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Guide for the Design of Threaded Screw or Stud Type Electrical Equipment Terminations

RATIONALE

The revision of this document enabled updates of reference standards, and updates Table 2 notes section, providing clarification of stud and terminal lug applications. The revision also added special termination handling restrictions in alignment with AS50881 and removed the requirement for chromate treatment of parts due to hazardous material restrictions.

INTRODUCTION

The standardization and use of electrical wire lug terminals are generally well covered in various government and commercial specifications and practices. Design of the terminations on electrical equipment, to which lug terminals are attached, however, is less well covered. Therefore, this guide sets forth design recommendations for equipment terminations that will provide satisfactory connections to lug terminals.

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1. SCOPE

To establish design recommendations that will provide a basis for safe and reliable connections to threaded screw-type or stud-type electrical equipment terminations. These recommendations are directed primarily, but not solely, to the aerospace and ground support equipment industries.

Since individual design criteria may alter the details as outlined, it is therefore important that this SAE Aerospace Information Report (AIR) not be considered mandatory, but be used only as a design guidance.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR6540	Fundamentals in Wire Selection and Sizing for Aerospace Applications
ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
ARP4404	Aircraft Electrical Installations
AS7928	Terminals, Lug: Splices, Conductor: Crimp Style, Copper, General Specification for
AS7928/4	Terminals, Lug and Splices, Conductor, Crimp Style, Copper Terminal, Lug, Crimp Style, Copper, Insulated, Ring Tongue, Bell-Mouthed, Type II Class 1 (For 150 °C Total Conductor Temperature)
AS8879	Screw Threads - UNJ Profile, Inch Controlled Radius Root with Increased Minor Diameter
AS17143	Terminal, Lug, Crimp Style, Copper, Insulated, Rectangular Tongue, Type II, Class 1, for 105 °C Total Conductor Temperature
AS20659	Terminal, Lug, Crimp Style, Copper, Uninsulated, Ring Tongue, Type I, Class 1, for 175 °C or 260 °C Total Conductor Temperature
AS21004	Terminal, Lug, Uninsulated, Rectangular Tongue, Crimp Style, Copper, Type I, Class 1, for 175 °C Total Conductor Temperature
AS25036	Terminal, Lug, Crimp Style, Copper Insulated, Ring Tongue, Bell Mouthed, Type II, Class 1 (For 105 °C Total Conductor Temperature)
AS25435	Terminal Lug, Crimp Style, Straight Type, for Aluminum Aircraft Wire, Class 1
AS27212	Terminal Board Assembly, Molded-In Stud, Electric
AS50151	Connectors, Electrical, Circular Threaded, AN Type, General Specification for
AS50881	Wiring, Aerospace Vehicle
AS70991	Terminals: Lug and Splice, Crimp Style, Aluminum, for Aluminum Aircraft Wire

2.2 AIA/NAS Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

NASM6812 Bolts, Aircraft

NASM25027 Self-Locking Nuts

NASM21042 Nut, Self-Locking, 450 °F, Reduced Hexagon, Reduced Height, Ring Base, Non-Corrosion Resistant Steel

NASM21044 Nut, Self-Locking, Hexagon - Regular Height, 250 °F, 125 ksi FTu and 60 ksi FTu

NASM21045 Nut, Self-Locking, Hexagon - Regular Height, 450 °F, 125 ksi FTu

NASM25440 Washers, for Use with Aircraft Aluminum Terminals

NASM35338 Washer, Lock-Spring, Helical, Regular (medium) Series

NASM35649 Nut, Plain - Hexagon, Machine Screw, UNC-2B

NASM35650 Nut, Plain - Hexagon, Machine Screw, UNF-2B

2.3 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

FED-STD-H28 Federal Standard, Screw Thread Standards for Federal Services

FF-N-836 Nut, Square, Hexagon Cap, Slotted, Castle, Knurled, Welding and Single Ball Seat

FF-S-85 Screw, Cap, Slotted and Hexagon Head

MIL-HDBK-131 Identification Markings for Fasteners (Handbook H-131)

MIL-HDBK-454 General Guidelines for Electronic Equipment

MIL-STD-108 Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment

MIL-STD-889 Dissimilar Metals

MIL-STD-7179 Finishes, Coatings, And Sealants, For the Protection of Aerospace Weapons Systems

3. GENERAL

Solderless crimp-type lug terminals are now widely used and accepted as a means to satisfactorily terminate electrical conductors. A high degree of reliability has been achieved through standardization of sizes, dimensions, materials, crimping techniques, and performance specifications. The overall connection reliability, however, is equally dependent on the integrity of the interface contact between the lug terminal tongue and its mating surface. This critical connection has often been overlooked when threaded fasteners are used, probably due to the apparent simplicity of attachment.

There are many design factors to consider in achieving the same degree of reliability at the tongue contact as in the crimp contact to the conductor. Both mechanical and electrical requirements are to be taken into account including such factors as selection of screw size, fastening hardware, materials, insulator design, and consideration for both copper and aluminum wire.

3.1 Lug Terminal Selection

Since the equipment termination is an electrical extension of a lug terminal, proper design must include considerations of the style and characteristics of the lug terminals expected to be used. Preferred copper crimp-type lug terminals are those specified in AS7928. Several of the more common straight types are detailed in the following associated SAE Standards, although a variety of other tongue configurations are also standardized:

AS17143	Insulated Rectangular Tongue
AS20659	Uninsulated Ring Tongue
AS21004	Uninsulated Rectangular Tongue
AS25036	Insulated Ring Tongue
AS7928/4	Insulated Ring Tongue

These range in wire size from No. 26 AWG through 0000 AWG with stud holes from No. 2 (0.086 inch) through 0.875 inch diameter. The temperature rating of tin-plated copper lug terminals is 105 to 150 °C for the insulated type and 175 °C for uninsulated. Specialized terminals such as tin whisker resistant types are also available. The MS20659-2XX nickel plated uninsulated ring tongue terminal lug offers the highest temperature rating, of up to 260 °C.

Preferred aluminum crimp-style terminals are those specified in AS70991 for aluminum aircraft wire. AS25435 details a straight, uninsulated tongue with aluminum wire size from No. 8 AWG through 0000 AWG and stud holes from No. 10 (0.190 inch) through 0.500 inch diameter. Uninsulated aluminum terminals are rated for 105 °C conductor temperature.

Recommended military practice is to use Class 1 pre-insulated terminal lugs. Uninsulated terminal lugs are also used to meet the system temperature and performance requirements.

Both AS70991 and AS7928 provide the lug terminal performance requirements which could also be applicable, in part, for the stud contact on equipment terminations.

4. SCREW AND STUD SIZE SELECTION

4.1 Threads

Screws and studs should be of the unified standard form and be selected in accordance with AS8879 so that the maximum usage is of a limited number of sizes for aircraft. Refer to FED-STD-H28 and its related documents (FED-STD-H28/1, /2, and /4 through /23). Recommended sizes are listed in Table 1.

4.2 Size

Screw or stud size is initially established from wire size and current requirements of the equipment.

Table 2 lists minimum recommended termination screw sizes for various current loads with both copper and aluminum wire, when terminated with terminal lugs. These are based on bundled cable wire ratings from AS50881.

Selection of aircraft wiring size is determined by various factors (e.g., wire size, temperature rating, number of wires in a bundle, altitude, ambient temperature, load factor, etc.). AS50881 provides the recommended maximum wire ampacity. Further guidance and examples are provided in AIR6540. When determining the largest probable wire size to be used, consider one stud size larger. This will assure adequate termination conductivity when voltage drop or circuit protection considerations require larger wires than on the basis of wire current rating alone.

4.3 Length

Length should be sufficient to accommodate at least two, but not more than four lug terminals, plus a flat washer, a split lock-washer, and a nut while maintaining a minimum of 1-1/2 screw threads showing after the assembly is complete lug terminals are usually positioned back-to-back as illustrated in Figure 2. For aircraft installations, refer to AS50881 for guidance on how and the number of terminals or bus bars to be used on one screw or stud.

4.4 Strength

In addition to meeting the electrical requirements, screws or studs should have sufficient mechanical strength to resist deformation or damage from tension test loads in any direction. The terminal tongue of a straight lug may be bent up to 90 degrees maximum, provided the bend radius is not less than twice the thickness of the lug tongue, and the distance from the tip of the tongue to the beginning of the bend is not less than the diameter across the lug. The size of the screw or stud and retaining means, should meet the equipment physical test requirements and withstand repeated torque loads from attaching terminated wires. Consideration should be given to tensile, shock, vibration, and thermal cycling loads to meet performance testing and service conditions.

Unless equipment design dictates specific strength criteria, Table 1 lists recommended minimum static tensile and torque test values to ensure satisfactory mechanical and electrical performance.

5. TERMINAL CONTACT AREA DESIGN

5.1 Equipment Leads

5.1.1 Contact areas of equipment leads should be flat, clean, burr free, and raised above the surface of the surrounding insulator material. The area should preferably be equal to the mating surface of the tongue of the largest wire terminal expected to be used, but never less than required to permit the current density to exceed 1000 amps per square inch (155 amps per square centimeter).

5.1.2 It is recommended practice that the lug terminal stud hole be selected to match the stud size for both maximum effective electrical connection and mechanical security. Also, when lug terminals of different tongue sizes are attached to the same stud the largest should be located on the bottom directly against the equipment lead as illustrated in Figure 6.

5.1.3 Current carrying stud should be avoided where possible, to ensure the optimum mechanical strength of the connection. However, when necessary, the contact area should be an integral part of the stud with a shoulder section as illustrated in Figure 3. Separate spacers or washers should not be used between the integral stud shoulder and the lug terminal tongue. This adds another interface in series with the circuit creating additional contact resistance. Refer to AS27212 terminal board application for additional guidance on stud terminations.

5.2 Contact Supporting Materials

The pressure for electrical contact must not be transmitted through, or dependent on materials that shrink or relax with time or at elevated temperatures. Soft metal plating or interfaces such as soft solder are to be avoided. No insulating material should be in compression when the screw or nut is tightened over the lug terminal tongue. Insulating plastic materials may be used with retaining studs or captive nuts due to repeated torque or tension loads, but must remain contact pressure-free, since most are subject to varying degrees of excessive relaxation. The use of split lock washers ensures consistent pressure is applied for maintaining electrical contact during thermal expansion and contraction (refer to 7.3, Figure 2, ARP1870).

5.3 Contact Materials and Finish

5.3.1 Current carrying members should be made of copper or high-conductivity copper alloy and be plated with silver, tin, nickel, gold, or other suitable finishes to resist corrosion and maintain low and stable contact resistance. Steel is to be avoided but may be used for low current applications and must be cadmium plated. Stainless steel does not generally require plating. Aluminum equipment leads may be used with special design considerations and must be tin plated, at least at the contact interface (see 4.4).

5.3.2 Screws, studs, and nuts are preferably steel, or other suitable high-strength materials. Softer screw or stud materials such as copper or aluminum could result in excessive thread wear and should be avoided. Brass nuts should be considered where greater corrosion resistance or where high wear is anticipated. Current carrying studs of heat treated beryllium copper or high tensile phosphor bronze offer improved thread wear resistance, yet provide good conductivity.

5.3.3 Magnesium equipment leads or termination hardware is to be avoided especially in contact with copper due to the high level of galvanic corrosion potential. Due to chemical incompatibility, cadmium plating of termination hardware is not recommended for use in fuel or hydraulic systems (AS50881).

5.4 Aluminum Considerations

5.4.1 Special consideration must be given to connecting aluminum equipment leads, aluminum lug terminals, or combinations of copper and aluminum materials which must be taken into account to provide reliable terminations. These differences are related to lower conductivity, oxide formation, galvanic corrosion, creep, and thermal expansion.

5.4.2 Since conductivity of aluminum is lower, larger cross-sectional areas are used in current carrying members. Lug terminal ring tongues have larger contact surface areas, which must be provided for on-equipment terminations. Aluminum has different properties than copper.

5.4.3 Aluminum oxide is always present on bare aluminum and creates a high-contact resistance barrier to current flow. Plating, such as tin, provides intimate contact to the bare aluminum and presents a low-contact resistance to adjacent members.

5.4.4 Aluminum will corrode and is sacrificial, relative to copper, in the presence of humidity. Tin plating also greatly reduces the galvanic corrosion rate between aluminum and copper, since it falls between them in the galvanic series. A moisture seal, or protective coating, may be applied to aluminum-copper connections to minimize galvanic action. The proper arrangement of dissimilar metals for control of galvanic, or electrolytic corrosion, should be consider using MIL-STD-889 and ARP1870 as guidance.

5.4.5 Aluminum has a high rate of creep, or cold flow, and will continue to relax when stressed until the stress is equal to its yield strength. This has the effect of significantly reducing the residual contact pressure to the point of possible failure. To compensate for creep, it is common practice to use a spring split lock washer under the screw head (Figure 2). The creep problem is compounded with aluminum-copper terminations since aluminum, when heated, expands about 40% more than copper. If the heating is sufficiently high, such that the stresses exceed the elastic limit of the aluminum, then permanent deformation will occur.

With repeated heating and cooling, the contact pressure will be progressively reduced. Application temperature limitations and the use of a spring lock washer will ensure more reliable copper-aluminum terminations despite differences in thermal expansion ratios of the two types of metal components being terminated.

6. INSULATOR DESIGN

6.1 Materials

Insulator performance must first comply with the equipment and application requirements. Material selection, however, should include consideration of many characteristics such as:

- Arc resistance (non-carbon tracking)
- Dielectric strength
- Flame resistance
- Mechanical strength
- Noxious or toxic fume emission
- Impact strength
- Heat distortion temperature
- Temperature endurance
- Corrosion resistance to metals
- Solvent resistance

- Moisture absorption

- Fungus resistance

In general, an insulation material should combine the more important properties of high insulation resistance, flame resistance, arc resistance, and low toxicity along with good electrical and mechanical properties.

MIL-HDBK-454, Guideline 1 and Guideline 11, provide good references for safety and establishes criteria for the selection and use of a broad range of insulating materials.

6.2 Terminal Spacing and Barriers

6.2.1 Terminal spacing should provide adequate creep distance to meet the voltage requirements of the equipment. Table 4 lists minimum spacing for various voltages and altitudes and is based on AS50151 for standard AN connectors. Additional spacing guidance is in ARP4404 and in MIL-HDBK-454, Guideline 69, for electronic equipment, which Table 5 is from.

6.2.2 Barriers increase the creepage path and help prevent accidental shorting between lug terminals. In addition to the electrical requirements, the size of the equipment should be taken advantage of to provide as much space as possible to simplify lug terminal installation with tools and to minimize electrical hazards.

6.3 Covers

Covers should be designed to provide electrical and mechanical protection for all equipment terminations and accommodate at least two lug terminals. Covers are usually made of a substantial insulating material, although if metal is required for electrical shielding, care must be taken to afford adequate support against shorting if accidentally crushed. Provision for cover removal is necessary so that when used in an otherwise protected location, such as inside an enclosed junction box, it can be removed to eliminate the weight. For AS22712 terminal board applications, standard covers meet AS18029.

7. FASTENER HARDWARE

Fastener hardware should preferably be selected in accordance with MIL-HDBK-454, Guideline 12, which establishes guidance for electronic equipment. For aviation applications, fastener hardware should agree with AS50881 and/or the specific termination standard requirements. Fastener marking information is detailed in MIL-HDBK-131.

7.1 Screws

Selection of screw and bolt types will vary widely with user preference and equipment requirements; however, head styles should be those with larger diameters. Pan head, binding head, or hexagon head will provide maximum contact area over a washer. Screws may directly be selected from the following specifications:

FF-S-85	Cap Screws
NASM6812	Bolts, Aircraft

7.2 Nuts

Plain nut types are preferred as detailed in NASM35649 and NASM35650 as specified in FF-N-836. In applications where vibration is of concern, self-locking nuts may be required to ensure the integrity of the connection; however, caution is advised in their use. They should not be used on brass studs, nor where frequent removal is anticipated due to greater thread wear. Neither should self-locking nuts be used on stainless steel studs, since there is a tendency to seize. Self-locking nuts are detailed in NASM21042, NASM21044, NASM21045, and specified in NASM25027.

7.3 Washers

Flat washers and spring split lock washers must always be used to ensure maximum electrical contact reliability at various temperatures. Flat washers distribute pressure over the lug terminal tongue. Spring split lock washers, in addition to resisting nut loosening, maintain contact pressure when metals relax, such as when they are compressed.

This follow-up is especially important for aluminum.

Plain flat washers may be selected from various materials, although Grade II aeronautical, cadmium-plated steel or tin-plated brass are preferred for use on copper wire terminals and copper equipment leads. Aluminum terminations require a special flat washer as shown in NASM25440. This is an oversized, cadmium-plated, steel washer to match larger aluminum lug terminal tongues while preventing incidental contact.

Spring split helical lock washers are detailed in NASM35338. Steel lock washers should be cadmium plated. Where greater corrosion protection is required, phosphor bronze lock washers may be used. External or internal tooth-type lock washers should not be used.

8. HARDWARE ARRANGEMENTS

Preferred hardware arrangements for equipment terminations are shown in Figures 1 through 7. These include typical equipment lead configurations with screws and studs on combinations of copper and aluminum materials. The insulators and equipment leads as illustrated, are schematic only, and not intended to represent any specific detail design.

In general, flat washers must be used directly over all lug terminal tongues, and spring split lock washers used under all screw heads or nuts. Washers should never be placed in the current path. Care must be exercised in the proper selection of base metals and plating for electrolytic corrosion considerations, especially where aluminum is involved (MIL-STD-889).

8.1 Copper-to-Copper Terminations

Figures 1, 2, and 3 show typical arrangements for copper-to-copper connections with screws and studs. Note that lug terminals are always placed directly against the equipment lead and that only standard size washers need to be used.

8.2 Aluminum-to-Aluminum Terminations

Figure 4 shows an aluminum equipment lead connection to an aluminum lug terminal. In this case, the special oversize NASM25440 washer is used over both the aluminum lug terminal tongue and the equipment lead. Split lock washers should never be placed directly on any aluminum surface. Figure 5 shows the situation where there may be no equipment lead involved and the current path is directly through two aluminum lug terminals, such as found on a terminal board or binding post. This illustrates that the NASM25440 washer preferably be used on both sides of the wire terminals for full bearing pressure.

8.3 Copper-to-Aluminum Terminations

Figure 6 shows the arrangement of both copper and aluminum lug terminals to a copper equipment lead. When the aluminum lug terminal tongue is larger than the copper tongue, it should be placed directly on the equipment lead as shown. If the copper lug terminal is larger than the aluminum, then it should be placed on the equipment lead, in which case a NASM25440 washer would be used under the split lock washer.

Figure 7 shows the case where a copper equipment lead is connected to aluminum lug terminals in which the NASM25440 washer is used directly on the aluminum tongue.

8.4 Special Hardware Termination Restrictions

Cadmium plated hardware should not be used in space applications. Self-tapping screws, zinc plated, un-plated and anodized hardware, should not be used in aviation applications (AS50881). Aluminum hardware should not be used at temperatures above 300 °F, while Cadmium plated steel hardware should not be used at temperatures above 450 °F (AS50881).

9. SPECIAL TOOLS

Selection of hardware and insulator design should be such that no special tools are required and that adequate clearance space is provided for assembly, maintenance, and ready replacement of damaged or worn parts. The design should accommodate standard maintenance tools such as pliers, screwdrivers, socket and wrenches.

10. NOTES

NOTICE

This document references a part which contains cadmium as a plating material. Consult local officials if you have questions concerning cadmium's use.

10.1 Revision Indicator

A change bar (|) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

Table 1 - Recommended screw sizes and strength of screw or stud terminations

	Material	
	Steel (60000 psi Tensile Strength Minimum)	Brass/Aluminum (55000 psi Tensile Strength Minimum)
Screw Size	Recommended Torque Values 1/	Recommended Torque Values 1/
#6 (0.138 in) -32 UNC	8- 10	7- 9
#6 (0.138 in) -40 UNF	8- 11	8- 10
#8 (0.164 in) -32 UNC	11- 17	11- 17
#8 (0.164 in) -36 UNF	11- 19	11- 18
#10 (0.190 in) -24 UNC	20- 25	18- 23
#10 (0.190 in) -32 UNF	20- 29	20- 25
1/4 in -20 UNC	55- 62	50- 58
1/4 in -28 UNF	60- 70	58- 66
5/16 in -18 UNC	80- 105	70- 80
5/16 in -24 UNF	90- 140	80- 90
3/8 in -16 UNC	110- 145	85- 105
3/8 in -24 UNF	115- 175	90- 110
7/16 in -14 UNC	125- 160	100- 125
7/16 in -20 UNF	130- 190	120- 150
1/2 in -13 UNC	135- 175	115- 150
1/2 in -20 UNF	150- 200	150- 200
9/16 in -12 UNC	195- 215	195- 215
9/16 in -18 UNF	210- 275	210- 275
5/8 in -11 UNC	270- 300	230- 300
5/8 in -18 UNF	300- 400	300- 400
3/4 in -10 UNC	475- 530	400- 530
3/4 in -16 UNF	525- 700	525- 700
7/8 in -9 UNC	770- 850	650- 850
7/8 in -14 UNF	835-1100	835-1100

1/ All values are in inch-pounds. This data was developed using 60 KSI fasteners only. If a different strength fastener is used, consult your engineering group for any changes required.

Table 2 - Minimum recommended termination screw or stud sizes for current and conductors

Maximum Current Rating Continuous Duty Amperes 1/	Wire Size		Minimum Termination Screw or Stud Size
	Copper	Aluminum	
	26	-	No. 2 (0.086) - 56 - UNC
2	24	-	No. 4 (0.112) - 40 - UNC
5	22	-	
7.5	20	-	No. 6 (0.138) - 32 UNC
10	18	-	
13	16	-	No. 8 (0.164) - 32 UNC
17	14	-	
23	12	-	No. 10 (0.190) - 32 UNF
33	10	-	
36	-	8	
46	8	-	
50	-	8	
60	6	-	
66	-	4	0.250 - 28 UNF
80	4	-	
82	-	2	
100	2	-	
105	-	1	0.312 - 24 UNF
123	-	0	
125	1	-	
145	-	00	
150	0	-	
175	00	-	
162	-	000	0.375 - 24 UNF
190	-	0000	
200	000	-	
210	-	2(1) 2/	
225	0000	-	
246	-	2(0) 2/	
250	2(1) 2/	-	
290	-	2(00) 2/	
300	2(0) 2/	-	
324	-	2(000) 2/	
350	2(00) 2/	-	
380	-	2(0000) 2/	
400	2(000) 2/	-	

1/ Typical maximum current carrying capacity of wires in conduit or bundles (refer to AS50881).

2/ Notation of “2(X)” before the wire size identifies two of the same size wires terminated to the same screw or stud (see Figure 2, or 3). It reflects twice the current load of a single wire connection of the same size. Example: “2(000)” copper wire maximum current load for two wires is 400 amps, while “000” for one wire termination is 200 amps.

Table 3 - Grouping of dissimilar metals for electrolytic corrosion protection

Based on MIL-STD-889 - Dissimilar Metals

Group I	Group II	Group III	Group IV
Magnesium alloys	Aluminum Aluminum alloys (all)	Zinc Cadmium	Copper and its alloys Nickel and its alloys
Aluminum alloys 5052, 5056, 5356, 6061, 6063	Zinc Cadmium	Steel Lead	Chromium Stainless steel (passive)
Tin	Tin Stainless steel (active) Tin lead (solder) Titanium	Tin Stainless Steel (active) Nickel and its alloys Tin lead (solder) Titanium	Gold Silver Titanium

Metals listed in the same group are similar and considered compatible when in contact and when protected in accordance with MIL-STD-7179. Metals listed in different groups are considered dissimilar and incompatible with one another. The tendency toward galvanic corrosion is greater between widely separated groups than between adjacent groups. Metals from different groups may be placed in contact where suitable protection against galvanic action is provided. The method of protection required will be largely dependent on design and usage environments. Surface composition of a part should be considered when determining dissimilarity; a cadmium- or tin-plated copper part is considered similar to aluminum, thus in the same compatibility group (Table 3).

Table 4 - Minimum spacing for various voltages and altitudes

Minimum Distance 1/				Voltage at Sea Level		Voltage at 50000 Feet Altitude (15240 m)		Voltage at 70000 Feet Altitude (21336 m)	
Air Space		Creepage Distance		Min Flashover	Test	Min Flashover	Test	Min Flashover	Test
Inches	mm	Inches	mm	V_{rms}	V_{rms}	V_{rms}	V_{rms}	V_{rms}	V_{rms}
-	-	0.046	1.19	800	600	300	225	200	150
*0.031	0.79	0.062	1.59	1400	1000	500	375	375	300
0.046	1.19	0.078	1.98	2000	1500	700	525	500	375
0.062	1.59	0.109	2.78	2500	1800	900	675	600	450
0.078	1.98	0.125	3.18	3000	2250	1050	790	675	500
0.093	2.38	0.156	3.97	3600	2700	1200	900	750	560
0.125	3.18	0.187	4.76	4500	3300	1400	1065	900	675
0.187	4.76	0.250	6.35	6100	4500	1800	1350	1100	825
0.250	6.35	0.312	7.94	7300	5400	2000	1500	1300	975
0.312	7.94	0.375	9.53	8500	6300	2300	1725	1420	1065

1/ Contacts should be continuously insulated. There should be no open airspace between any parts of the conductors having this mechanical spacing.

The creepage distances apply to dry, clean, smooth surfaces. For installations unprotected from contamination by dust and/or subject to the condensation of moisture by thermal or altitude cycling, it is recommended that the creepage distance be increased. For installations exposed directly to moisture or other conductive contaminants, it is recommended that sealing or other environment-resisting methods be used.