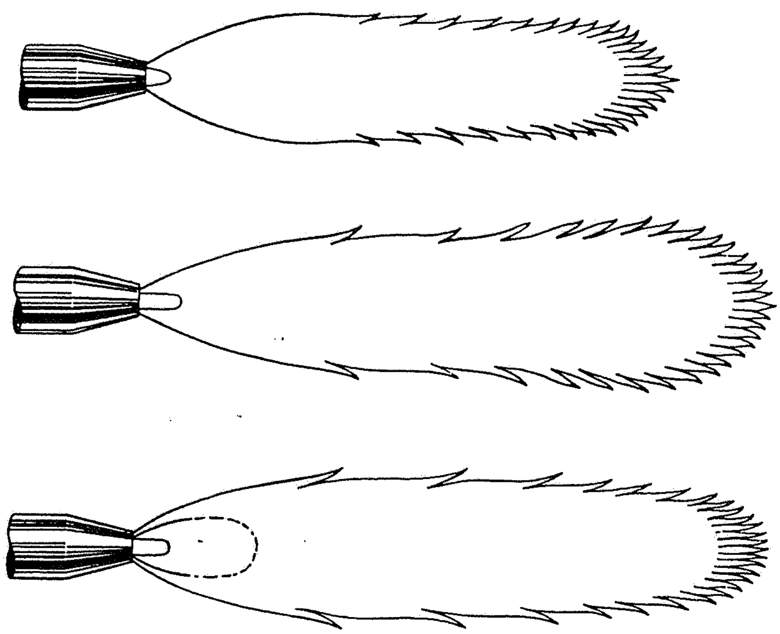


Figure 4 FLAME ADJUSTMENT

11.2.1 The flux should be removed by washing the parts in boiling water for a minimum of 30 minutes, changing the water frequently or using a continuous flow. The washing should be repeated until all traces of flux are removed. The parts should be finally rinsed in hot water and then dried.

11.2.2 Alternatively, flux may be removed by immersing the parts for 20 minutes in a solution of 10% nitric acid in water, maintained at a temperature of 65°C, after which they should be rinsed. The parts should be immersed in a second 10% nitric acid bath for up to 30 minutes, the time depending upon the amount of residual flux, after which the parts should be washed in hot water, drained, dried and inspected. If flux residue still remains, this treatment should be repeated.

NOTE: It may be an advantage to add a small proportion (1 to 5%) of sodium bichromate to the second nitric acid bath.

11.2.3 The efficiency of the final washing operation (whether or not acid treatment has been used) can be checked by adding a small quantity of silver nitrate test solution to a sample of the water in which the joint was washed. If a white precipitate appears it indicates that flux residues are still present and that further cleaning is necessary.

12 HEAT TREATMENT In general, steels having a carbon content in excess of 0·26% are liable to crack after welding unless suitable pre-welding and post-welding heat treatment procedures are employed. It is essential that when such steels are welded the heat treatment prescribed in the relevant specification or drawing is followed.

12.1 Where heat treatment of a welded part is necessary, the part, or a control sample heat treated with the part, should be mechanically tested to ensure that the physical properties of the material still comply with the requirements of the material specification or the drawing.

12.2 The local application of heat for the purpose of final heat treatment is not permitted, neither should attempts be made to correct distortion by the application of local heat without the agreement of the Design Organisation.

12.3 Parts made from carbon and low alloy steels, which can be used in the 'as welded' condition, are sometimes normalised, i.e. heat treated after welding with the object of refining the coarse grain structure in the weld and heat-affected areas.

13 INSPECTION The production of satisfactory welded joints depends on close supervision of the welding process and careful inspection of the completed weld. The depth of inspection of a particular weld will depend to a large extent on the use for which the part is required, and may include visual inspection, pressure tests, radiography, fluorescent or dye penetrant, or magnetic flaw detection. The types of inspection or tests to be carried out should be as stated on the appropriate drawings or manufacturer's instructions.

13.1 **Visual Inspection.** All welds should be subjected to a visual inspection, and this may be all that is required on structures which are neither highly stressed nor critical from fatigue considerations. A visual inspection should ascertain the following:—

(a) That fusion is satisfactory. Adhesion (i.e. as a result of the weld metal flowing on to the unfused parent metal outside the weld bead) may be caused by the use of too large a flame or careless manipulation of the blowpipe.

(b) There should be no undercutting where the weld metal joins the parent metal. The welded part must not be reduced in thickness by the welding operation.

(c) With butt welds, penetration should be obtained right through the joint; an under bead should appear through the full length of the weld.

(d) The build up of the weld should be satisfactory; a concave surface on the face of the weld will indicate lack of metal with consequent weakness.

(e) The weld should show regular surface ripples of close texture; it should be free from indentations, porosity, scale, slag or burn marks.

(f) The dimensions of fillet welds should be correct, especially the leg length (spread of the weld on each side of the joint) and the throat thickness (depth of the weld at the angled joint). Lack of corner fusion or 'bridging' is a common fault in fillet welds and can result in a weak joint; penetration of the weld through both sheets is also considered undesirable.

(g) A weld which has been inspected and subsequently dressed by filing, grinding or machining, as specified on the drawing, should be re-inspected on completion of these operations.

NOTES: (1) Welds in certain alloys are improved by hammering during cooling, but this should only be done if specified on the drawing or in the process specification.
(2) A visual examination may be carried out using a lens of low magnification.

13.2 **Additional Tests.** The type of examination applied to a weld subsequent to the visual inspection depends on the effect a failure would have, and whether the part is highly stressed or subject to fatigue. Any of the following examinations may be prescribed:—

(a) Fluorescent dye (Leaflet **BL/8-7**) or penetrant dye (Leaflet **BL/8-2**) are used to reveal surface defects and are an amplification of the visual examination.

(b) Magnetic flaw detection (Leaflet **BL/8-5**) is used on magnetic materials in preference to dye penetrants as it is more selective and will reveal defects not reaching the surface.

(c) Radiography, using X-rays or gamma rays (Leaflet **BL/8-4**), is used to reveal defects which are contained within the material and do not break the surface.

(d) Alternative methods of detecting hidden defects, including ultrasonic (Leaflet **BL/8-3**) and eddy current (Leaflet **BL/8-8**), may also be specified.

NOTE: In each case a technique suitable for the weld and the defects normally expected will have been decided upon, and should be carefully followed when carrying out an examination.

13.2.1 **Pressure Tests.** Pressure tests should be used on all welded pressure vessels, ducts and similar parts. The pressure to be used in a particular case should be as stated on the appropriate drawing.

14 SAFETY PRECAUTIONS Because of the intensity of the flame used in welding and the fumes given off by certain alloys at high temperatures, special precautions are necessary to safeguard operators. These precautions include the following:—

(a) All operators should wear protective clothing as a safeguard against burns from splashes of molten metal.

(b) All operators should wear protective face masks or goggles and should ensure that they are kept in a satisfactory condition.

(c) The precautions outlined in H.M. Factory Inspectorate Code of Practice for Health Precautions with regard to the welding of leaded steels, should be observed, as necessary.

(d) The heating of steels containing certain alloying elements can result in potentially dangerous fumes, and Department of Employment Technical Data Note 2/73 should be taken into account when welding these materials.

14.1 In addition to the precautions necessary during welding, the use of X-ray or gamma ray inspection methods also calls for the careful attention to safety precautions. These precautions are outlined in the Radioactive Substances Act and in the Ionising Radiations (Sealed Sources) Regulations. Radiographic inspections should be carried out by, or under the supervision of, a person who has satisfactorily completed a course of instruction in radiography and is acceptable to the CAA in accordance with BCAR.

BL/6-5

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BASIC

ENGINEERING PRACTICES AND PROCESSES

ARC WELDING

1 INTRODUCTION This Leaflet gives guidance on metallic arc welding and inert gas arc welding. Carbon arc and atomic hydrogen arc welding are also briefly described, but since these methods now have little application for aircraft purposes brief details only are given. Inert gas metal arc welding is used mainly for medium and heavy gauge materials, and its use is limited in aircraft engineering.

1.1 Guidance on oxy-acetylene welding is given in Leaflet **BL/6–4,** on spot welding in Leaflet **BL/6–12,** on seam welding in Leaflet **BL/6–16** and on butt and flash welding in Leaflet **BL/6–17.**

1.2 The CAA requirements for the approval of welders are prescribed in British Civil Airworthiness Requirements (BCAR).

2 GENERAL The ease with which materials can be welded varies considerably; some materials are easy to weld, whilst others require particular care and additional heat treatment before or after welding to achieve full strength. To ensure that the parts are welded by the correct method and regain strength after welding, adequate information should be provided on the associated drawing or documents relating to the drawing. The following information should normally be quoted:—

(a) The welding process to be used.

(b) Details of any pre-cleaning treatment.

(c) Details of any pre-welding heat treatment required, including temperature and method of application.

(d) Details of current, electrodes and, where applicable, gas flow rates to be used.

(e) Details of joint preparation, location and dimensions of weld.

(f) Cleaning process for the removal of flux residue.

(g) Details of any post-welding heat treatment.

(h) Details of any additional treatment such as hammering the weld during cooling, or grinding of the finished weld.

(j) Details of any routine production tests.

(k) Any special requirements for non-destructive examination.

2.1 **Examination of Welds.** Apart from the usual visual examination of welded joints (see paragraph 8) there are a number of non-destructive examination methods available for ascertaining the quality of a weld.

These are as follows:—

(a) Oil and Chalk Process (Leaflet **BL/8–1**).

(b) Penetrant Dye Process (Leaflet **BL/8–2**).

(c) Ultrasonic Examination (Leaflet **BL/8–3**).

(d) Radiological Examination (Leaflet **BL/8–4**).

(e) Magnetic Flaw Detection (Leaflet **BL/8–5**).

(f) Fluorescent Penetrant Process (Leaflet **BL/8–7**).

2.2 **Arc Welding Processes.** The basic principles of the various arc welding processes are given in paragraphs 2.2.1 to 2.2.5 and the processes are described in detail in paragraphs 3 to 7. The electrical power required for the various arc welding processes is outlined in the relevant paragraphs, but the equipment obtainable from some manufacturers provides alternative power outputs to enable several different processes to be carried out using the same equipment.

2.2.1 **Metallic Arc Welding.** The heat is supplied by an electric arc struck between the workpiece and a consumable flux-coated electrode (see paragraph 3), the workpiece and electrode being connected in series between the output terminals of an electrical power source.

2.2.2 **Tungsten Inert Gas Arc Welding.** This process is commonly referred to as TIG welding. The arc, which is shrouded in an inert gas (usually argon), is struck between a non-consumable tungsten electrode and the parts to be welded (see paragraph 4).

NOTE: A filler rod may be used.

2.2.3 **Atomic Hydrogen Arc Welding.** The arc is struck between two non-consumable electrodes in a flow of hydrogen (see paragraph 5).

NOTE: A filler rod may be used.

2.2.4 **Carbon Arc Welding.** The arc is struck between a carbon electrode and the workpiece (see paragraph 6).

NOTE: A filler rod may be used.

2.2.5 **Metal Inert Gas Arc Welding.** This process is commonly known as MIG welding, and differs from TIG welding in that a consumable electrode, usually similar in composition to the basic metal, is used instead of a tungsten electrode (see paragraph 7).

2.3 **Distortion.** Due to the very high rate of heat generation obtained with electric arc welding where the welding arc temperatures are in the region of 6000°C (compared with 3000 to 3500°C for oxy-acetylene welding), it is possible to confine the heat to a small area, thus reducing considerably any tendency of the workpiece to distort. However, the high local heat input associated with this process usually results in an increased tendency of the workpiece material to crack compared with the oxy-acetylene process.

2.4 **Weldable Materials.** A wide range of materials may be joined by one or other of the arc welding processes and, although all their individual characteristics cannot be fully described in this Leaflet, some guidance is given in paragraphs 2.4.1 to 2.4.9. In addition, Table 1 lists some of the materials in the BS and DTD series which are suitable for welding, but the process for a particular material will usually be chosen by the design office and may have resulted from experimentation and experience with that material.

2.4.1 **Low Carbon Steels.** Mild steel has a carbon content in the range of 0·01 to 0·26% and a manganese content below 0·7%. The advantage of this material is that its properties are not affected by heat and it is therefore very suitable for welding.

TABLE 1

MATERIALS SUITABLE FOR WELDING

Material	Bars	Tubes	Sheets
Low carbon and low alloy steels	S14, S21, S91, S92	T45, T53, T62, T63, T64	S510, S511, S514
Aluminium alloys	L34	L54, L56	L16, L17, L59, L60, L80, L81, L113
Corrosion and heat resisting steels	S125, S126, S127, S128, S129, S130	T65, T66, T67, T68, T69, T70, T71	S524, S525, S526, S527, S528, S529, S530, S531
Magnesium alloys	DTD 142	DTD 737, L503	DTD 118
Copper alloys			BS 2780 DTD 283

2.4.2 **Low Alloy Steel.*** The carbon content of low alloy steel is such that hardening is more easily effected than in straight carbon steel, and although easily weldable, it will, in many cases, need heat treatment after welding to restore its properties.

2.4.3 **Medium Carbon Steels.*** These steels are employed where higher tensile strengths are required; they have a carbon content within the range of 0·3 to 0·6%. The weldability at the lower end of the carbon range is reasonably good, but heat treatment is necessary after welding to restore the original properties.

2.4.4 **Nickel and Nickel Alloys.** Nickel alloys should be annealed prior to welding in order to avoid buckling. These materials are readily weldable and the procedures used for welding low carbon steel are generally suitable.

(a) Some nickel alloys are not sensitive to heat treatment and are easily weldable by the TIG process. Others depend upon heat treatment for development of their optimum properties and the effect of welding must, therefore, be considered in relation to such heat treatment.

(b) Welding of the fully heat-treated material introduces a risk of stress cracking at the joint and inevitably leads to thermally affected zones, where the basic properties of the parent metal will be impaired.

(c) With heat treatable alloys of this kind, strict adherence to the drawing requirements regarding heat treatment is essential. As an example, one method used is to weld these alloys in the solution treated condition and to apply the age hardening treatment after welding.

2.4.5 **Aluminium and Aluminium Alloys.** The arc welding of aluminium and its alloys presents no particular difficulty, but the welding technique differs widely from that used for other materials. The pre-weld and post-weld heat treatment, as well as the equipment used and the method of manipulation, need special attention and care.

*With both low alloy steels and medium carbon steels, cracking in the weld area can be serious, especially with steels at the higher end of the carbon range (see paragraph 3.7).

2.4.6 **Magnesium and Magnesium Alloys.** A number of magnesium alloys are difficult to weld by an arc welding process. Unsatisfactory results may be obtained with metallic arc welding; therefore, no attempt should be made to weld these materials by this process unless it is specified by the drawing, and previous experience of the weldability of the material is available.

2.4.7 **Titanium and Titanium Alloys.** Commercially pure titanium and several of the titanium alloys can be satisfactorily welded by the TIG process, provided that the process is closely controlled.

2.4.8 **Zirconium and Zirconium Alloys.** These materials are easily welded by the TIG process. The mechanical properties and corrosion resistance of the weld are generally good.

2.4.9 **Corrosion and Heat Resisting Steels**

(a) Ferritic steels which contain between 16 and 30% of chromium are normally used, because of their high resistance to heat and corrosion. A variety of these steels can be welded by the TIG process, but pre-weld heat treatment is generally required. Austenitic stainless steel filler wires are often used.

(b) Austenitic steels (corrosion resisting) normally contain approximately 18% chromium and 8% nickel, they also contain small quantities of titanium and niobium as stabilising elements to render the steel resistant to weld decay. They are easily welded but greater allowance must be made for distortion than with low carbon steel.

2.5 **Preparation of Surfaces.** Accurate fitting of the abutting edges is essential to good welding, but the metallurgical quality of the weld depends to a marked extent on the surface condition of the workpiece and filler rod. Dirt, oil, grease, paint and protective finishes must be removed from the weld area immediately before welding, as also (where aluminium alloys and non-corrodible steels are concerned) must the oxide films.

2.5.1 Tricholorethylene (Leaflet **BL/6-8**), acetone and other similar solvents are often employed as degreasing agents. All are very effective in removing extraneous surface deposits, but care is necessary to ensure that no traces of the degreasing agent are left when welding commences. The parts should be degreased, washed and thoroughly dried, otherwise vapours may be produced by the arc on any residual degreasing agents, and these may be toxic to the operator (see paragraph 2.6.5) as well as being a likely cause of gas porosity in the weld.

2.5.2 The tenacious surface oxide films on aluminium and magnesium alloys are best removed by brushing with a stainless steel wire brush or, for magnesium alloys, treatment to DTD 911 requirements. Manual scratch brushing may not be very effective unless carried out vigorously, and the use of a high-speed rotary wire brush is recommended. A number of proprietary brands of pickling solutions are also suitable for cleaning and removing surface films, but when such solutions are used, it is essential, to prevent corrosion, to ensure that all traces of the solution are subsequently removed by thorough washing. All these operations should be done as soon as possible prior to welding, as the effect of the pickle will be lost if delayed too long.

2.5.3 Filler rods (if not flux coated) must not be omitted from the cleaning operations. All filler rods are specially cleaned before despatch, but if left for any time, especially in damp conditions, they may be affected by oxidisation.

2.5.4 Further details on methods of joint preparation are given in Leaflet **BL/6-4**.

2.6 **Safety Precautions.** Safety equipment is necessary, and a helmet, or face shield, in which renewable protective glasses of appropriate tint can be inserted, is essential, as are gauntlets and suitable well-ventilated flameproof clothing.

2.6.1 Both ultra-violet and infra-red rays are emitted during electric arc welding, the effects being greater with the higher currents.

2.6.2 With arc welding the eyes should be protected using a special filter in addition to the normal lens (BS 679).

2.6.3 Welding leathers or overalls with high ultra-violet absorption characteristics, and head shields and gauntlets should always be worn during the welding operation, especially when welding with an inert gas and consumable electrode.

2.6.4 When operators' assistants are within two or three metres of the arc, it is advisable that they should wear anti-flash goggles with opaque sides to protect the eyes from radiation. When welding is being done in an erecting or assembly shop, portable screens should be placed around the welding area to avoid flash injuries to workshop personnel.

2.6.5 One source of danger is the formation of poisonous or objectionable gases as a result of the breakdown of solvent vapours in the welding arc. For example, phosgene gas (which is dangerous in minute concentrations) is produced when trichloroethylene is subjected to high temperatures, and, since the vapour of this particular solvent cannot always be detected by smell, a dangerous situation could exist if it were not completely removed before welding commenced. All solvent degreasing, washing and drying operations should, therefore, be conducted outside the welding shop.

2.6.6 With all electrical welding units, the manufacturer's instructions regarding precautions to be taken should be carefully observed. When the normal open-circuit voltage is likely to be dangerous, an automatic safety device, which reduces the voltage at the electrode holder to a safe value when the welding arc is broken, should be fitted.

2.6.7 **Hydrogen Gas.** When welding with the atomic hydrogen process, it should be noted that the presence of hydrogen in a confined space may represent an explosion hazard, unless sufficient ventilation is provided to prevent the hydrogen forming a dangerous mixture with the oxygen in the atmosphere.

3 METALLIC ARC WELDING

3.1 **Introduction.** In metallic arc welding, the electrode, which is also the filler rod, is coated with flux and is consumed during the welding operation. The electrode melts and supplies the filler metal required to make the joint, the arc being maintained by feeding the electrode at uniform rate and maintaining a constant distance between it and the workpiece.

3.2 **Materials.** No attempt should be made to weld materials which are not designated as suitable for metallic arc welding but, with the exception of aluminium and magnesium alloys, many materials may be welded by this process.

3.2.1 **Scope.** Metallic arc welding is used mainly for the welding of plain carbon and low alloy steels, but many non-ferrous materials, such as nickel alloys and heat-resisting and non-corrodible steels, can be successfully welded by this method. Materials thinner than 1.6 mm (16 s.w.g.) must not be welded by this process.

3.2.2 **Electrodes.** The electrodes are supplied as proprietary items and are coated with flux. The flux covers and adheres firmly to the core or rod of the electrode in a semi-flexible sheath. As the flux melts under the heat of the arc it produces a thick slag covering for the molten weld and an envelope of non-oxidising gas, which together protect the molten metal from the oxidising and nitriding effects of the surrounding air. Only electrodes specified on the drawing should be used; they should be stored in clean dry conditions, and should be heated to a temperature, and for a period, recommended by the manufacturer immediately before use. In the case of low hydrogen electrodes, it is essential that they should be stored in specially heated ovens which keep the moisture content of the coating at a low value.

3.2.3 The flux on the electrodes may also be used to introduce alloy additions into the weld deposit.

3.3 **Welding Process.** To strike an arc between the electrode and the work, the electrode, which is fixed in a special insulated holder, is applied to the work and immediately withdrawn a short distance, thus initiating an arc of intense heat. The tip of the electrode melts and vaporises, and the molten metal is transferred across the arc from the electrode to the joint. Simultaneously, the heat generated melts the workpiece at the joint, and fusion with the electrode material is effected; the arc is maintained by feeding the electrode, at a uniform rate, towards the workpiece. During welding there must be a balance between arc length, current and welding speed, and these factors are dependent upon one another to achieve a satisfactory weld.

3.3.1 **Arc Gap.** The distance between the electrode and the joint is determined by experience, but several variables, such as the voltage used, the type of electrode and the size and type of the materials to be joined, have to be considered. Skill is also required in the manipulation of the electrode, especially in striking and maintaining the correct arc, since if the electrode is allowed to remain in contact with the work it will become welded to the work; sometimes, in such cases, the electrode may be broken loose by a quick thrust of the holder, otherwise it will have to be cut away. However, should the electrode be withdrawn too far, the arc will be lost and the process of striking the arc will have to be repeated. One suggested procedure to facilitate re-striking is that the cup of flux at the end of the electrode should be squeezed between the thumb and forefinger of the welder's glove; this will break away the cup and, at the same time, will not damage the coating of the electrode.

3.3.2 **Positional Welding.** This term defines the position of the workpiece in relation to the operator, and is illustrated in Figure 1. For downhand butt welds, the best angle for the electrode is between 20 and 30° from the vertical to minimise the risk of slag entrapment. However, when low hydrogen or alloy rods are used in the downhand position, the angle of the electrode should be about 10°; in this way the arc is kept as short as possible and loss of the alloying element is avoided. For overhead welds, the arc must be kept very short and the current reduced by about 10% of the usual downhand figure. In vertical welding, the electrode is best held more or less at right-angles to the work and the current should be kept to about 80 to 85% of the usual downhand figure.

3.3.3 **Low Current Welding.** As low a current as possible should be used, consistent with avoiding a 'sticky' arc; this is the tendency of the workpiece or filler rod not to flow, and is caused by the temperature drop during fusion.

3.3.4 **Fillet Welds.** For fillet welds, where the thickness of the parts to be joined is the same, a 45° electrode position, bisecting the fillet, is recommended. Where parts of dissimilar thickness are to be joined, the electrode should be positioned so that the arc tends to play more on the thicker of the two materials.

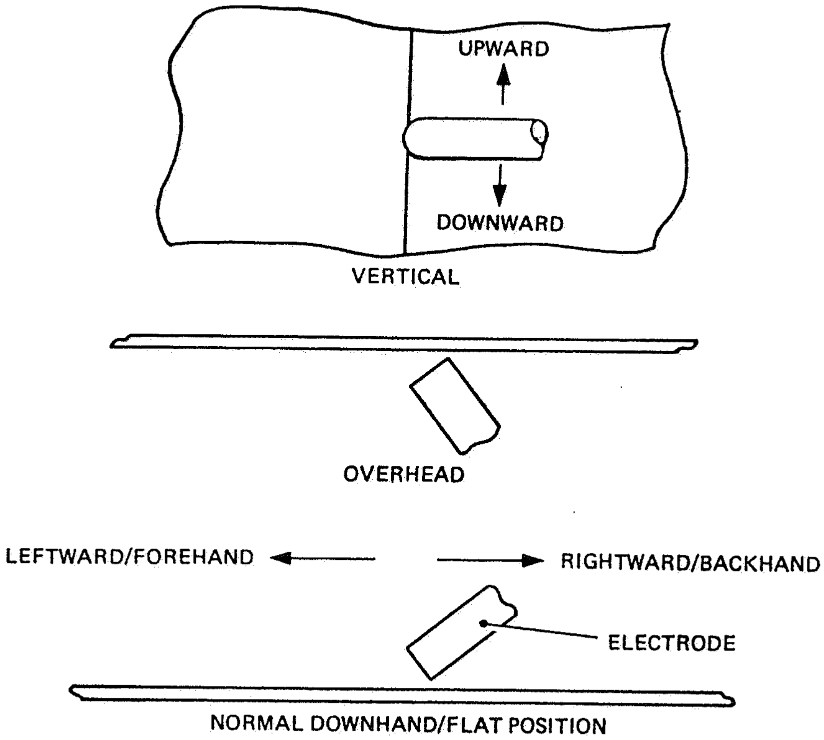

Figure 1 POSITIONAL WELDING TERMS

3.3.5 **Arc Breaking.** When breaking the arc, or when the electrode has been consumed, the arc should be made as short as possible and a circular motion should be made in the welding pool, terminating at the centre of the weld. At this stage, the arc should be broken suddenly to avoid the formation of craters or porosity. To recommence welding, the arc should be struck at the end of the previous run, going back over the 'tail' rather quickly and then welding in the usual way.

3.3.6 **Arc Blow.** When direct current is used, the arc may tend to wander and become uncontrollable. This is known as 'arc blow' and is caused by the magnetic field of the arc stream creating a magnetic field in the material being welded, with a resulting interaction between the fields. The usual methods of counteracting arc blow are to weld in a direction moving away from the earth connection, to change the position of the earth connection, or to change the position of the work on the welding table. With alternating current arc blow does not occur, but a.c. tends to produce an unstable arc, unless a high-frequency oscillator, which stabilises the arc by injecting a high-voltage, high-frequency current, is fitted.

3.3.7 **Spatter.** If small particles of metal are found scattered around a finished weld, this is known as 'spatter' and may be caused by excessive current, arc blow or too high a voltage.

3.4 **Distortion.** The correct sequence of welding operations must be followed in order to reduce distortion and stress concentrations to a minimum. Although there is less distortion with metallic-arc welding than with oxy-acetylene welding, because of the more intense heat which can be confined to a smaller area, it is, however, important to ensure that any jigs used are so designed to allow for expansion and contraction of the work. During welding, the areas surrounding the weld will be in varying conditions of expansion and contraction and stresses will be set up in the material; some of these stresses will disappear on cooling, but others may remain. These stress effects may be reduced, where applicable, by subsequent heat treatment.

3.4.1 The amount of localised heat can be reduced by decreasing the speed of welding. If the largest electrode consistent with the size of joint and the highest welding current is used, then the heat input per unit length of weld is greater, so that a larger area is heated and the rate of cooling is slower.

3.4.2 Reduction of localised heat can also be effected if the weld metal is deposited in short lengths, either with each length ending where the previous one began, or with each length as far apart from the previous one as possible.

3.4.3 When butt welding long joints, such as metal plates where the joints have been set slightly apart, the edges will tend to come together, as the weld proceeds. This may be prevented by first tack welding the joint at regular intervals.

3.4.4 **Design of Joints.** For butt welds on materials less than 3·2 mm (0·125 in) thick, bevelling of the edges is not necessary; the plates can be set as an open square butt with a gap equal to half the thickness of the metal. For thicker materials the edges should be bevelled to form a 'V' butt joint with an included angle of 120°. However, when high alloy steels are welded, a greater heat input is necessary to retard the cooling rate and an angle of 140° is recommended.

NOTE: Removable backing bars should be used whenever possible (see paragraph 4.7).

3.5 **Current and Voltage.** The details of the current range are usually recommended by the manufacturers of the electrodes, but Table 2 lists approximate values. However, it should be noted that the value of the current used will depend to a great extent upon the nature of the work; in general, the higher the current in the range given for one electrode size, the deeper the penetration and the faster the rate of deposit. Table 2 refers to a general purpose steel electrode which may be used as the positive or negative electrode according to the instructions given on the drawing. The voltage varies from 20 to 25, according to electrode size. Alternating current is usually supplied from a simple step-down transformer which reduces the mains voltage to that required for welding. Direct current is obtained either from a mains supply through a suitable rectifier or from a generator driven by external means.

3.5.1 Should the current be too high, the crater and the penetration will be too deep and the deposited layer will be too flat. The arc will be fierce, giving a loud crackling sound, and the electrode will become overheated and burn away quickly; spatter will also be excessive.

3.5.2 When the current and the welding speed are correct, the arc will give a steady crackle and it will be stable and easily controlled, the crater will be of medium size and the penetration good; the deposited metal will present a smooth and even surface.

TABLE 2

ELECTRODE/CURRENT VALUES

Diameter of Electrode	Approximate Current in Amperes		
	Minimum	Maximum	Normal
2·4 mm (0·1 in)	50	90	80
3·2 mm (0·125 in)	60	130	115
4 mm (0·156 in)	100	180	165/175
6 mm (0·25 in)	150	250	220/230

3.5.3 When using direct current, the voltage must not be too low or the electrode will stick to the work. The arc will be difficult to maintain and it will go in and out with a spluttering sound causing the weld metal to be deposited in blobs and with no depth of penetration. Should the voltage be too high, the arc will be fierce, giving a noisy hissing sound and will tend to wander; the deposited metal will be porous and flat, and spatter will be excessive.

3.5.4 Alternating current machines often have a high frequency current superimposed on to the welding current to initiate and stabilise the arc when welding certain materials.

3.6 **Removal of Flux.** Unless a flux is specifically approved as being non-corrosive, it is essential that all traces of flux residue should be removed.

3.6.1 **Ferrous Parts.** Flux can be removed from welded ferrous parts by immersing them in boiling water for not less than 30 minutes. The water in the cleaning bath should be changed at suitable intervals to avoid the risk of contamination. If the flux residue is brittle, it can sometimes be removed by tapping with a light hammer.

3.6.2 **Nickel and High Nickel Alloy Parts.** After welding, the flux residue should be removed by mechanical means, e.g. wire brushing, as the fused flux is not soluble in water. Removal by chemical means is not recommended, as the necessary solution will attack the base metal. For welds intended for service at high temperature, complete removal of the flux is essential, because of the possibility of reaction with the parent metal when subjected to long periods at high temperature.

3.7 **Heat Treatment.** In general, steels with a carbon content in excess of 0·26% are liable to crack after welding unless the pre-and post-welding heat treatment prescribed in the relevant specification or drawing is adhered to.

3.7.1 Where hardening and tempering of the welded parts is prescribed, tests should be carried out in accordance with the requirements of BS S100, S500 or T100, as appropriate. If the drawing specifies stress relieving, the stated temperatures should not be exceeded.

3.7.2 The local application of heat for the purpose of final heat treatment is not permitted, neither should attempts be made to correct distortion by the application of local heat, without the concurrence of the Design Office.

3.7.3 Parts made from carbon and low alloy steels, which can be used in the 'as welded' condition, are sometimes normalised, i.e. heat treated after welding with the object of refining the coarse grain structure in the weld and heat-affected areas.

3.8 **Inspection.** See paragraph 8.

4 TUNGSTEN INERT GAS (TIG) ARC WELDING In this process the heat for welding is supplied by an arc struck between a tungsten electrode and the material to be welded. The weld area and the arc are surrounded by an inert gas (usually argon gas) which prevents contamination of the weld zone by atmospheric oxygen and nitrogen. Welding may be carried out in a welding chamber containing inert gas, or in the open with gas being supplied through a shield around the electrode; in the latter case an inert gas or a flux may need to be provided on the underside of the work.

4.1 This process gives neat welds of excellent metallurgical qualities. Compared with gas welding, the welding speed is high and distortion is reduced to a minimum. Finishing operations are considerably reduced as there is no flux residue; smooth welds are usual, so that no dressing or grinding is required.

NOTE: Discoloration of the weld or base metal, such as the presence of dark or light deposits along or near the weld, should not be taken as an indication that the weld is unsatisfactory without further investigation.

4.2 **Materials.** All welding operations should be performed strictly in accordance with the relevant drawings. No attempt should be made to weld materials which are not designated in the appropriate specification as being suitable for tungsten inert gas arc welding. All the materials weldable by the oxy-acetylene process are suitable for welding by this process.

4.2.1 **Application.** Although suitable for welding any material which can be fusion welded, TIG welding has brought notable improvements in fabrication techniques and also enables satisfactory welding of materials previously considered unsuitable for fusion welding. It is particularly useful for welding aluminium and aluminium alloys, the Nimonic alloys and non-corrodible and heat-resisting steels.

4.2.2 **Material Thickness.** Due to the deep penetrative qualities of TIG welding, a very wide range of metal thickness can be successfully welded; for example, non-corrodible steel sheet of 0·25 mm (0·01 in) thickness and aluminium alloy plate 12·5 mm (0·5 in) thick can be readily welded by hand torch. However, it is usually considered to be uneconomic to use this process on thicker gauge material which could be welded by the metallic-arc process. As the distortion which occurs with gas welding generally restricts the gauge of the metal to be welded, it will be appreciated that with the localised nature of the heat application used in TIG welding, this restriction is considerably eased.

4.3 **Equipment.** The equipment required consists of a welding 'torch' (air or water cooled) and a current regulator, together with a source of current and a supply of inert gas (usually argon). The filler rods to be used for all types of welding are specified in BS 2901.

4.3.1 **Argon Supply.** Argon is present in the atmosphere in concentrations of approximately 0·94% by volume. It is extracted by fractional distillation and is stored in cylinders at a pressure of about 132 atmospheres. It is chemically inert, odourless and non-toxic. Cylinders containing argon are painted blue in accordance with BS 349. It is important that argon lines should be checked periodically for leaks, since serious contamination by oxygen and nitrogen can sometimes arise from this cause.

(a) The rate of gas flow is important and must be suitably regulated (see Tables 3 and 4). When welding thin materials at low current, a small flow of gas gives adequate protection to the small area of molten metal, but a larger flow is required when welding heavier gauge materials. Where higher welding currents are needed, bigger gas nozzles, designed to shroud a wider area, are also required.

(b) Arc stability is also important, less current being required for the more stable type of arc. It is essential to use a flow regulator and meter in the argon line, so that the supply of gas can be controlled for the particular job in hand. The use of a gas economiser is recommended to reduce wastage.

(c) To ensure that the purity of the gas will be satisfactory, it is essential to stress, when ordering, that it is required for the purpose of welding.

4.3.2 **Nature of Current.** The tungsten inert gas arc process is used with both direct and alternating current, the choice of current being determined by the material to be welded. Metals with refractory surface oxide films, e.g. magnesium alloys and aluminium and its alloys, are generally welded with a.c., while d.c. is used for carbon, low alloy, non-corrodible and heat resisting steels, nickel alloys, Nimonic alloys and copper. The maintenance of a stable arc is essential in reducing the current required.

4.3.3 **Alternating Current.** The use of a.c. with a tungsten electrode combines the advantages of reasonable penetration with only moderate heating of the electrode and adequate dispersal of the oxide film from the weld surface. The reversal of current in the a.c. cycle, however, raises a particular difficulty in conjunction with the difference in arc characteristics in the respective half cycles. Twice in each cycle, as the arc current changes in direction, it passes through zero and at these times the arc is extinguished and must be re-ignited for welding to continue. Re-ignition, however, is opposed by the arc gap and, to an added extent, when the polarity of the work is negative; in fact, the resistance during the change of direction may become sufficient to prevent arc re-ignition. This is overcome by the insertion of a series of high-voltage, high-frequency oscillatory sparks across the arc gap at the instants of zero arc current to prevent the arc gap becoming non-conducting, or by means of a surge injector which provides a surge when the arc voltage is at zero.

4.3.4 **Equipment.** The a.c. equipment consists of the welding transformer, d.c. suppressor, HF unit with or without surge injection, and a power-factor correction condenser. A pedal operated control switch for the HF unit must be incorporated, otherwise unsatisfactory welds may result. The switch may be one which controls the HF unit alone, or may be of a type which incorporates a toe-action switch for switching on the current and a heel-action switch for controlling the HF unit.

4.3.5 **Direct Current.** With TIG welding, the choice of polarity depends only on the type of material being welded, since a tungsten electrode is used throughout and is virtually non-consumable. In a d.c. arc, approximately two-thirds of the heat is concentrated on the positive end of the arc and one-third on the negative end. If the tungsten electrode is made positive and the workpiece negative the relatively smaller mass of the tungsten electrode is subjected to the larger proportion of arc heat and the

TABLE 3

ALUMINIUM AND ITS ALLOYS (A.C. ONLY)

Material Thickness mm (s.w.g.)	Current (amperes)	Electrode Diameter mm (in)	Filler Rod Diameter mm (in)	Argon Consumption l/h(ft³/h)
0·90 (20)	45 to 60	1·6 (0·0625)	None or 1·6 (0·0625)	336 (12)
1·20 (18)	60 to 70	2·4 (0·0938)	2·4 (0·0938)	336 (12)
1·60 (16)	75 to 90	2·4 (0·0938)	2·4 (0·0938)	336 (12)
2·00 (14)	90 to 110	3·2 (0·125)	2·4 or 3·2 (0·0938 or 0·125)	354 (13)
2·50 (12)	110 to 130	3·2 (0·125)	3·2 (0·125)	354 (13)
3·20 (10)	130 to 150	4·0 (0·125 to 0·1875)	3·2 (0·125)	354 (13)

NOTE: The tungsten inert gas arc welding of aluminium and its alloys less than 1·6 mm (16 s.w.g.) thick is not generally recommended because the arc is too severe to permit proper control; oxy-acetylene welding is to be preferred.

TABLE 4

NON-CORRODIBLE AND HEAT RESISTING STEELS (A.C. AND D.C.)

Material Thickness mm (s.w.g.)	Current (amperes)	Power	Electrode Diameter mm (in)	Filler Rod Diameter mm (in)	Argon Consumption l/h(ft³/h)
0·55 (24)	15 to 30	d.c. a.c.	1·0 (0·047)	None or 1·0 (0·047)	84 to 112 (3 to 4)
0·70 (22)	20 to 40	d.c. a.c.	1·2 (0·047) 2·4 (0·0938)	None or 1·2 (0·0625)	84 to 112 (3 to 4)
0·90 (20)	30 to 50	d.c. a.c.	1·2 (0·0625) 2·0 (0·0938)	None or 1·2 (0·0625)	84 to 112 (3 to 4)
1·20 (18)	40 to 60	d.c. a.c.	1·6 (0·0625) 2·0 (0·0938)	1·6 or 2·0 (0·0625 or 0·0938)	112 to 140 (4 to 5)
1·60 (16)	60 to 80	d.c.	1·6 (0·0625) 2·4 (0·0938)	2·0 or 2·4 (0·0625 or 0·0938)	140 to 168 (5 to 6)
2·00 (14)	70 to 90	d.c.	2·4 (0·0938)	2·4 (0·0938)	168 to 200 (6 to 7)
2·50 (12)	90 to 110	d.c.	2·4 or 3·2 (0·0938 or 0·125)	2·4 (0·0938)	168 to 200 (6 to 7)
3·20 (10)	110 to 130	d.c.	3·2 (0·125)	3·2 (0·125)	168 to 200 (6 to 7)

relatively larger mass of the joint assembly absorbs the lesser proportion of heat. If, therefore, the tungsten electrode is connected to the negative pole of the generator and the work to the positive pole, the electrode remains comparatively cool, thus negative pole d.c. is widely used for all tungsten inert gas arc welding of steels and high nickel alloys.

4.3.6 **Equipment.** D.C. power may be drawn from a motor-generator plant or a metal-rectifier set.

4.3.7 **Arc Initiation.** Arc initiation and stability can be improved by superimposing a high-frequency current at low power upon the welding current; this also helps to maintain electrode shape and reduce tungsten inclusion in the weld deposit. Suitable units for generating this HF current are available and can be used just for arc initiation, or throughout the welding operation, according to choice.

4.3.8 **Torches.** Torches ranging from 50 to 600 amperes are available for manual welding. For welding currents up to 150 amperes, air-cooled torches are normally used, but for higher currents water cooling is desirable. In either case the argon gas is supplied through a combined power cable and gas hose, and emerges from the refractory (ceramic) shield designed to direct an even flow of argon around the electrode and weld area.

(a) Most torches are designed to take a selection of various sizes of electrodes and gas shields, so that a wide range of material thicknesses can be welded with the same torch.

(b) Should difficulty arise in manipulating a standard torch in awkward positions, a variety of special designs are available. A typical example of a lightweight torch used for welding thin gauge metals is the 'pencil' torch; it has a wide range of application in the aircraft industry. A similar type is also available with a swivel head for welding at different angles.

4.3.9 **Electrodes.** The tungsten electrode, with a melting point of over 3350°C, is virtually non-consumable. The addition of small percentages of other elements is often made to improve arc striking qualities and stability at low welding currents. The electrode extension beyond the shield is important and should be about 3·2 mm (0·125 in) for butt welding and slightly more for fillet welding.

4.4 Welding Technique

4.4.1 **Joint Preparation.** For the butt welding of high nickel alloys, aluminium and aluminium alloys, less joint preparation is required than with gas welding. No special joint preparation is required for any material up to 3·2 mm (0·125 in) thick, and in the case of aluminium alloys, parts up to 6 mm (0·25 in) thick can be welded without bevelling. When the joint edges are not bevelled (square) a gap of half the thickness of the plate should be left between the edges. In general, however, for materials thicker than 3·2 mm (0·125 in), the edges to be welded should be bevelled, so that when the plates are joined a 70° 'V' is formed leaving a thickness of about 0·8 mm (0·03 in) at the bottom of the plates. Backing bars (see paragraph 4.7.1) should be used whenever possible.

4.4.2 **Cleaning.** Argon has no fluxing action and the joint to be welded must, therefore, be absolutely clean; any oxide, grease or dirt will lead to welds of poor quality. Storage of clean materials leads to the formation of a surface oxide film which requires mechanical removal; degreasing alone is not effective. Care should be taken to ensure that the edges to be joined, as well as their top and bottom surfaces, are clean. Materials oxidised during previous heat treatment should first be pickled, and all materials should be cleaned by mechanical means (such as wire brushing) and degreased before welding; any filler rod must be treated in the same way. If more than one pass is used, the previous weld must be thoroughly cleaned before the next run. For details of surface preparation for all materials weldable by the TIG process see paragraph 2·5.

4.4.3 **Butt Welding.** The angles of the torch and the filler rod should be 80 to 90° and 10 to 20°, respectively, from the surface of the horizontal plate (see Figure 2). The arc length (defined as the distance between the tip of the electrode and the surface of the weld crater) varies between 3 mm (0·125 in) and 6 mm (0·25 in) depending on the type of material and the current used.

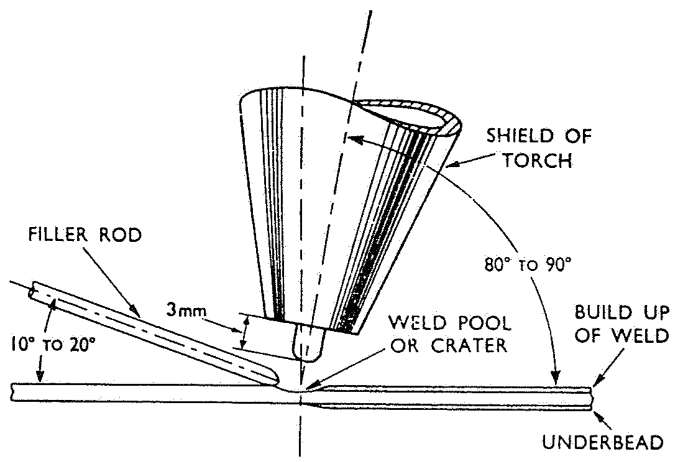

Figure 2 RECOMMENDED ANGLES FOR TORCH AND FILLER ROD

(a) The filler rod is fed into the edge of the molten pool and not directly into the arc; it should be fed in with a slightly transverse scraping motion, with the tip of the filler rod making contact with the weld metal. This ensures that the rod is at the same electrical potential as the plate during transfer of metal to the weld and avoids any tendency of the rod to spatter (see paragraph 3.3.7).

(b) The hot end of the filler rod should always be kept within the influence of the argon gas to prevent oxidation.

(c) Butt welds in thin gauge materials are best made with a progressive forward motion without weaving, but a slightly different technique is required when welding medium or heavy gauge plate. As the filler rod diameter increases with increase in plate gauge, there is a tendency for the filler rod to foul the electrode. Contamination of the tungsten electrode by particles of molten metal causes immediate 'sputtering' of the electrode and particles of tungsten may become embedded in the weld. If this occurs it is essential to change the electrode and, to avoid repetition, the arc length should be increased slightly to accommodate the filler rod. This procedure is limited, however, as there is a maximum arc length beyond which good welding becomes impossible.

(d) To avoid contact between the electrode and the filler rod when welding heavier section plate, it is essential that a filler rod of the correct diameter for the thickness of material being welded is used (see Tables 3 and 4). The weld area is melted under the arc, the torch is withdrawn backwards for a short distance from 6 to 12 mm (0·25 to 0·5 in) along the line of the seam, and the filler rod is inserted in the molten pool. The torch is moved forward and the filler rod is withdrawn from the pool simultaneously. This movement of both torch and filler rod, backwards and forwards in a progressive forward motion, melts down filler rod and plate without the filler rod entering the core of the arc.

4.4.4 **Fillet Welding.** The axis of the tungsten electrode should bisect the angle between the horizontal and vertical members of the joint, whilst the angle of the electrode with respect to the longitudinal axis of the joint should approach as closely as possible to 90°. This prevents, as far as possible, fouling of the argon shield on the plate surface and provides the best shrouding of the molten metal. The filler rod should be fed into the molten weld pool at a very acute angle and with the same technique as used for butt welding. On sections thicker than 1·6 mm (0·0625 in) the forward and backward motion of the torch should be employed to obtain full root penetration (see paragraph 4.4.3 (d)).

(a) **Electrode Length.** In awkward corners it may be desirable to extend the electrode tip beyond the normal 6 mm (0·25 in) or so from the argon shield in order to obtain better visibility. Provided this procedure is not carried to extremes and that the argon flow is increased slightly, no detrimental results in the quality of the weld should occur.

4.5 **Positional Welding.** The downhand technique (see paragraph 3.3.2) should be used where possible, since other techniques reduce the welding speed without decreasing heat input and may induce distortion. The downward vertical technique can be used on sections thicker than 2·4 mm (0·09 in). Some side-to-side motion may be necessary with upward vertical welding to avoid excessive droplet formation, and the filler rod should be inserted in fairly rapid, short bursts, depositing a small quantity of metal with each movement.

4.6 **Completing the Weld.** Until experience is gained with a particular material, operators are likely to have some difficulty in preventing crater formation at the end of a run. To assist in overcoming this difficulty, devices are available which reduce the welding current gradually; alternatively, extension tabs may be left on the component, on which the weld can be run out and the tab then discarded. To assist in preventing oxidation, the argon should not be cut off too soon after the completion of welding.

4.7 **Jigs and Fixtures.** Accurate alignment and careful preparation of joints are essential for tungsten inert gas arc welding, and use should be made of jigs and fixtures whenever possible. Tack welds may be used, but these should be small and short, and must be thoroughly wire brushed before they are incorporated in the main weld.

4.7.1 **Backing Bars.** Backing bars are widely used with automatic TIG welding and serve to minimise distortion and to control penetration. They usually form part of a fixture which also serves to ensure accurate alignment of the welded joint. Good contact between the backing bars and the sheet material is necessary. The bars can be grooved to suit the type of underbead required, and argon is often supplied separately to the underside of the joint, via such a groove. Various materials may be used for backing bars, but where an insert is used chromium plated copper is the usual choice and water cooling is sometimes applied. Care must be taken to ensure that the backing bars are clean and that condensation does not contaminate the argon supply. Figure 3 shows a typical arrangement of backing bar.

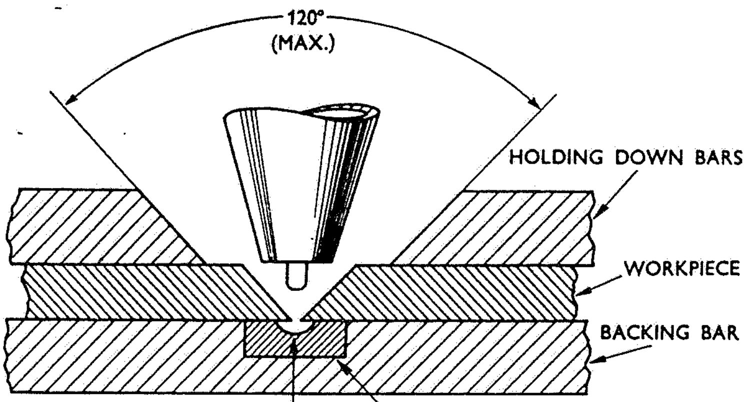

Figure 3 TYPICAL GROOVED BACKING BAR

4.7.2 **Other Backing Methods.** For some components it may be impossible to fit a backing bar. In these circumstances other backing methods may be tried. Refractory materials or appropriate welding fluxes may be applied to the underside of the joint. Fluxes so applied should be thoroughly dry before welding is begun, and procedures to guard against undesirable flux reactions and for the final removal of flux residue from the weld area should be in force.

4.7.3 **Underbead.** An argon atmosphere maintained at the underside of a weld may improve penetration and help to control the form of underbead, but in some components, such as those of small tubular type, a jig may be unnecessary and it may be possible to contain the argon within the component.

4.7.4 **Magnetic Holders.** Magnetic devices for holding components together are widely used. Permanent magnets are available to give pulls of up to 225 N (50 lbf) and electro-magnets can be obtained with considerably greater strength.

4.8 **Flux Removal.** In instances where a flux has been used on the underside of a weld, any flux residues should be removed as soon as possible after welding. Steel and nickel parts should be treated as described in paragraph 3.6, and aluminium and magnesium parts should be treated as described in paragraphs 4.8.1 and 4.8.2 respectively.

4.8.1 **Aluminium Parts.** Flux should be removed by washing the parts in boiling water or in a solution of 5% nitric acid in water at 60°C for at least 15 minutes, then thoroughly rinsing in running water and drying. The process should be repeated until no flux remains.

(a) The efficiency of the final washing operation, whether or not acid treatment has been used, can be checked by adding a small portion of silver nitrate test solution to a sample of the water in which the joint was washed. If a white precipitate appears, it indicates that the flux residues are still present and further cleaning is necessary.

NOTE: The fluxes used in welding aluminium alloys are highly corrosive and the products of the corrosion are also actively corrosive, corrosive action is, therefore, progressive and any trapped flux will continue to act until the material is penetrated.

4.8.2 **Magnesium Parts.** Flux should be removed by vacuum blasting or washing in boiling water. This cleaning should be carried out in conjunction with the preparations for the application of the chromate treatment to DTD 911.

4.9 **Heat Treatment.** Some form of heat treatment may be required on many parts, and precise details will be specified on the relevant drawing.

4.9.1 Stress relieving heat treatment may be prescribed prior to the welding of some stainless steel or chromium-nickel alloys to relieve residual stresses, and after welding of complex structures in non-heat-treatable alloys.

4.9.2 Heat treatable alloys may require a full heat treatment to restore their properties after welding. The times and temperatures of the heat treatment will vary according to the type of alloy, and some compromise may have been made when joining parts made from different alloys. There may also be a restriction on the number of heat treatments given to a particular alloy (for example, magnesium alloys should not be heat treated more than three times).

4.10 **Inspection.** See paragraph 8.

5 ATOMIC HYDROGEN ARC WELDING Heat is produced by an arc struck between two inclined tungsten electrodes. A stream of hydrogen passed through the arc is dissociated (temporarily broken down into atoms) with a corresponding increase in energy content, the extra energy being released as heat when the atoms re-combine to form molecular hydrogen at the relatively cool surface of the weld joint.

5.1 The process is used mainly for the welding of steels and is particularly applicable to automatic production welding. Filler rods should be those recommended for gas welding.

5.2 Although remaining useful for specialised and quantity production work, this method is not now widely employed and has been mainly superseded for aircraft work by the TIG process.

5.3 **Inspection.** See paragraph 8.

6 CARBON ARC WELDING In this process, which has been largely superseded by TIG welding, the characteristic principle is that an arc is drawn between the parts to be welded and the carbon electrode which is manipulated by the welder. The filler wire (or rod) and the flux are the same as used in oxy-acetylene welding, and welding is usually done by the leftward procedure.

6.1 The process is not normally used for welding materials thinner than 1·2 mm (18 s.w.g.) and is usually restricted to straight butt joints.

6.2 Direct current is used, the carbon electrode being positive and the workpiece negative.

6.3 Electrode loss by disintegration is very high and care must be taken to ensure that the weld is free from carbonising, which causes the weld to harden with a tendency to surface cracking. This process is not recommended for high quality work owing to the risk of carbon pick up.

6.4 **Inspection.** - See paragraph 8.

7 METAL INERT GAS (MIG) ARC WELDING In this process, a consumable electrode in the form of a filler wire is fed automatically into the arc at a controlled rate, the wire and weld area being shrouded with an inert gas.

7.1 **Scope.** The MIG arc welding process is used on the heavier gauge materials and requires a certain continuity of production for it to be a practical proposition; at present, plates thinner than 3·2 mm (0·125 in) cannot be satisfactorily welded by the process and, because of this limitation, it is not usually used in the aircraft industry.

7.2 **Equipment.** The equipment comprises the following essential parts — a gun or torch to which the filler wire and current are fed, a carriage unit which houses the reel of filler wire and the control circuits, a d.c. power unit (which may be a standard d.c. welding generator) and an inert gas supply with a suitable regulator.

8 INSPECTION Close supervision of a welding operation is not generally possible and the production of a satisfactory weld depends mainly on the skill of the welder. During the welding operation, careful attention to the following points will help to ensure the production of a satisfactory weld:—

(a) The welding process used is in accordance with the drawings.

(b) Evidence is available that the welder is authorised to weld the particular work concerned.

(c) The materials being welded are those stipulated on the drawing.

(d) The type and size of electrode, current characteristics and any flux used are as specified on the drawing.

(e) Where filler rod or wire is used it is of the type specified on the drawing.

(f) The specified number of runs per weld and rate of deposition are observed.

(g) Heat treatment, if required, is effected as specified on the drawing.

(h) The identity of the welder is established for any weld submitted to inspection.

(j) The rate of burning of the electrode and the progress of the weld.

(k) The amount of penetration and fusion.

(l) The manner in which the weld metal is flowing.

(m) The sound of the arc (see paragraph 3.5) indicating correct current and voltage for the particular work in hand.

8.1 **Carbon Arc Process.** The weld must be free from carbonisation, which would be indicated by the smooth hard appearance of the weld.

8.2 **Atomic Hydrogen Process.** The flow of hydrogen must be according to drawing requirements.

8.3 **Cylinders.** Argon cylinders should not be used at pressures less than 140 N/m^2 (20 lbf/in^2) as the reduction in argon flow beyond this limit will increase the danger of contamination of the weld by air, and the subsequent purging of a cylinder empty of argon is a serious problem for the manufacturer.

8.4 **Final Inspection.** After cleaning, the completed weld should be examined for the following points:—

(a) Fusion should be satisfactory between the weld and the parent metal on both edges.

(b) There should be no undercutting where the weld metal joins the base metal, and the welded parts should not be reduced in thickness by the welding operation.

(c) Good penetration should be apparent, and an underbead should show throughout the whole length of the weld.

(d) The build-up of the weld should be satisfactory (a concave surface on the face of the weld indicates lack of weld metal with consequent weakness).

(e) The weld should show a regular surface, and should be free from porosity, scale, slag or burn marks.

(f) The area surrounding the weld should be free from spatter.

(g) The dimensions of the weld should be correct, especially the leg lengths and throat depth in fillet welds.

(h) All welds should be carefully examined for cracks, particular care being taken with magnesium alloys.

8.4.1 It must be ascertained that any method of non-destructive examination called for on the drawing has been applied (see paragraph 2.1).

8.4.2 All welds, except those which are required by the drawing to be hammered during cooling, must be examined in the 'as welded' condition. If, after inspection, the weld is dressed by filing, grinding or machining, it is again to be inspected. Light tapping with a hammer to break off flux residue resulting from the use of flux-covered electrodes is necessary as an aid to inspection and should not be regarded as a dressing operation.

8.4.3 Welds in certain alloys are improved by hammering during cooling. This treatment is only done when required by the drawing. Attention is drawn to the danger that cracks may develop in magnesium alloys which are hammered cold; it is a general practice to hammer such welds within a temperature range of 300 to 400°C, and in no circumstances should hammering take place below 250°C.

9 ARC 'SPOT' WELDING In certain circumstances an arc 'spot' welding process can be employed as an alternative to resistance spot welding (Leaflet **BL/6-12**). It is of particular value if only one side of the workpiece is accessible.

9.1 The process is suitable for the joining of non-corrodible steels, some alloy steels and titanium, but should not be used in conjunction with aluminium or magnesium alloys. The welding of some plain carbon steels and heat resisting steels may give rise to some difficulties.

9.2 The thickness of the top sheet of the weld may be between 0·037 and 1·6 mm (28 and 16 s.w.g.) and it can be welded to an under sheet of like thickness or greater thickness, but for sheets in excess of 1·6 mm (16 s.w.g.) the penetration of the weld becomes progressively shallower.

9.3 The weld is made by the TIG process and is effected by holding the torch firmly against the exposed face of the joint and pressing the torch switch. The welding process is then automatically controlled by the welding machine.

9.4 The controlled current causing the arc flows for a pre-set period of up to a few seconds, resulting in the melting of the area of the top sheet which is under the torch head. The molten metal crosses the interface of the joint, becomes common to both components, and solidifies into a solid 'U' or 'V' shaped nugget, joining the sheets together at this spot.

9.5 A backing bar may be necessary to achieve the necessary contact between sheets and, in some instances, e.g. when welding titanium, it may be necessary to carry a stream of argon to the underside of the weld through a groove or duct in the backing bar.

9.6 The welding current must not be cut off abruptly after the welding operation, otherwise a crater will form in the top surface of the weld nugget. The usual method of cut off is to reduce the current to zero in several stages. This is usually known as 'current decay'.

9.7 The essential factors for successful welding with this process are to ensure that current values and times, arc length and current decay control are in accordance with drawing requirements.

9.8 **Joint Preparation.** Prior to welding, the surface of the joint should be prepared either by a pickle or abrasive process, but if the surface is free from scale, degreasing alone may be sufficient. Unless otherwise stated on the drawing, the gap between the two mating parts should not exceed 0·025 mm (0·001 in).

9.9 **Inspection.** Procedures should be instituted to ensure that:—

(a) The position and pitch of the welds are in accordance with drawing requirements and, if stipulated on the drawing, the underside of the weld is free from excessive penetration.

(b) Both sides of the weld are free from excessive concavity, craters, cracks, holes or fissures. A satisfactory weld usually has a convex top surface upon which often appears a small 'pip' resulting from controlled current decay.

(c) If the drawing stipulates light hammering, the blows are to be applied only to the centre of the weld surface (but see paragraph 8.4.3). After hammering, the welds should again be examined for freedom from defects.

(d) A weldability test is carried out on each cast of steel to verify its satisfactory response to this process.

(e) The process should be controlled by a system of test samples subjected to the appropriate prising tests and micro-examinations. Details of suitable test pieces are given in Leaflet **BL/6-12**, but as the welding characteristics for a given single weld are not influenced by its neighbours, a two spot sample may be employed instead of the three spot test piece shown in Leaflet **BL/6-12**. The test piece prepared from the sample must, however, contain both welds.

(f) Every effort should be made to check the welds by a radiological method, since this is a valuable aid to visual inspection.

BASIC

GENERAL WORKSHOP PROCESSES

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 Board'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 six 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. 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 doing this is to cut the sample 3·8 inches long, by 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 20 lb. and 36 lb. per cubic foot. For grade A spruce the density should not be less than 24 lb. 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 5½ inches long by 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 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 0·5 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, 12 inches long by 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 13 foot-pounds without showing signs of tension failure on the vertical sides. Where doubt exists, a further blow of 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 inch varies to some extent. Timber with a rate of growth of less than six rings per 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 two 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.

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."

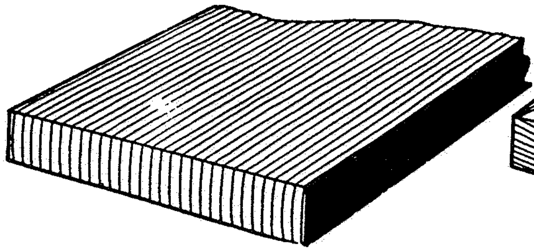

Figure 1

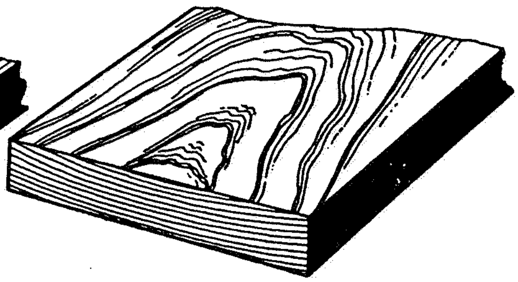

Figure 2

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 4 inches by 2 inches are required and a 4 inch rift-sawn plank of timber is available, it should be cut tangentially to give a size of 4 inches by 4 inches, after which a radial cut will give rift-sawn pieces 4 inches by 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 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.

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BASIC

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SYNTHETIC RESIN ADHESIVES

1 INTRODUCTION This Leaflet gives guidance 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 **AL/7-9.**

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:—

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

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 should be 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 two 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 two to three 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 acccordance 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 components 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 19 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 two to three weeks as in paragraph 8.1.

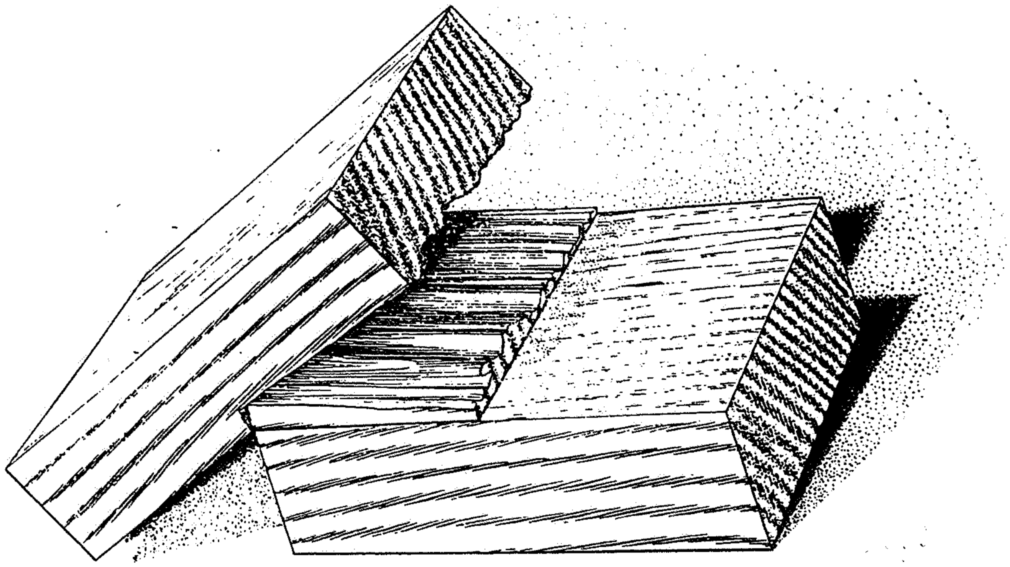

Figure 1 BROKEN TEST PIECE

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.

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 formaldehyde based 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 the glue.

STORAGE Apart from the very limited pot life of the mixed adhesive, the resin itself will not keep indefinitely, even under ideal storage conditions, and in 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.

5.3 Care should be taken to ensure that the parts to be cleaned are dry before being placed in the plant. In some cases it may be necessary to dry components of complicated shape in a heated oven; when this is done the component must be allowed to cool before being placed in the plant. The inside of the plant should be kept free from water or steam which could cause corrosion of ferrous parts and ultimately of the plant itself. Condensation of atmospheric moisture in the plant can be reduced by adjusting the temperature of the water in the cooling coils so that the outlet water is tepid.

5.4 Shrink-fitted articles should not be placed in the plant unless a keeper has been fitted to retain the parts in position.

5.5 After ensuring that the plant is functioning properly, the parts may be degreased by suspending them from wires in the vapour (rope or string must not be used) and small parts may be placed in wire baskets. Most plant have perforated plates near the bottom of the tank and, if found convenient, the parts may be placed on the plates.

5.6 When the parts become so warm that the vapour will not condense on them, they should be removed from the plant. If further degreasing is necessary, the parts should be allowed to cool before replacing in the plant, but such "double treatment" can be rendered unnecessary by the use of a dip or wash in the solvent. The advice of the manufacturer should be sought as to the best method of achieving this, and any ban on the use of "double treatment" to be observed, e.g. titanium.

5.7 When removing parts of complicated form from the plant they should be turned over several times, allowing the solvent which may have collected in cavities to drain back into the plant. Parts should be withdrawn slowly so that they are dry by the time they are clear of the plant.

5.8 Whilst it is good practice to allow parts to cool off before any further operation or protective treatment is applied, the parts must not be exposed to the atmosphere for too long a period as they are very susceptible to corrosion in the fully degreased condition. Temporary or permanent protection must be provided for degreased parts which are to be stored.

NOTE: Caustic soda must not be used in the immediate vicinity of trichloroethylene as the resulting chemical reaction may be dangerous. When caustic soda is used for washing engine parts, it is essential to ensure that all traces of caustic solution are removed before the parts are put in the plant.

6 MAINTENANCE OF PLANT

6.1 The successful operation of the plant can only be ensured by systematic and careful maintenance in accordance with the maker's instructions. The following is a summary of essential points which should receive attention to ensure that the cleaning process will have no detrimental effects on the parts to be cleaned.

6.2 The solvent should be maintained at the correct level, and should not fall below the level of any immersed thermostat or heating coil. The temperature of the solvent should be strictly controlled and should not exceed 120°C as above this temperature trichloroethylene tends to decompose and form hydrochloric acid which would cause corrosion of the plant and of the articles under treatment.

6.3 The solvent should be re-distilled at regular intervals, depending on the amount of work passing through the plant. Re-distillation should only be effected in accordance with the manufacturer's instructions applicable to the type of plant. Indications of the need for re-distillation are a low vapour line in the plant and an excessive time being required to clean a batch of parts. If, after re-distillation and topping-up, the vapour line is still low, the heating apparatus may be at fault.

6.3.1 The amount of oil present in the solvent can be determined by taking a hydrometer reading of the solvent in the sump or by direct analysis of a sample of the solvent by laboratory test.

6.3.2 The amount of oil and grease present should not exceed 40%. At regular intervals, usually determined by the nature of the work, all grease deposit and solid matter should be removed from the sump. When this is done, the plant should be checked for corrosion, the presence of which may indicate acidity. Reference should be made to the manufacturer's instructions regarding the cleaning of the plant.

6.3.3 Many of the larger degreasing plant, where large quantities of contaminated solvent require distilling, have small auxiliary stills for reconditioning the sump liquor from the main plant. Recovery of solvent is increased by the addition of water to the contaminated solvent in the distillation plant.

6.4 Aluminium and Magnesium Reaction

6.4.1 Aluminium and magnesium, or their alloys, in finely divided form (swarf or dust) will react with trichloroethylene complying with BS 580, Type 1, causing acidity. The presence of acid will result in serious corrosion of the plant and of any parts being cleaned. This reaction can be avoided by the use of a proprietary neutral stabilised trichloroethylene complying with BS 580, Type 2. There are several signs which indicate that aluminium reaction is commencing, as follows:—

(a) The presence of unusual fumes as distinct from the sweet smell of trichloroethylene.

(b) The formation of a black sticky substance.

(c) The colour of the copper cooling coils, which are normally tarnished, changing to a vivid green, accompanied, in some instances, by a crystalline deposit.

(d) The rapid corrosion of parts removed from the plant.

6.4.2 Twice weekly, the trichloroethylene should be tested by the laboratory to ensure that it is not acidic.

NOTE: A rapid test for acidity may be done by shaking vigorously 25 ml of solvent (condensed from the vapour) and 25 ml of distilled water with a few drops of phenolphthalein. If the mixture remains colourless, it is possible that acid is present and an accurate laboratory test should be made.

6.4.3 "Triklone N" Type 2 may require a modified form of alkalinity check, the frequency of which will be determined by usage, considering the following factors:—

(a) Frequency of distillation and tank cleaning.

(b) Proportion of new solvent required to make good the evaporation of losses.

(c) Work output of plant.

6.4.4 To prevent acidity, the following precautions should be observed:—

(a) All traces of small particles of aluminium or magnesium swarf or dust, etc., should be removed from the articles to be degreased by brushing off or by using a dry air jet. This may be done by washing in a light fuel oil or, when there is no risk, in paraffin or white spirit.

NOTE: It is recommended that, if the degreasing plant is heated by gas, flammable fluids should not be used as it is possible for vapour to be produced from trichloroethylene and paraffin which could ignite at the plant burner. The manufacturer's instructions, that the plant should not be topped up with trichloroethylene if the plant liquor is boiling, should be observed.

(b) The plant should be cleaned thoroughly (at least once a week) ensuring that every trace of finely divided metal is removed from the sump, heating coils, etc. However, when trichloroethylene Type 2 is used, it should be possible to relax the weekly cleaning of baths; it is, nevertheless, still necessary to ensure that no undue contamination of the heating surfaces occurs.

(c) Ensure that the level of trichloroethylene never falls too low. (See paragraph 6.2.)

(d) Small quantities of powdered soda-ash (anhydrous sodium carbonate) should be added twice daily to neutralise acidity in BS 580 Type 1 Baths, but the amount added per week should not exceed 0·1% by weight of the trichloroethylene charge. With the Type 2 trichloroethylene it should be possible to relax this requirement.

NOTE: Trichloroethylene weighs approximately 7 kg (15 lb) per gallon.

6.4.5 If acidity does develop, the manufacturer's advice should be sought and the plant treated in accordance with the manufacturer's instructions.

6.4.6 After a contaminated plant has been cleaned, it should be filled to above the condensing pipes with a solution of 5% soda-ash solution and boiled for several hours. Any work basket, scraper, etc., which may have been contaminated with the products of reaction should be immersed in the plant during boiling. After this treatment the plant should be well rinsed out with clean water and dried before filling with fresh trichloroethylene.

6.4.7 After the plant has been returned to service a careful watch should be kept for any recurrence of acidity.