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Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety

RATIONALE

The document is still a valid standard which may benefit from a future update. The basic technology described in the document is still valid. The subcommittee designated to update the document is not currently active, so stabilization of the document is the best approach until such time as a committee can be established to open a WIP.

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1. SCOPE:

1.1 Purpose:

This document establishes the minimum requirements for the electrical bonding and grounding of electric, avionic, armament, communication, and electronic equipment installations for aeronautical and aerospace applications. The bonding and grounding requirements specified herein are to ensure that an adequate low resistance return path for electric, avionic, armament, communication and electronic equipment is achieved which can withstand operating conditions and corrosion. This is essential for the reduction of coupling of electromagnetic fields into or out of the equipment as well as for providing electrical stability to control the currents and/or voltages caused by static charges and discharges and for suppressing the hazardous effects thereof.

1.2 General:

A prerequisite to effective control of electromagnetic interference (EMI) and the hazards of electrical effects is the establishing of a reference ground plane and the means of providing adequate connections to it. Making a connection to the ground plane is grounding, and the mechanical method of providing a low impedance union between conductors is electrical bonding.

2. REFERENCE DOCUMENTS:

The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this standard to the extent specified herein.

Standards

MIL-STD-889	Dissimilar Metals
MIL-STD-1250	Corrosion Prevention and Deterioration Control in Electronic Components and Assemblies
MIL-STD-1757	Lightning Qualification Test Techniques for Aerospace Vehicles and Hardware

Specifications

MIL-M-3171	Magnesium Alloys, Processes for Pretreatment and Prevention of Corrosion on
MIL-B-5087	Bonding, Electrical and Lightning Protection, for Aerospace Systems
MIL-S-5002	Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems
MIL-C-5541	Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-E-6051D	Electromagnetic Compatibility Requirements, Systems
MIL-C-7439	Coating System Elastomeric Rain Erosion Resistant and Rain Erosion Resistant with Anti-Static Treatment for Exterior Aircraft and Missile Plastic Parts
MIL-I-46058	Insulating Compound, Electrical (for Coating Printed Circuit Assemblies)
MIL-T-83454	Terminals, Stud, Blind Plate, for Electrical Bonding and Grounding (Noninsulated)

2. (Continued):

TT-L-32	Lacquer, Cellulose Nitrate, Gloss for Aircraft Use
TT-L-20A	Lacquer, Camouflage
MS 25083	Jumper Assembly, Electric, Bonding and Current Return
NATO Stanag 3859	Standardized Data List for Interoperability Studies and Certification of Aircraft Stores on Fixed Wing Aircraft and Helicopters
DH1-4	Design Handbook, Electromagnetic Compatibility
Military Handbook MIL-HDBK-274 (AS)	Military Handbook - Electrical Grounding for Aircraft Safety

Miscellaneous Publications

ASCC 12/24	Air Standardization Coordinating Committee Document
SAE ARP1481	Corrosion Control and Electrical Conductivity in Enclosure Design
NASA RP-1008	Lightning Protection of Aircraft
FAA AC 20-53 ( )	Protection of Aircraft Fuel Systems Against Lightning
BCAR D4-6	Electrical Bonding and Lightning Discharge Protection

3. DEFINITIONS:

For the purpose of this specification, the following definitions are applicable:

Bond - An electrical connection between conductive parts which provides the required electrical conductivity.

Bonded - Conductive parts that are considered to be bonded when they are mechanically interconnected to maintain a common electrical potential.

Equipotential - For all practical purposes, an identical state of electrical potential for conducting item(s).

Equipment - Any electrical, electronic or electromechanical device, or collection of items, intended to operate as an individual unit and performing a singular function. As defined herein, equipments include, but are not limited to, the following: receivers, transmitters, transceivers, transponders, power supplies, electrical office machines, hand tools, processors, test apparatus and instruments, and material handling equipment.

Ground - A conducting connection, whether intentional or accidental, by which an electric current or equipment is connected to the earth, or to a conducting structure that serves a function similar to that of an earth ground (that is, a structure such as a frame of an air, space or land vehicle that is not conductively connected to earth).

3. (Continued):

Ground Plane - A surface, all points of which are assumed to be at the same potential, usually the zero reference potential for the system. (Note: A true, equipotential ground plane does not exist in practice. The deviations from the ideal increase with the frequency of the signals appearing on the ground plane conductor and can become a very important consideration in system design.)

4. GENERAL BONDING AND GROUNDING GUIDANCE:

4.1 Electrical Bonding:

Electrical bonding is the process employed to obtain an electrical union between conductors that meets specified requirements. This can be accomplished mechanically by connecting cleaned metal parts together by use of such techniques as bolts, rivets or welding. Electrical bonding is required to minimize electrical potential differences between individual metal parts for all voltages and frequencies capable of causing interference.

4.1.1 Bond Effectiveness: The effectiveness of a bond at radio frequencies is neither fully dependent upon nor measurable only in terms of its DC electrical resistance. This is especially true at high frequencies, where lengths of bonding devices tend to approach the wavelengths of undesirable electromagnetic radiation. DC measurement is an indication of very low-frequency bonding effectiveness. At high frequencies, however, bond effectiveness may be determined by means of impedance measurements because bond capacitance and inductance become significant and will cause high RF bond impedances, despite low DC resistance readings. In practice, DC resistance measurements may be utilized to detect grossly defective bonds and to determine quickly, by comparison with manufacturer’s test data, whether or not bonds on existing equipment have deteriorated. In general, the effectiveness of an electrical bond for a given purpose depends on the characteristics of its application such as frequency range, magnitude of current passing through it, and environmental conditions such as vibration, temperature, humidity, fungus, and salt content in the ambient.

4.1.2 Precedence: In case of conflict between corrosion control requirements and electromagnetic compatibility (EMC) electrical bonding requirements, it is imperative that the conflict be resolved to the mutual satisfaction of all parties. This resolution should be reached as early in the design process as practical. In the event of a compromise between EMC and corrosion protection requirements, continuing maintenance instructions should be written to ensure any necessary periodic inspection and service or treatment of the affected bond(s).

4.2 Grounding:

Electrical grounding is accomplished by establishing a minimum series impedance path between the electrical equipment and the ground plane. A ground is used to establish a zero signal reference for any equipment or other item required to be grounded. On metal vehicles, the metal frame should be designated the ground plane. On nonmetallic vehicles, an equipotential ground system should be installed. A uniform grounding philosophy must be established to avoid personnel shock hazards, ground current loops and common mode coupling. Any voltage exceeding 42.4 volts (NATO recommended) in either DC or peak AC magnitude should be considered a personnel shock hazard. NOTE: This voltage refers to a shock hazard only. Other hazard considerations such as fire or damage to the bond may require other voltage limits. See paragraph 5.13.1.

4.3 Earthing of Aircraft and Ground Services:

It is essential that both the aircraft and also any ground servicing equipment such as electrical ground supply trucks or refueling vehicles be properly referenced to a true earth point before any connection is made between the aircraft and any ground servicing equipment. This is necessary to avoid the risk of shock to personnel, for consideration of fault conditions which might arise on the aircraft or the ground equipment during servicing, and to avoid any risk of sparks occurring during refueling.

4.4 Design Requirements:

In designing and establishing bonding and grounding criteria, it is necessary to consider the equipment interference emissions and susceptibility frequency spectrum. Of additional importance are the physical characteristics of the bonds and grounds selected such as size, strength, forces holding the surfaces together, fatigue resistance, corrosion resistance, resistivity, and temperature coefficients. The design should provide bonds and grounds that will not deteriorate when the equipment is subjected to environmental conditions required by the equipment specification. The designer must specify adequate bonding to ensure that the end product will require minimum use of suppression components. A recommended checklist for electrical bonding and grounding is:

(1) Provisions should be made to assure electromagnetic compatibility in the original design.

(2) Where possible, compatible materials should be selected in order to minimize corrosion.

(3) Bonding of dissimilar metals may be accomplished by selecting a compatible, conductive finish.

(4) Bonding must remain within specified limits of resistivity under vibration and thermal expansion.

(5) If the bonding of dissimilar metals is unavoidable, the joint area should be coated after bonding with a protective sealant such as polysulfide, silicone RTV, or equivalent.

4.4 (Continued):

(6) Mating surfaces should be clean and free from oil, dirt, oxides, or other contaminants before bonding or before applying bonding materials to surfaces.

(7) External or internal tooth-lock washers should not be used in any application where long-term and RF grounding is required.

(8) Bonds made by conductive gaskets or adhesives and involving dissimilar metal contact should be sealed after bonding with a protective sealant if required by ARP1481.

(9) A combination environmental and electromagnetic seal, such as wire mesh or other metal form in an elastomer, or lake copper (silver bearing), is preferred over an environmental seal only. The environmental part of the seal must exclude moisture from the conductive portion of the seal in order to prevent corrosion.

(10) When a coating may be stripped to provide a clean surface for subsequent bonding, compatibility of coating and surface should be established prior to use.

(11) The designer must determine which surface areas are to remain unfinished or require a conductive finish in order to provide acceptable electrical continuity for bonding. Reference Table 1 for DC bonding resistance limits.

(12) The designer must determine that the mating metals used to bond or ground articles of equipment to the ground plane are of adequate cross-sectional area to carry necessary normal and fault current. Reference Chart 1.

(13) Grounding and bonding connections should be located in protected areas, where practical, and should be located in accessible areas to permit ease of inspection and, if necessary, replacement.

(14) Grounding and bonding connections should not severely inhibit removal or reinstallation of line replaceable units.

(15) Wherever bolts or screws are used, the minimum and maximum torque for the given size of hardware should be specified.

(16) A low resistivity paint should be considered for use on nonconductive aircraft skins to help prevent streamering currents due to precipitation static through poorly conducting paths in the nonconductive aircraft skin. A resistance of 0.5 to 15 megohms per square is suggested in MIL-C-7439. This is not a requirement but can become a problem under certain conditions.

(17) Bonding and grounding hardware should be designed and positioned so as to prevent mechanical interference and intermittent contact with other parts when motion of these parts is necessary for equipment function.

4.5 Types of Electrical Bonds:

There are two classifications of electrical bonds: direct and indirect. The most desirable of these is the direct bond. This term is applied to permanent, metal-to-metal joints such as are provided by welding, riveting or bolting. Indirect bonds result when electrical connection between two metallic parts is made through a third metal part, such as a flexible metal strap. These are used when metals to be bonded cannot be placed in direct contact (for example, when there is a need for motion between bonded members). Metal-to-metal or conductive coated metal-to-metal contact at the point of bonding is required for proper operation. Corrosion should not be allowed to compromise this requirement. Refer to Table 2 for best material selection where possible.

4.5.1 Direct Electrical Bonds: Direct electrical bonds include permanent metal-to-metal joints formed of machined metal surfaces or with electrically conductive gaskets held together by lock-threaded devices, riveted joints, tie rods, or pinned fittings driven tight. The direct bonded joint may also be formed by welding, brazing or sweating. Soldered joints should be avoided. Basic requirements for direct bonding are that metal-to-metal or conductive coated metal-to-metal contact be provided and that precautions be taken to seal the joint against moisture. Dissimilar metals in direct contact should be avoided. In particular, sheet metal type screws are not acceptable for use in bonding. If two structural members are held together by screws, direct contact should be provided. Joints that rely on press-fitted floating nutplates for the current path cannot be relied upon to provide a low-impedance bond at high frequencies. Riveted joints, with the rivets equally spaced around a 3/4 inch radius circle, are acceptable if the rivet holes are bare of insulating material, using three rivets minimum. More rivets will be needed as current requirements are increased. Enough rivets should be used to meet the resistance requirements of Chart 1 when the bond is tested at the necessary value.

4.5.2 Indirect Electrical Bonds: When a direct bond is not feasible, the designer must select an indirect bond. A good indirect bond is one that presents a low impedance throughout the interference spectrum and retains its usefulness for service life of the equipment. An indirect bond is usually a bond strap or jumper. This is attached by direct methods. Lockwashers are used with bolt fasteners to assure metal-to-metal contact of bond strap connections. The most significant physical features of a bond strap are its material, geometry and thickness. Beryllium copper or phosphor bronze are typical materials used and, under conditions of severe vibration, a corrugated strap made of these materials is recommended to provide mechanical damping and to provide desired service life. Indirect bonds should in all instances be as short as possible. Single straps should always be used; two or more straps should not be connected in series. Bolts or screws used to secure bonding straps should have the minimum and maximum torque specified per the hardware specification.

4.6 Bonding Straps:

4.6.1 Characteristics of Individual Bonding Straps: Bonding straps are flat, solid straps. The large surface area of such a strap keeps both the inductance and AC resistance due to skin effect low (RF currents flow along conductor surfaces). The effective AC resistance becomes many times larger than the DC resistance at radio frequencies (see Figure 31), but is insignificant relative to inductive reactance (see Figure 32). Therefore, the skin effect resistance may be neglected when evaluating bond impedance. The measured RF impedance of a typical flat bond strap itself increases almost linearly with frequency up to about 30 MHz. At higher radio frequencies, where length of a bond strap is an appreciable part of a wavelength, the bond strap is equivalent to an RF transmission line, and impedance will vary periodically from a minimum to a maximum with increasing frequency. When this happens, the bonding strap becomes an efficient radiator of RF energy because it has RF current flowing through it and RF voltage across it. These effects will be avoided by keeping bond strap inductance low. This can be achieved by making bond straps with a low length-to-width ratio and a high width-to-thickness ratio. The length-to-width ratio should be 5:1 or less. Bond straps made of beryllium copper, phosphor bronze, or brass material should have a minimum thickness of 0.025 inches. Bond straps made of aluminum should have a minimum thickness of 0.040 inches.

To illustrate the effect of relative dimensions on the inductance of a bonding conductor, two conductors of equal cross-sectional areas but different cross-sectional dimensions are compared below with typical values of inductance:

2 foot, #0000 solid copper wire	L = 0.53 µh
2 foot, solid copper strap, length/width = 5	L = 0.345 µh

The inductance of the wire is 54 percent greater than that of the strap, and therefore would offer a higher impedance at a given frequency.

To further illustrate the need for low bond strap impedance, consider that radiated EMI specification limits are such that a voltage on the order of 1 to 10 mV across a typical bond strap will often radiate a field level equal to the specification limit. The higher the bond strap impedance at a given frequency, the lower will be the current required through the bond strap to produce a voltage across the bond strap from 1 to 10 mV, or even greater. At 10 MHz, a few milliamps or even a fraction of a milliamp may be all that is necessary to exceed the limit.

4.6.2 Characteristics of Bonding Strap Installations: When a bond strap is installed in a typical configuration, the distributed capacitance between bonded members is in parallel with the inductance of the bond strap. This combination has the characteristics of a parallel capacitance-inductance resonant circuit. At resonance, the impedance is high enough that the bond strap is ineffective.

The bond strap may also be ineffective if the frequency of concern is high enough that standing waves occur along the structure to be bonded. This can occur if the length of the structure is greater than 0.1 wavelength.

The inductance of the bond strap can be chosen such that bonding degradation due to resonance will occur at a frequency where degradation due to standing waves would have occurred anyway. The equations shown in Figure 33 use this principle to calculate bond strap geometry. Equation 1 calculates the lowest frequency at which standing waves can occur. Equation 2 establishes the LC resonant frequency at twice this frequency. Equation 3 calculates the capacitance between the structure and ground. Equation 4 then uses the resonant frequency and capacitance from the previous equations to calculate the design value of bond strap inductance. Equation 5 uses the geometry of the strap to calculate a bond strap inductance that will meet the requirement of Equation 4. If more than one bond strap is used, the individual inductances can be combined in parallel to meet the design inductance of Equation 4.

In some applications, the LC resonant frequency produced by this method may still be within the operational frequency range of the equipment. In this case, the resonant frequency should be raised beyond the operational frequency range, if practical.

4.7 Bonding Jumpers:

Braided bonding jumpers may be preferred for low frequencies and DC applications because they offer greater flexibility than solid jumpers. Bonding jumpers are round or flat, flexible conductors, such as specified in MS 25083. Because of AC/RF frequency requirements, jumpers should, when possible, be made from low inductance type wire such as litzendraht (litz) wire and not of unilay or concentric lay stranded conductors. Because of their helixed strands, such stranded conductors exhibit a high series inductance, increasing as frequency increases due to increasing current flow in the outer strands of the conductor. Thus, the impedance of the conductor increases as frequency increases. Litz wire consists of a number of separately insulated strands woven together so each strand successively takes up all possible positions in the cross-section of the entire conductor. This reduces skin effect and thereby reduces RF resistance. Litz wire presents assembly and maintenance problems and should only be used where other techniques fail. Bonding jumpers should in all instances be as short as possible and of sufficient cross-sectional area to carry fault or lightning currents, as applicable, without disintegration. The lugs on bonding jumpers should have adequate surface area to achieve the required bonding resistance.

Maintenance practices for testing the strength of these bonds should not bend or weaken the wire where it is crimped to the end termination. “Waggling” the jumper to see whether the end terminations are tight is thus unacceptable because only a small number of reverse bends are required to fatigue the wire.

4.8 Bonding Metal and Finish Selection:

The choice of material for a given electrical bonding application is dictated by consideration of the metals being bonded and the environment within which the bond must function. In bonding, when joining dissimilar metals, corrosion becomes an important consideration. Factors that contribute to corrosion are the degree of separation of metals in the electromotive series and the amount of moisture present. Direct contact of dissimilar metals in the presence of moisture may result in two types of electrolytic reaction (corrosion). Either type impairs the effectiveness of any electrical bond and weakens the structure in which it occurs. A galvanic reaction (the exchange of ions in a solution) results from the different electromotive potentials of different metals. An anodic reaction (electroplating accompanied by deposit of salts) results from any flow of direct current through the moist contact area. For minimizing or preventing corrosion and its adverse effects on electrical bonding, metals low on the activity table, such as copper, are recommended to be used when possible. Where members of the electrolytic couple are widely separated on the activity table, plating should be used to reconcile the dissimilarity (reference MIL-STD-889). When dissimilar metals are in contact, the one with the more negative electrode potential will be more affected by corrosion. Table 2 lists groups of materials which may be used as compatible couples. Use of this table will allow material selection resulting in the least corrosion due to galvanic action. Acceptable contact surface materials that may be used to fasten bonding jumpers to structures are indicated in Table 3. The presence of electrolytic action necessitates care in designing joints that serve as bonds. Consider the relative sizes of the potential anode and cathode when dissimilar metals are bonded. A larger cathode implies greater electron flow (due to a greater source of galvanic supply) and therefore more corrosive action at the anode. A reduction in cathode size results in less electron flow and therefore less corrosion. Surfaces should be dry and clean (except for the presence of bonding coatings) before mating, and should be held together under high pressure to minimize the possibility of moisture entering the joints. The cleaned area should be about 1-1/2 times greater than the area necessary for actual mating, or should extend at least 1/8 inch around the mating area, whichever is less. The atmosphere in which bonding is performed should be clean and free of fumes such as ammonia, acidic, and organic vapors. After a metal-to-metal joint (free of moisture) is assembled, the periphery of the exposed edge should be sealed using an appropriate compound.

4.9 Intermetallic Contact:

The finishing of metallic surfaces to be placed in intimate contact by assembly presents a special problem, since intermetallic contact of dissimilar metals results in electrolytic couples which promote corrosion through galvanic action. To provide the corrosion protection required, intermetallic couples should be restricted to those permitted by Table 2 unless the bond is suitably treated before and after for compatibility per processes specified in this standard. ARP1481 provides a more detailed table of compatible couples and may be used as an aid to Table 2 of this document. The table from ARP1481 is being constantly updated and therefore is not repeated herein.

5. DETAIL REQUIREMENTS:

5.1 Aluminum Surface Preparation:

A clean, smooth surface should be obtained. The surface preparation for an electrical bond requires the following:

a. Clean electrical bonding surfaces with approved cleaning solvent. When working in an enclosed area, use some means of supplying fresh air to prevent a concentration of vapors. Refer to vendor data sheets or request Environmental Protection Agency's safety data sheets.

b. Nonsoluble films should be removed by sanding or polishing with very fine garnet paper (silicon carbide or aluminum oxide, 320 grit or finer) or fiberglass eraser, using caution so as not to remove excessive metal. A small area may be cleaned by using a fine stainless steel wire brush. Note: No emery or iron oxide paper or cloth is permitted. Stainless steel wire brushes should be used on one type of metal only to prevent galvanic action due to dissimilar metals.

c. Apply a chemical conversion coating such as Alodine 1200 (brush-on strength) or equivalent (reference MIL-S-5002 and MIL-C-5541) to the area with clean scotch-brite (abrasive impregnated nonwoven nylon), sponge, or equivalent. Keep area wet 3 to 5 minutes or until yellow color develops. Note: Materials other than Alodine may exhibit lower bonding impedances.

d. Allow 1 to 24 hours for the chemical conversion to dry at room ambient temperature.

e. Clean bond area with clean, deionized water to remove chromic oxide and dry. Wipe with care. If the bond coating is broken, retouch with the chemical conversion coating.

f. Install bonding hardware or equipment.

Note: Electrical bonds should be achieved by using the same materials whenever possible. Dissimilar metals should not be in intimate contact unless suitably protected against electrolytic corrosion. If for any reason corrosion must be tolerated, the design must be such that only replaceable hardware items (such as jumpers, bolts, nuts, washers or separators which are not part of the basic structure) should be affected.

5.2 Magnesium Alloy Surface Preparation:

a. Remove grease and oil from surface with approved cleaning solvent. When working in an enclosed area, use some means of supplying fresh air to prevent a concentration of vapors.

b. Remove paint or lacquer, if present, from the surface with an appropriate solvent.

c. Brush area liberally with chrome pickle solution for one minute, then rinse immediately with clean, deionized water to remove all chemicals (reference MIL-M-3171).

d. Dry thoroughly with clean cloth or air dry.

5.3 Steel Surface Preparation:

When the surface is corrosion resistant or plated steel, clean bonding surfaces as follows:

a. Remove grease and oil from surface with approved cleaning solvent. When working in an enclosed area use some means of supplying fresh air to prevent a concentration of vapors.

b. Remove paint or lacquer, if present, from surface with an appropriate solvent and dry thoroughly.

Note: Do not remove zinc or cadmium plate from steel surfaces.

5.4 Structural Metallic Parts:

When in compliance with other applicable parts of this standard, structural metallic parts on the aircraft which are normally considered good electrical conductors and require no further bonding include:

a. Welded parts
b. Brazed parts
c. Riveted parts with a minimum of three rivets (see paragraph 4.5.1).
d. Treated metal-to-metal joints held together by threaded-locking devices.

5.5 Refinishing:

After completion of the bonding and inspection requirements, when it has been necessary to remove any protective coating (e.g., anodic films, grease, oil, paint, lacquer or other high resistance coatings) on metallic surfaces, the area from which the coating has been removed should be refinished with its original finish or other suitable protective finish within 24 hours. On surfaces not requiring paint or other special finishes, conformal coating per MIL-I-46058 or clear lacquer per TT-L-20A may be used to facilitate subsequent inspection. Gold, nickel, chromium, rhodium, tin-lead alloys or sufficiently thick platings of these metals are satisfactory without additional protection or treatment other than buffing or cleaning.

5.6 Conductive Paste:

The use of conductive pastes are permitted when other bonding methods in this specification are not practical. Flanging pressures up to 10 psi should be applied to obtain the low resistivity of the paste. The binder used in the conductive paste must be continuously capable of withstanding the highest operating temperatures encountered.

5.7 Electrical Bonding Methods:

The DC electrical bond resistance measured from an assembly or equipment to the ground plane should be less than 0.0025 ohms unless otherwise specified. The following subparagraphs specify bonding methods for certain parts and equipment.

a. Parts should be bonded with as short a bond lead or strap as possible to the nearest ground plane, when it is not possible to attain a direct electrical bond.

b. Bonding of cylindrical or tubular conducting members, not inherently bonded, should be accomplished by a clamp with a jumper as in Figures 4 and 5. Bonding clamps, when required on flexible metallic conduit or hose, should be so installed as not to crimp or damage the conduit or hose. All metallic pipes, tubes and hoses that carry petroleum products or other fluids including gases should have a mechanically secure connection to the ground plane that will measure 0.01 ohm DC resistance or less. The pipe, tube or hose installation should not be a path for primary electrical power under normal or fault conditions. Nonmetallic plumbing with metallic couplings should be limited in length to prevent a voltage buildup from exceeding the discharge/voltage breakdown level.

   To determine the maximum energy (E) present, determine the voltage breakdown (Vb) and measure the capacity (C). If $E = 1/2\,CVb^2$ is less than 0.20 millijoules, the components may be excluded from electrical bonding/grounding requirements. These tests are intended to be performed at normal ambient temperatures and atmospheric pressure.

c. Equipment with mounting feet should be installed to directly bond with the ground plane in compliance with applicable specifications when prepared in accordance with Figure 18.

d. When bonding straps are required on electrical and electronic shock mounted equipment, bonding should be accomplished in accordance with Figure 26. If bond straps are not part of the shock mount isolator, the installation drawing should specify the type of bonding strap to be used. This is to prevent degradation of the protection requirements to the equipment.

e. Wherever bolts or screws are used, the minimum and maximum torque should be specified. The equipment manufacturer’s requirement should be followed when applicable.

5.8 Bonding Antenna Installations:

5.8.1 Impedance: Radiating elements, exclusive of radar scanners and similar devices where the counterpoise (ground plane) is actually part of the equipment, should be installed and bonded to the counterpoise. This provides negligible impedance within the operating frequency ranges of the equipment. Care should also be taken as far as possible to ensure that the impedance of the aircraft skin near the transmitting aerial is mainly resistive with as little nonlinearity as possible. Nonlinear impedances may generate intermodulation products when multiple channel simultaneous transmission is made. The counterpoise area should be of adequate dimensions so as not to detract from the desired antenna radiation patterns.

5.8.2 Bonding Resistance: DC bonding resistance should be measured from the metal base or antenna connector to the airframe ground plane to determine if it is within allowable limits of 0.0025 ohms.

5.8.3 Return Path: Antennas which are so designed that the antenna radiation pattern and efficiency depend on a low impedance path to the ground plane should be installed to maintain a uniform resistance and reactance between the antenna mounting surface and the surface to which the antenna will be mounted. If a nonconductive gasket is required for moisture/pressure sealing between the antenna and mounting surface, the gasket can be cut out around the mounting bolts to permit bonding washers to be used for spacers. The paint must be removed where the washers contact the ground plane. The cleaned area must be chemically treated per MIL-C-5541. These washers/spacers limit the gasket compression and make it possible to maintain a constant uniform torquing pressure on all mounting bolts.

5.8.3.1 Alternate Return Path: Although the method called out in Paragraph 5.8.3 may be superior to using conductive gaskets without washers, conductive gaskets may be used for purposes of a current return path. Care should be taken to ensure that the gasket retains its conductive properties through several cycles of compression/decompression.

5.8.4 Lightning Paths: Equipment such as antennas, lights, drain masts, etc. which mount on the external skin of the aircraft and which lie within lightning attachment zones 1 or 2 (see MIL-STD-1757) must be carefully electrically bonded to the skin. This is to prevent dangerous lightning-caused voltages and currents from appearing on the internal wiring and piping which interface with the externally mounted equipment. When the internal area opposite the external equipment is designated a fuel vapor area, lightning testing of the proposed installation is highly recommended. The extremely complex nature of the electrical bonds of most externally mounted devices which penetrate the skin make high-current simulated lightning testing the most effective way to assure the safety of these installations.

5.9 Electrical Grounding:

For current return leads (wires) of size 4 AWG or larger, the connection should not be made directly to a ground plane structure but should be made to a tab or doubler of sufficient size which has been properly attached to the structure as shown in Figure 12. In this way, damage to the ground plane structure resulting from high currents flowing through defective bonds can be avoided. Either rivets or bolts may be used provided, when a bolt(s) is used, the washer or backup plate has an equivalent diameter to that required by Paragraph 5.9.2. For leads smaller than above, the method should be in accordance with Figures 1, 2 and 3. Grounds are to be direct and with the shortest possible path, where practical, from the operating equipment, and in no case are ground paths to be routed through other equipment. Ground current loops through equipment grounds and basic structure grounds must be avoided. Nuts, bolts and screws are not to be made a part of the major current path. They are to be used only as a mechanical means to secure a bonded connection. Self-locking nuts should be considered, except as indicated in Figure 2. A maximum of four terminals may be installed on each individual ground stud. If two or more wires are applied per terminal, each wire must form a mechanically sound connection in the terminal and must meet its applicable bonding resistance limits. Common connections of AC and DC grounds should not be allowed. Case bonding and current return bonding should be kept separated and connected to separate ground studs. Chart 1 gives the fault current versus maximum allowed resistance for bonding between equipment and structure.

5.9.1 Methods of Grounding or Bonding: See Figures 1 through 28 for various grounding and bonding methods.

5.9.2 Cross-Sectional Consideration: Grounding conductor bonding jumpers must have a circular mil area that is at least equal to that of the largest supply conductor or other conductor that can supply current to a fault in the equipment, but not less than the equivalent of a 10 AWG wire. This is to ensure that the bond stays intact until the circuit is opened, thus preventing the enclosure from becoming a shock hazard under fault conditions.

When bonding to thin structures, the ground stud/ground plane interface must be of sufficient size (area) to distribute the current over an adequate area. The following relationship should be observed:

$$D = \frac{A_1}{T_\pi}$$

Where:

D = Diameter of surface hardware (washer)
T = Thickness of ground plane
π = 3.14
A_1 = Equivalent cross-sectional area of maximum current carrying conductor

The minimum cross-sectional area of the bonding interface surface should be one square centimeter (0.155 square inches).

5.10 Lightning Bonding Considerations:

To minimize damage by lightning, major parts of the aircraft such as engines should be bonded to the ground plane so that sparks cannot jump from one metallic structure to another within the aircraft. This is particularly important in areas where fuel vapors may be ignited due to the high currents that dissipate sufficient thermal energy at a resistive joint. High current indirect bonds are normally made with a substantial copper or tinned copper lead terminated with a tinned copper lug mated to a ground terminal. This is capable of carrying several hundred amps steady current and nearly an order of magnitude greater current for shorter periods without heating sufficiently to be an ignition hazard. Because of the rapid rise time of the current, bonds must have a low enough series inductance to prevent sparking at the bond discontinuity. The fact that bonding jumpers have been blown apart because they were not installed properly illustrates the need for low inductance. In aircraft skin, perforation of panels may result if sparking from panel to panel occurs. It can be seen that because of the rapid rise time, the requirements of lightning strike conduction are similar to those for RF current condition. Lightning strikes normally enter at one extremity of the aircraft and leave at another, for example, nose to tail or wing tip to wing tip. Control surfaces such as ailerons are also vulnerable and require proper bonding to the airframe. If possible bonding of aircraft skin at vulnerable places should not be so as to depend entirely on the rivets themselves for conduction between bonded surfaces (i.e., skins separated by nonconductive sealant). For detailed requirements, consult other military specifications. MIL-STD-1757 covers lightning test techniques. Design techniques are covered in NASA Reference Publication 1008, FAA Circular AC 20-53, and British BCAR D4-6.

5.11 Composite Bonding:

General information is not available to date and most information as yet is proprietary, therefore, guidelines are not included herein.

5.12 Nonmetallic Parts:

To overcome the effects of electrostatic charge, nonconductive materials such as plastic or glass may be coated with a conductive coating. Care must be exercised in cleaning conductive coating and resistance must be checked at regular intervals. If such a coating is used on radomes, it should have a characteristic impedance of from 10 megohms to 50 megohms per square. Coatings used for other applications should not exceed 50 megohms per square. Such a coating should be bonded to ground with a conductor or conductors that contact as much of the peripheral edge of the coating as possible, so as to firmly reference the coating to ground. Point contact bonds should be avoided.

5.13 Measuring Bond Resistance/Reactance:

Measurements of bond impedance can be categorized into DC measurements and RF measurements. DC measurements can be easily made but RF measurements present difficulties particularly with higher frequency measurements on realistic structures. It is for this reason that no RF impedance limits for bonds are generally specified; sufficiently low RF impedance can in most cases be achieved by following the procedures covered in this document.

Commonly used methods for measuring bond resistance are:

Milliohmeters (both DC and AC measuring)
Kelvin Bridge method.

AC measuring milliohmeters typically pass a 1000 Hz current through the bond. The advantage of measuring with this AC current method is that thermally induced EMF caused by temperature variations within the circuit are effectively cancelled. Caution: This test may induce currents in parallel circuits. AC milliohmeters are recommended for use around fueled aircraft. Kelvin Bridge methods may cause arcing.

The two Kelvin Bridge methods are shown schematically in Figure 29. The constant current generator in the Kelvin Bridge should be ±1% accurate or better. In the case of the constant voltage method, the variable resistance must be adjusted to different values each time a measurement is taken. Choosing measurement current values such as 1 amp or 10 amps can allow the millivoltmeter to read resistance directly times a power of ten. The minimum current value used should be 25 milliamps. Each end item should have the maximum electrical bonding resistance between any two selected points specified in the end item bonding specification. See Figures 29 and 30.

5.13.1 Shock and Fire Safety: A protective grounding bond must pass sufficient current to cause protective devices (i.e., fuse or circuit breaker) to operate within 0.2 seconds. The bond will be considered acceptable if this test results in the following:

a. Voltage on enclosure must stay below 4.5 volts.
b. No fire or damage to the bond.

6. QUALITY ASSURANCE PROVISIONS:

6.1 In-Progress Inspection:

An in-progress inspection should be conducted including measurement during the installation of bond straps, nonmetallic materials and ground systems as specified by this document. This inspection should consist of spot checking installation procedures, methods, and materials to determine compliance with the requirements specified herein. The inspection should also determine that:

a. Bond straps, nonmetallic materials and ground systems are installed in conformance with requirements for personnel safety.

b. Quality materials, methods and workmanship are used.

c. Each installation will satisfy the intent and purpose of the requirement.

d. Bond straps will not restrict the movement of any hinged or pinned item and installation methods will not place any bond strap in a binding or restrictive position that will lead to early breakage of the strap.

e. Bond straps, bonding hardware and nonmetallic materials are fabricated, installed and treated to prevent deterioration through corrosion, oxidation or weathering.

6.2 Final Inspection:

After the completion of all required installations, a final inspection should be made. This inspection should be in accordance with approved procedures to determine that all requirements have been accomplished and that the quality assurance provisions of 4.1 have been met.

6.3 Inspection Responsibility:

Unless otherwise required by the contract or purchase order, the contractor is usually responsible for performing and preparing the inspection procedures for in-progress and final inspection.

6.4 Inspector Certification:

The contractor should certify that the inspector is qualified to perform the inspections specified herein.

PREPARED BY SAE COMMITTEE AE-4,
ELECTROMAGNETIC COMPATIBILITY COMMITTEE

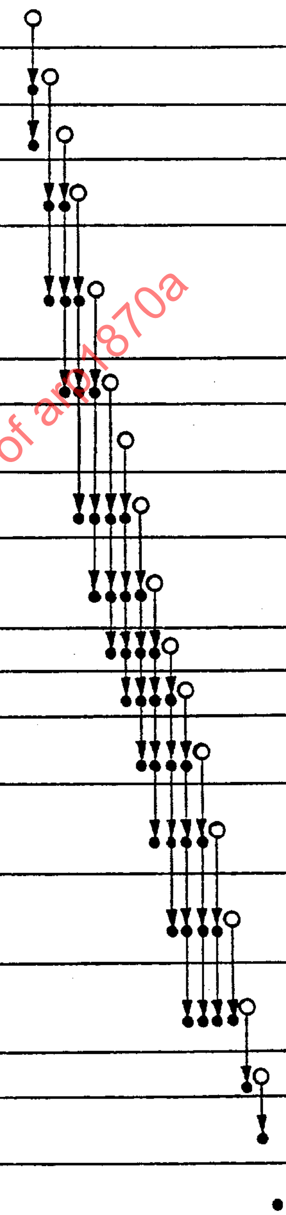
TABLE 1 - Direct Current Resistance Limits for Electrical Bonding

Component	Maximum Resistance to Reference Ground Plane (Recommended Value In Ohms)
Support brackets and electrical/electronic cabinets	0.0025
Access or inspection doors	0.01
Control surfaces (electrically bonded)	0.0025
Fuel, oil, hydraulic and air lines, and fittings (metallic)	0.01
Nonmetallic fuel, oil, hydraulic and air lines, and fittings	Special handling for these lines is required
Bearings (roller and ball)	0.01
Power conduit	0.10
Static dischargers	0.10
Conduit containing signal wires or low currents (routing)	0.0025
Filters (RFI)	0.0025
Electrical motors, starters, generators, and attenuators	See Chart 1
Metal tanks with fuel filler provisions (no electrical installations)	0.01
Tanks containing no flammable material	0.01
Other electrical devices attached to enclosures	0.005
Switches, circuit breakers, and potentiometers in circuits exceeding 50 V	0.10
Metal instrument panels	
(a) Nonelectrical	0.01
(b) No rotating or vibrating electrical equipment	0.01
(c) With rotating or vibrating electrical equipment	0.0025
Radiators and heat exchangers	0.0025
Metal ducts (nonelectrical: rigid and flexible)	1.0
Engine supports	As low as practical
Antennas (grounded type)	0.0025
Coaxial cables (HF)	0.0025
Structural joints or breaks	0.0025
Equipment enclosures	
(a) Cabinet seams	EMI 0.0025; Safety 0.10
(b) Drawers	EMI 0.0025; Safety 0.10
(c) Panels	EMI 0.0025; Safety 0.10
(d) Access doors	0.01

Note: Adequacy of the bond to carry current shall be established by measurement per para. 5.9.2 and 5.13.

TABLE 2 - Compatible Couples

Group No.	Metallurgical Category	EMF (Volt)	Anodic Index (0.01 V)	Compatible Couples (see note below)
1	Gold, solid and plated; gold platinum alloys; wrought platinum	+0.15	0	
2	Rhodium plated on silver-plated copper, graphite	+0.05	10	
3	Silver, solid or plated; high silver alloys	0	15	
4	Nickel, solid or plated; monel metal, high nickel-copper alloys, titanium	-0.15	30	
5	Copper, solid or plated; low brasses or bronzes; silver solder; German silver; high copper-nickel alloys; nickel-chromium alloys; austenitic corrosion resistant steels	-0.20	35	
6	Commercial yellow brasses and bronzes	-0.25	40	
7	High brasses and bronzes; naval brass; Muntz metal	-0.30	45	
8	18 percent chromium type corrosion-resistant steels	-0.35	50	
9	Chromium, plated; tin, plated; 12 percent chromium type corrosion-resistant steels	-0.45	60	
10	Tin-plate; terneplate, tin-lead solder	-0.50	65	
11	Lead, solid or plated; high lead alloys	-0.55	70	
12	Aluminum, wrought alloys of the duralumin type	-0.60	75	
13	Iron, wrought, gray, or malleable; plain carbon and low alloy steels, armco iron	-0.70	85	
14	Aluminum, wrought alloys other than duralumin type; aluminum, cast alloys of the silicon type	-0.75	90	
15	Aluminum, cast alloys other than silicon type; cadmium, plated and chromated	-0.80	95	
16	Hot-dip-zinc plate; galvanized steel	-1.05	120	
17	Zinc, wrought; zinc-base die-casting alloys; zinc, plated	-1.10	125	
18	Magnesium and magnesium-base alloys, cast or wrought	-1.60	175	



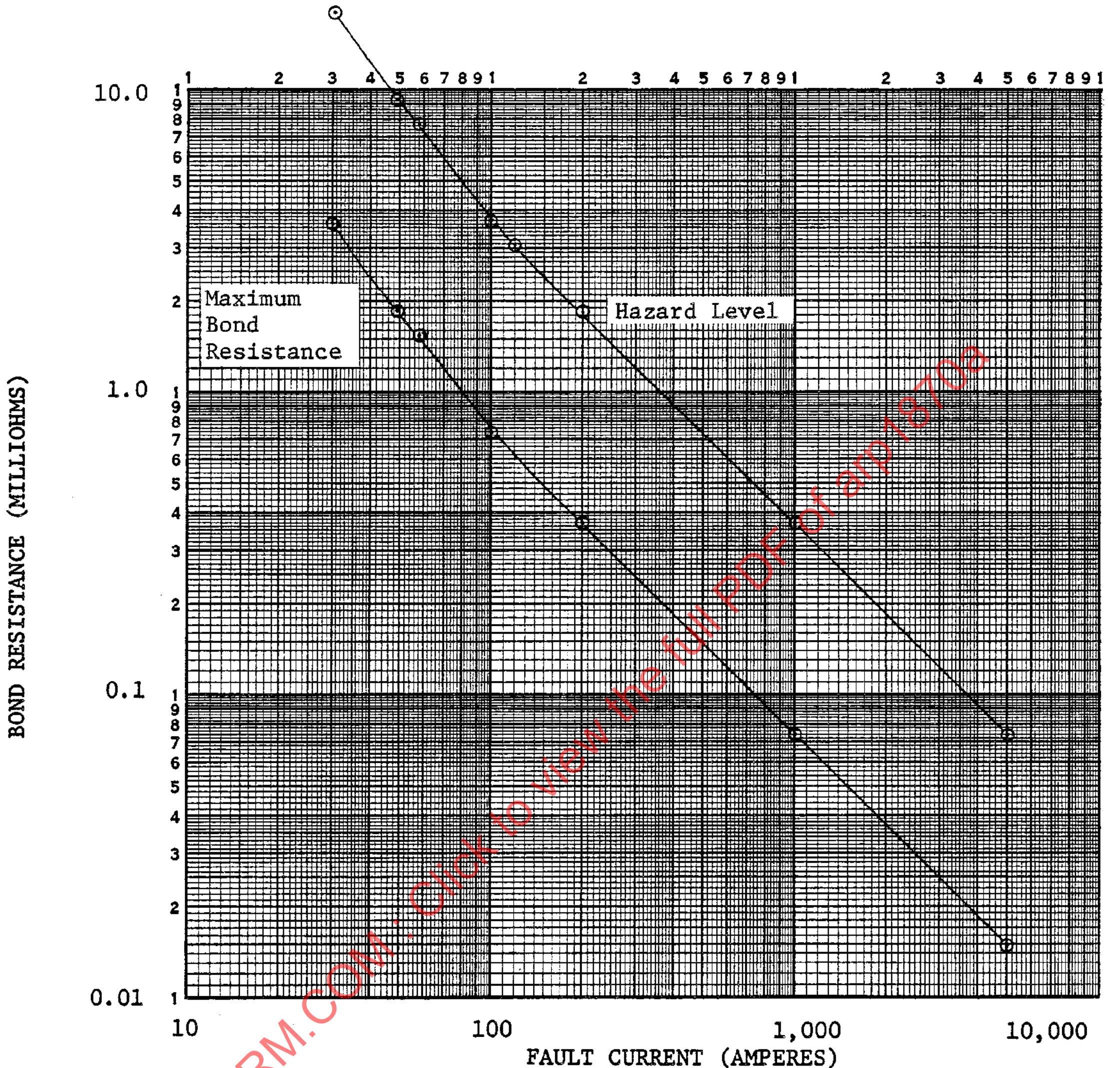
Note: ○ = Indicates the most cathodic members of the series.
● = Indicates an anodic member.
Arrows indicate the anodic direction.
Couples not listed as compatible in this table may be made compatible by preparing unmated metals and by finishing bonds in accordance with this standard.

TABLE 3 - Fasteners, Hardware

Metal Structure (Outer Finish Metal)	Connection for Aluminum Jumper	Screw Type (Note)	Connection for Tinned Copper Jumper	Screw Type (Note)
Magnesium and magnesium alloys	Direct or magnesium washer	Type I	Aluminum or magnesium washer*	Type I*
Zinc, cadmium, aluminum and aluminum alloys	Direct	Type I	Aluminum washer	Type I
Steel (except stainless steel)	Direct	Type I	Direct	Type I
Tin, lead, and tin-lead solders	Direct	Type I	Direct	Type I or II
Copper and copper alloys	Tinned or cadmium plated washer	Type I or II	Direct	Type I or II
Nickel and nickel alloys, titanium	Tinned or cadmium plated washer	Type I or II	Direct	Type I or II
Stainless steel	Tinned or cadmium plated washer	Type I or II	Direct	Type I or II
Silver, gold, and precious metals	Tinned or cadmium plated washer	Type I or II	Direct	Type I or II

Note: Type I is cadmium- or zinc-plated steel; Type II is stainless steel. Where either type is indicated as acceptable, Type II is preferred from a corrosion standpoint. Where metal contact is dissimilar, the bond shall be treated per applicable processes specified in this document.

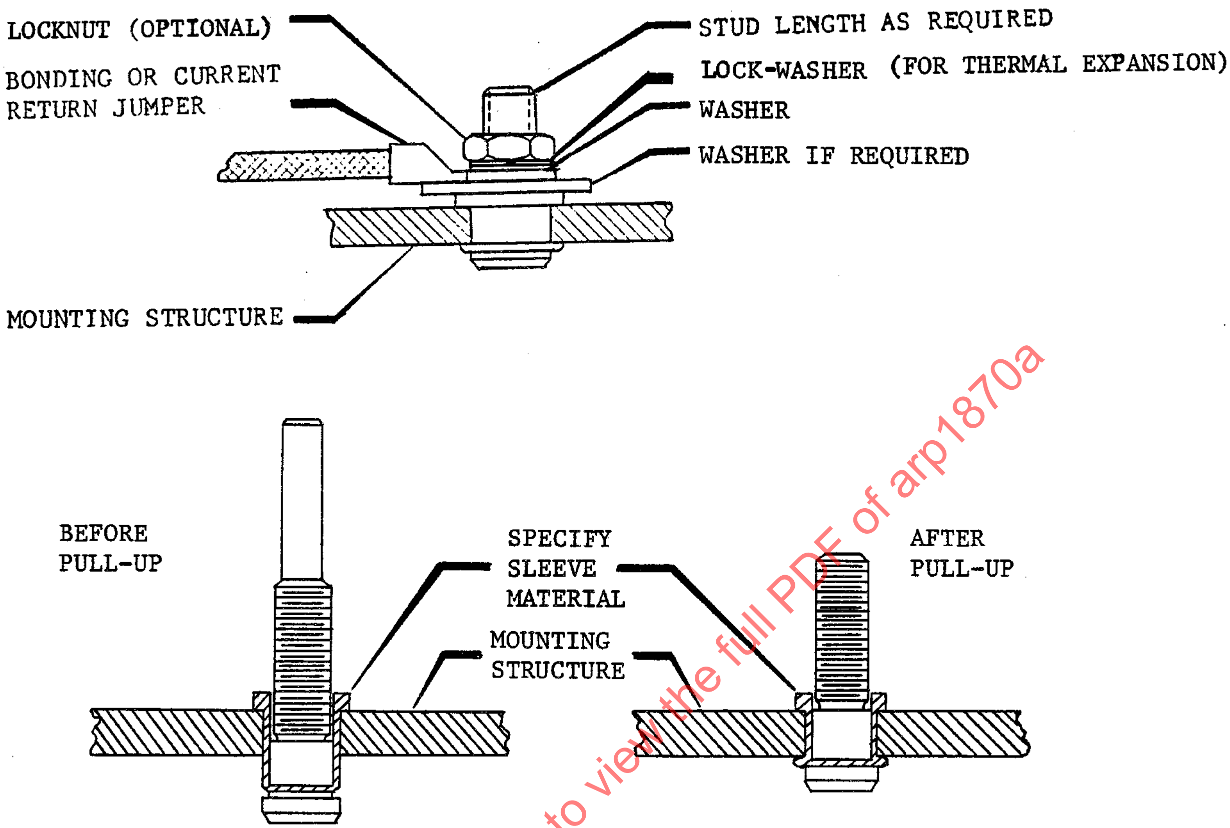
*Avoid connecting copper to magnesium.



NOTE 1. Data Points

AMPS	HAZARD RESISTANCE (MILLIOHMS)	MAX RESISTANCE (MILLIOHMS)
5000	0.074	0.0148
1000	0.37	0.074
200	1.85	0.37
120	3.08	--
100	3.7	0.74
58	7.7	1.54
49	9.3	1.86
30	18	3.6

CHART 1 - Fault Current Versus Maximum Allowed Resistance for Bonding Between Equipment (Such as Electric Motors, Starters, Generators) and Structure



STUD SIZE:

BONDING - 0.190 INCH DIAMETER STUD

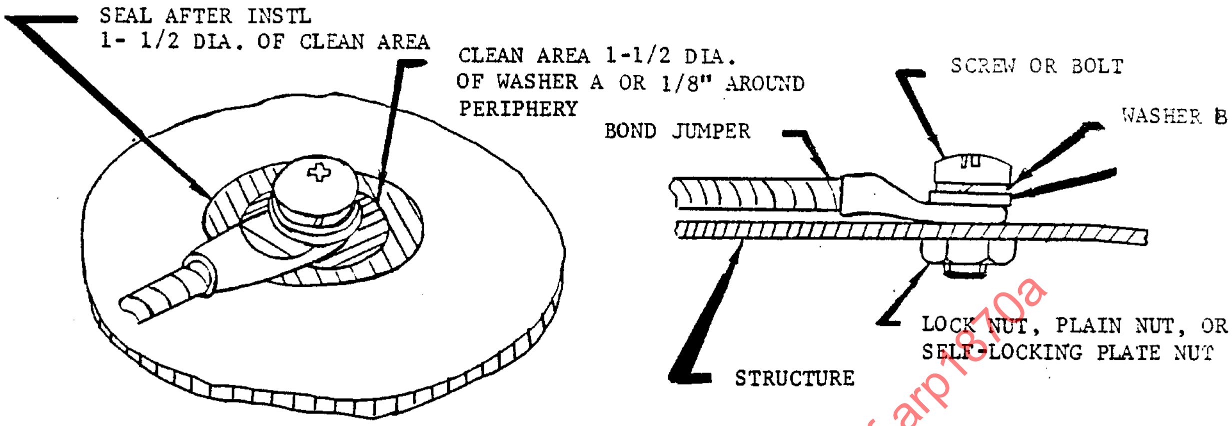
25 AMP RETURN - 0.138 INCH DIAMETER STUD
30 AMP RETURN - 0.164 INCH DIAMETER STUD
35 AMP RETURN - 0.190 INCH DIAMETER STUD
43 AMP RETURN - 0.250 INCH DIAMETER STUD

NOTES:

1. MOUNTING HOLE SHALL BE CLEAN AND FREE OF ANY SURFACE COATING.
2. NO REFINISHING REQUIRED.
3. STUD AND MOUNTING STRUCTURE MUST BE COMPATIBLE.
4. SEE MIL-T-83454 AMENDMENTS 1A AND 2 FOR FURTHER DETAILS ON THESE STUDS.

FIGURE 1 - Typical Bolted Connection Blind Plate Stud Terminals

SEE TABLE BELOW FOR MATERIALS



NOTE: MS35338 LOCK WASHER SHALL BE USED WITH THIS TYPE OF STUD BONDING OR GROUNDING ON ALL BOLTED BONDING/GROUNDING CONNECTIONS. THEIR FUNCTION IS TO ENSURE A TIGHT CONNECTION WITH PLAIN OR SELF-LOCKING NUTS UNDER CONDITIONS WHERE THERMAL EXPANSION OF THE BOLT OCCURS.

TABLE

STRUCTURE	SCREW OR BOLT; LOCK-NUT	WASHER A	LOCK-WASHER B MS35338	
	TINNED COPPER TERMINAL AND JUMPER			
ALUMINUM ALLOYS	CAD. PLATED STEEL	CAD. PLATED STEEL OR ALUMINUM	CAD. PLATED STEEL	
MAGNESIUM ALLOYS	AVOID CONNECTING COPPER TO MAGNESIUM			
STEEL, CADMIUM PLATED	CAD. PLATED STEEL	CAD. PLATED STEEL	CAD. PLATED STEEL	
STEEL, CORROSION RESISTING	CORROSION RESISTING STEEL	CAD. PLATED STEEL	COR. RESIST. STEEL	IF A NICKEL PLATED WIRE TERMINAL IS USED, WASHER A MAY BE CRES

BOLT SIZE:

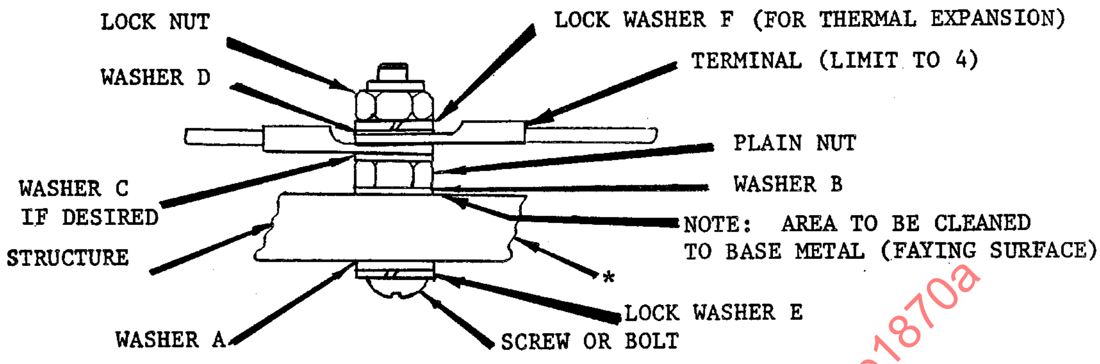
BONDING: NO. 6 AND NO. 8 SCREW WHERE EDGE DISTANCE WILL NOT PERMIT NO. 10 SCREW.

BONDING: 3/16-INCH DIAMETER MINIMUM WHERE POSSIBLE.

CURRENT RETURN: 100 AMP CURRENT RETURN 1/4-INCH DIAMETER MINIMUM
200 AMP CURRENT RETURN 5/16-INCH DIAMETER MINIMUM

FIGURE 2 - Typical Bolted Connection

SEE TABLE BELOW FOR MATERIALS



NOTE: MS35338 LOCK WASHER MAY BE USED WITH THIS TYPE OF STUD BONDING OR GROUNDING ON ALL BOLTED BONDING/GROUNDING CONNECTIONS. THEIR FUNCTION IS TO ENSURE A TIGHT CONNECTION WITH PLAIN OR SELF-LOCKING NUTS UNDER CONDITIONS WHERE THERMAL EXPANSION OF THE BOLT OCCURS.

TABLE

Structure	Screw or Bolt; Lock-Nut	Plain Nut	Washer A	Washer B	Washer C&D	Lock-Washer E MS35338	Lock-Washer F MS35338
Tinned Copper Terminal and Jumper							
Aluminum Alloys	Cad. Plated Steel	Cad. Plated Steel	Aluminum Alloy	Aluminum Alloy	Cad. Plated Steel	Cad. Plated Steel	Cad. Plated Steel
Magnesium Alloys	AVOID CONNECTING COPPER TO MAGNESIUM						
Steel, Cadmium Plated	Cad. Plated Steel	Cad. Plated Steel	None	None	Cad. Plated Steel	Cad. Plated Steel	Cad. Plated Steel
Steel, Corrosion Resisting	Corrosion Resisting Steel	Cor. Res. Steel	None	None	Cad. Plated Steel	Cor. Resist. Steel	Cor. Resist. Steel

BOLT SIZE:

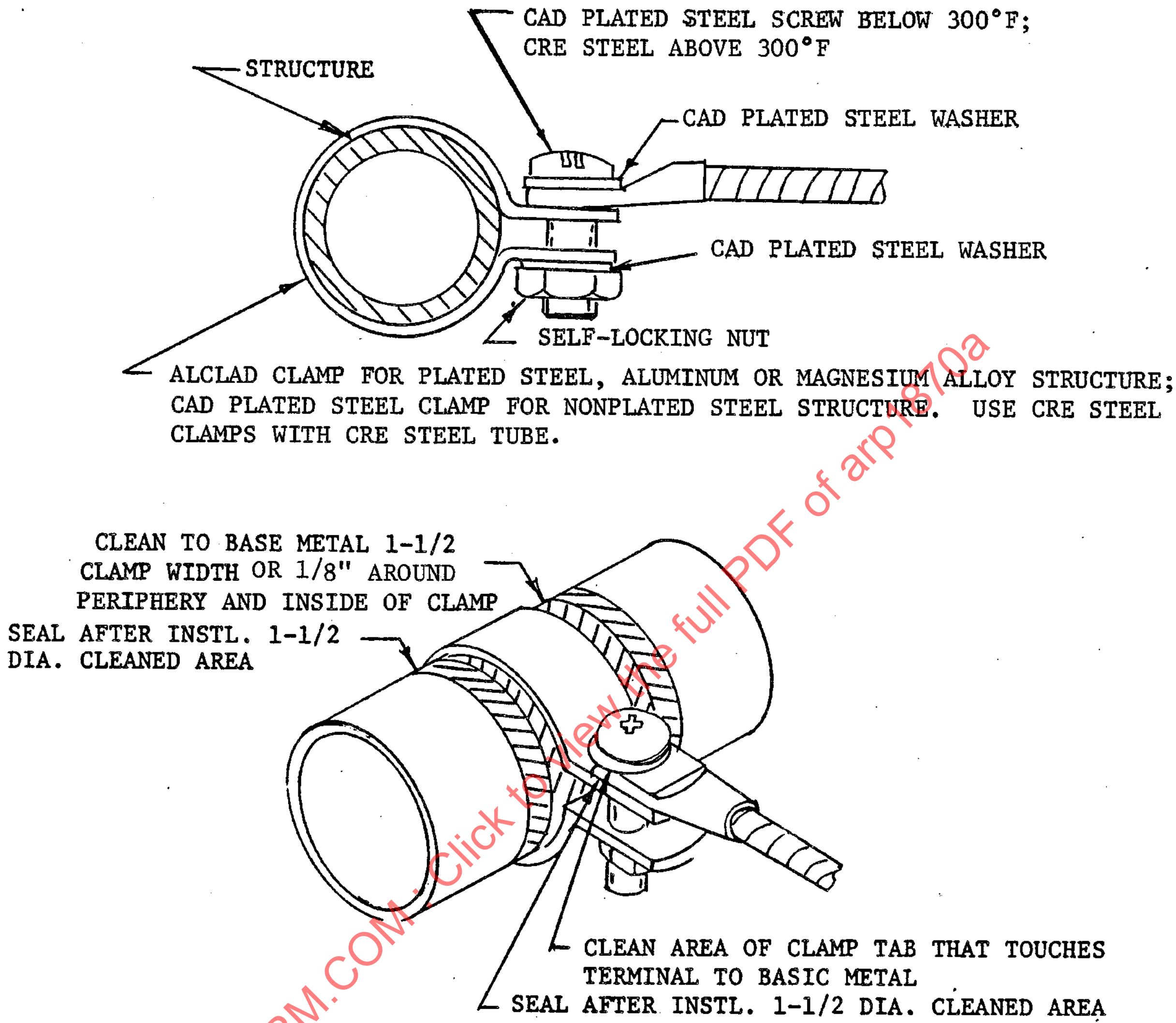
BONDING: NO. 6 AND NO. 8 SCREW WHERE EDGE DISTANCE WILL NOT PERMIT NO. 10 SCREW.

BONDING: 3/16-INCH DIAMETER MINIMUM WHERE POSSIBLE.

CURRENT RETURN: 100 AMP CURRENT RETURN 1/4-INCH DIAMETER MINIMUM
200 AMP CURRENT RETURN 5/16-INCH DIAMETER MINIMUM

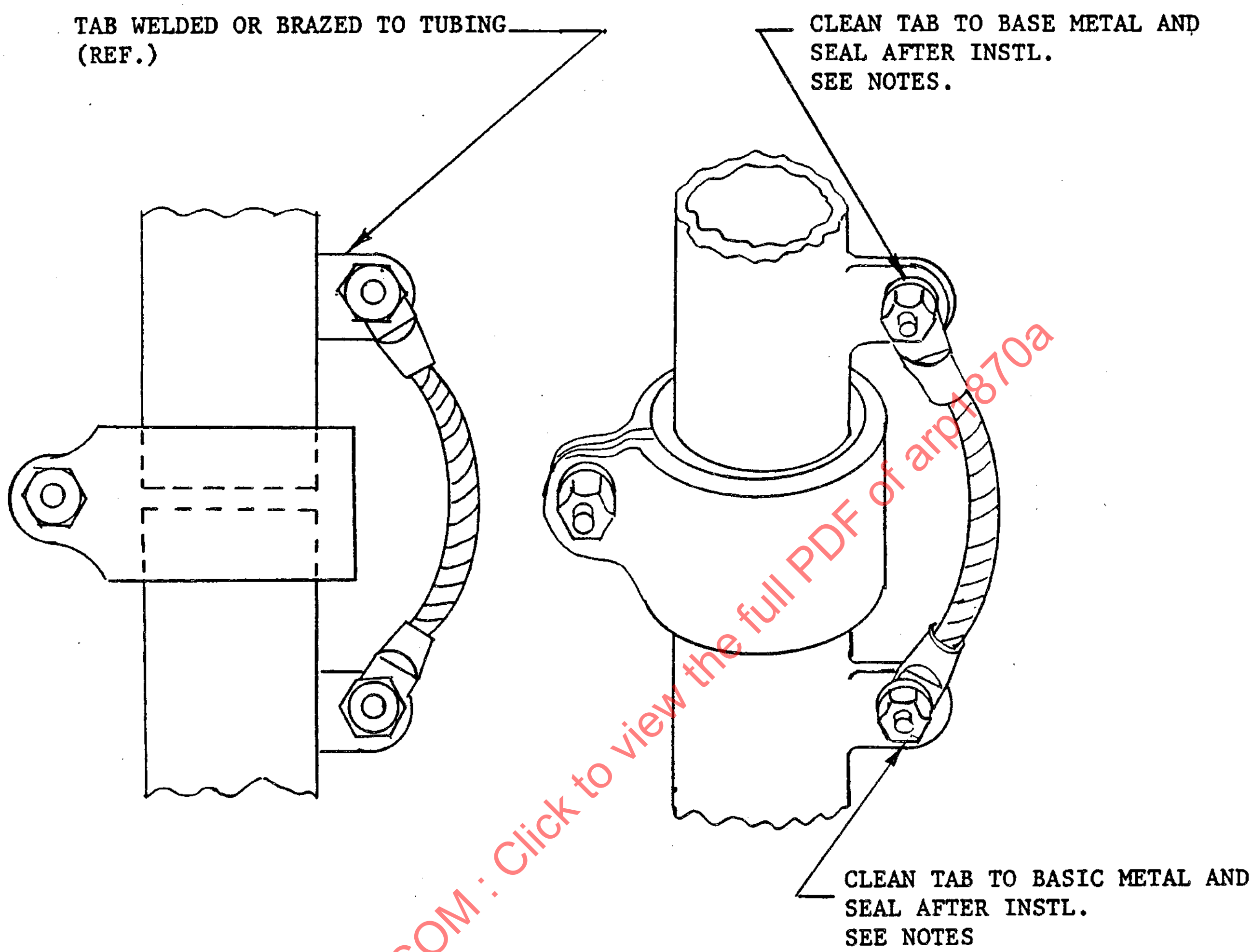
*THE BUILDUP SHOWN IN FIGURE 2 IS PREFERRED AND SHOULD BE USED WHENEVER POSSIBLE.

FIGURE 3 - Typical Grounding Stud



NOTES:
1. BOND JUMPER SHOWN IS NOT REQUIRED WHERE CLAMP IS BONDED DIRECTLY TO STRUCTURE.
2. LOCATION OF NUT OR HEAD OF BOLT OPTIONAL.
3. EQUIVALENT CLAMPS MAY BE USED IF DISSIMILAR METAL CONTACT IS AVOIDED.

FIGURE 4 - Typical Clamp Connection



NOTES:
1. CAD PLATED STEEL SCREWS BELOW 300°F
2. CRE STEEL SCREW OR BOLT ABOVE 300°F
3. CAD PLATED STEEL WASHER UNDER SCREW OR BOLT HEAD
4. SELF-LOCKING CAD PLATED STEEL NUT
5. CLEAN MATING SURFACE AND SEAL AS REQUIRED
6. CORROSION PROTECTION SHALL BE AS SPECIFIED

FIGURE 5 - Typical Method of Bonding Tubing Across Clamps

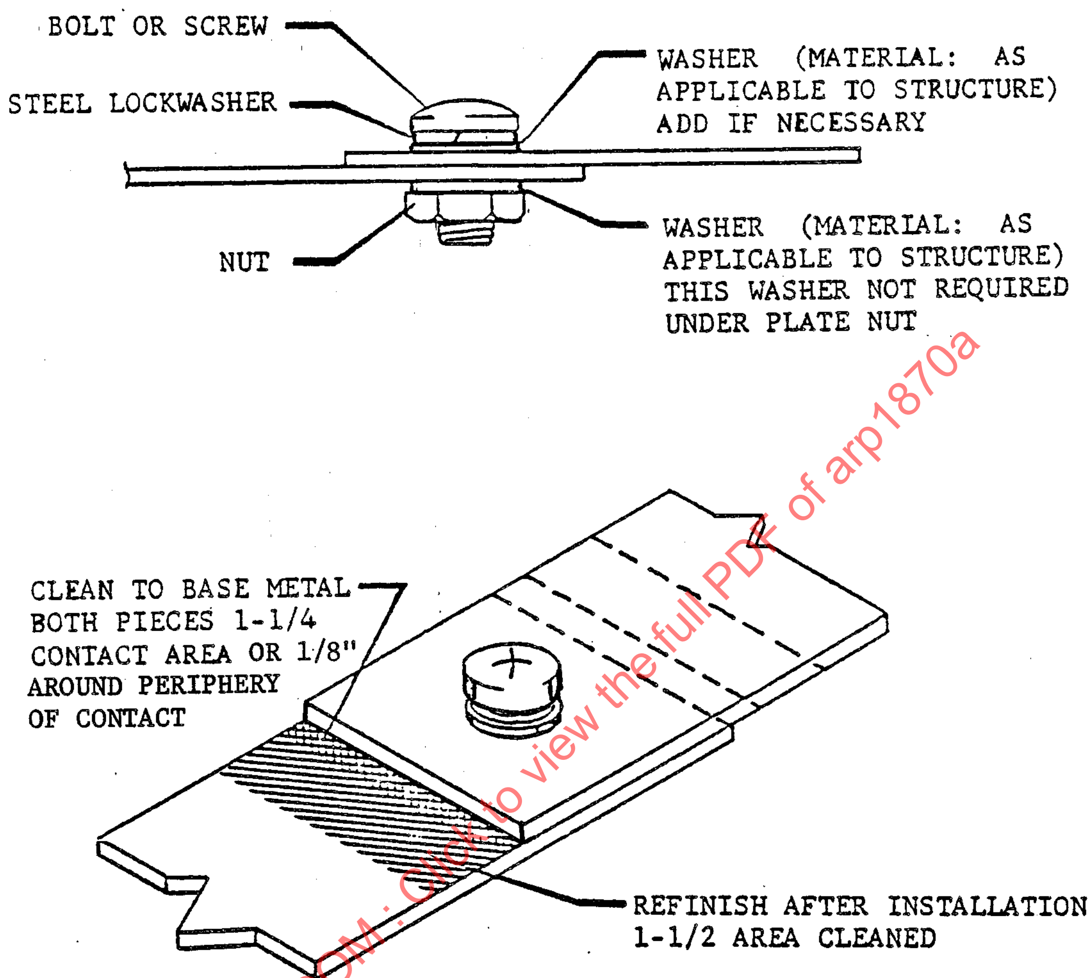
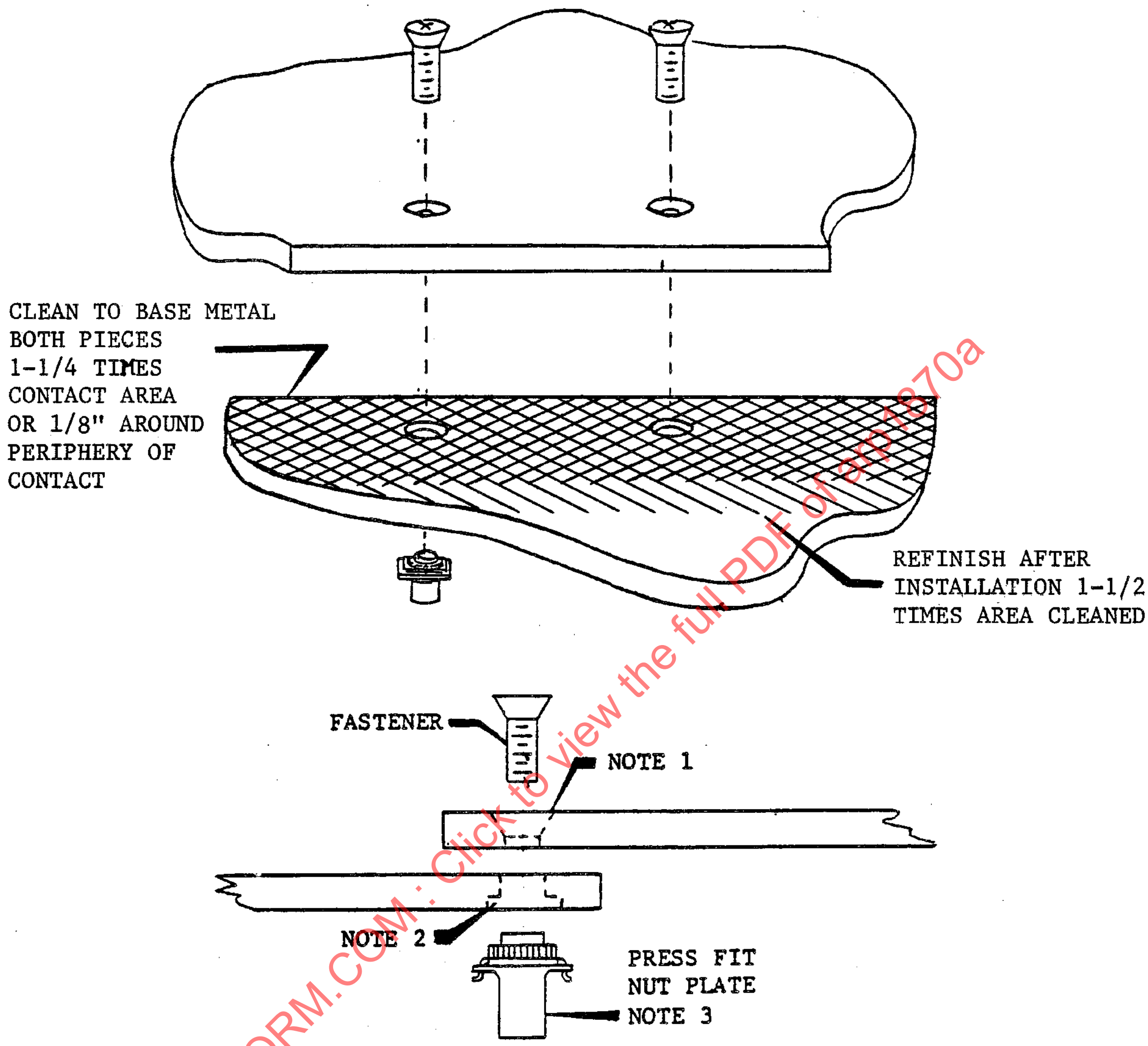
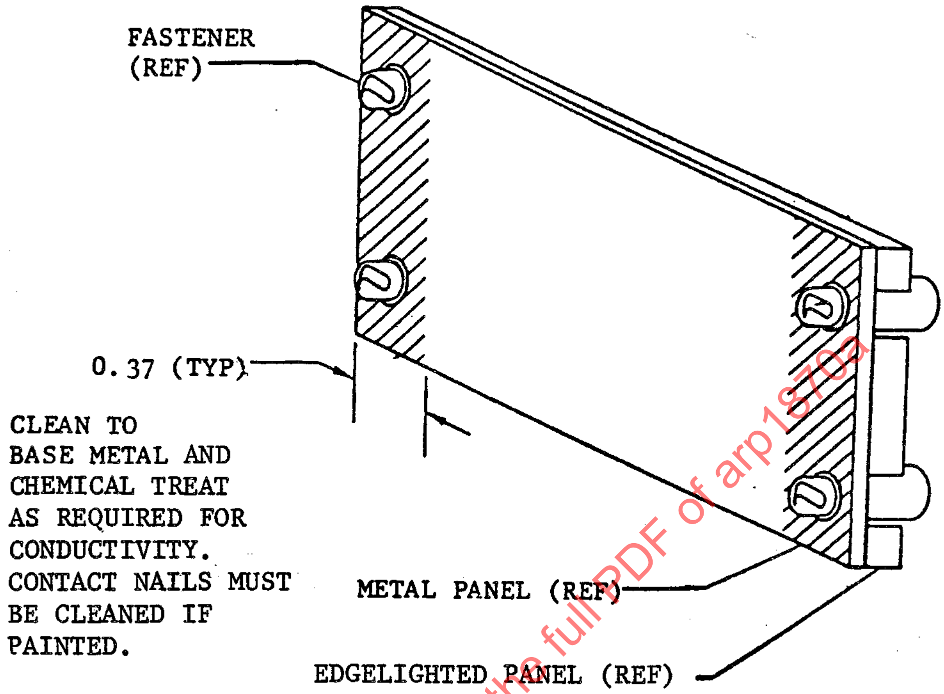


FIGURE 6 - Preparation of Bonding Connection in Bolted Structural Joints



NOTES:
1. COUNTERSINK SURFACE SHALL BE CLEAN AND FREE OF ANY SURFACE COATING.
2. MOUNTING HOLE SHALL BE CLEAN AND FREE OF ANY SURFACE COATING.
3. USE ONLY SELF-LOCKING PRESS FIT TYPE NUTPLATES WITHOUT DRY FILM LUBRICANT.
4. SEAL SCREWS AS REQUIRED AFTER INSTALLATION.
5. UNACCEPTABLE FOR COLD ROLLED SHEET STOCK OR FOR USE IN STRUCTURAL AREAS.

FIGURE 7 - Method of Bonding by Means of Fasteners



NOTE: MINIMUM AND MAXIMUM FASTENER COMPRESSION SHALL BE SPECIFIED TO PREVENT POINT CONTACT BONDS.

FIGURE 8 - Method of Bonding Edge Lighted Panels

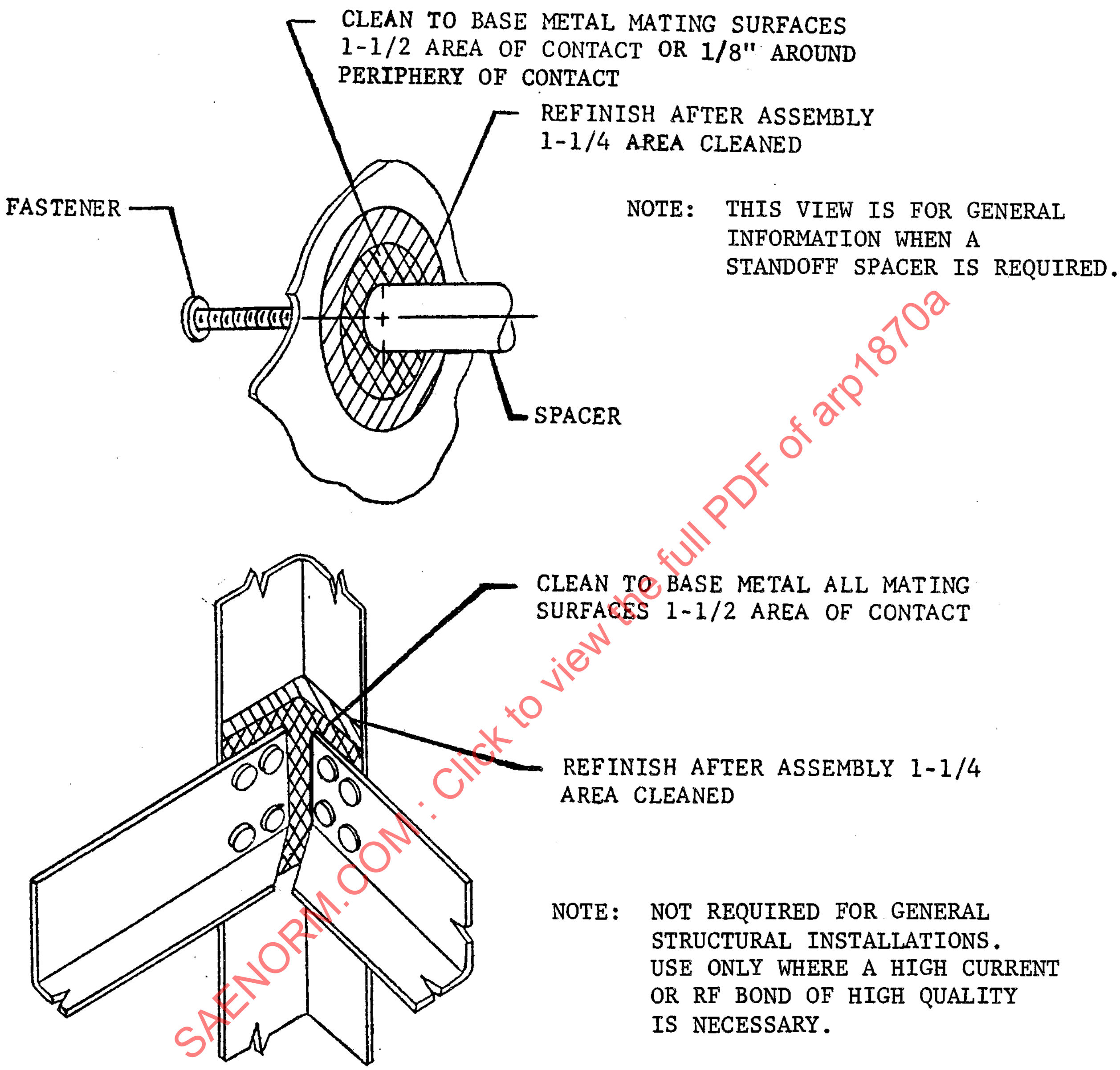
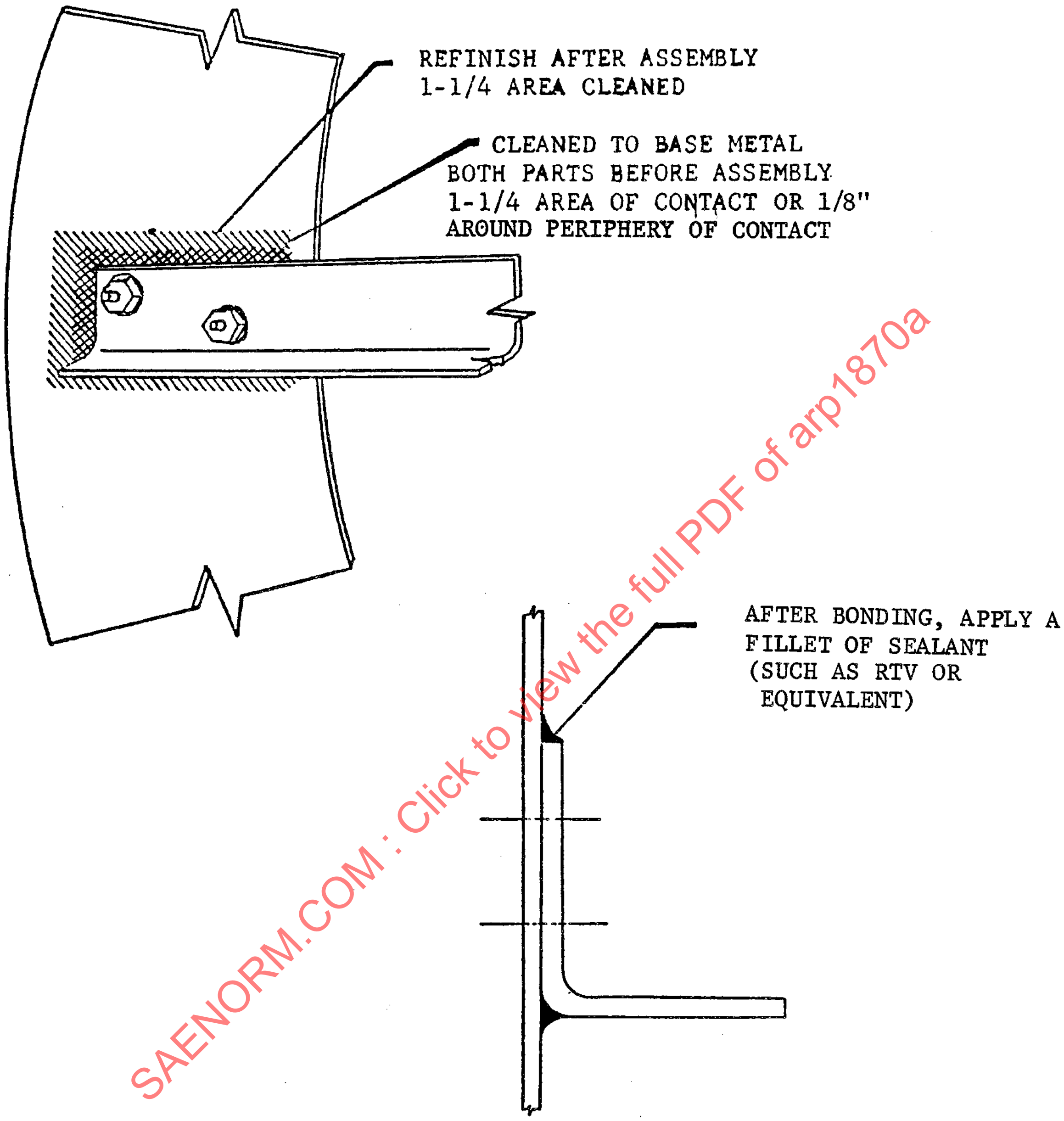
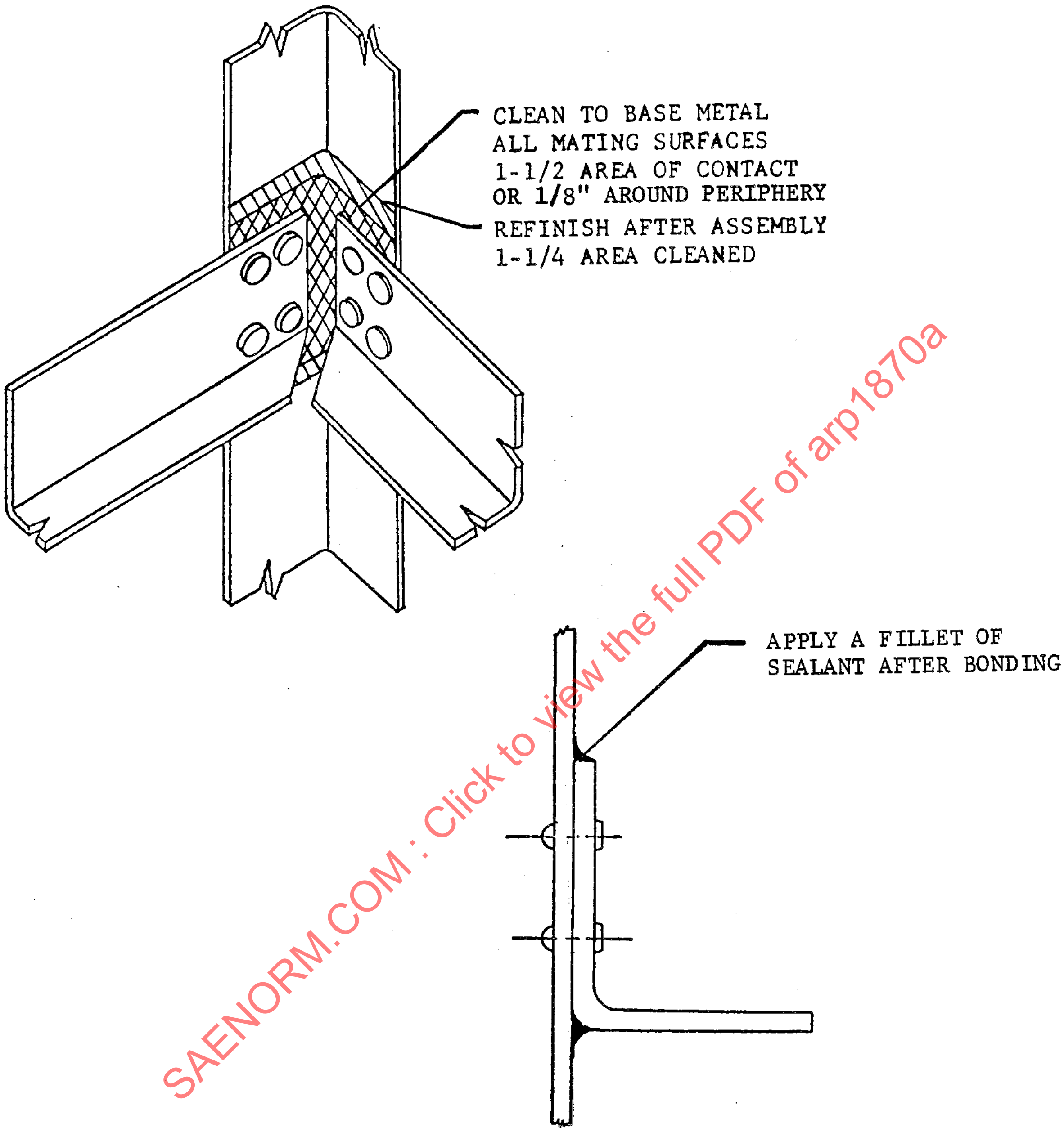


FIGURE 9 - Method of Bonding Between Structural Parts in an Assembly



NOTE: NOT REQUIRED FOR GENERAL STRUCTURAL INSTALLATIONS. USE ONLY WHERE A HIGH CURRENT OR RF BOND OF HIGH QUALITY IS NECESSARY.

FIGURE 10 - Method of Bonding Through Bolted Connection Requiring Sealant



NOTE: NOT REQUIRED FOR GENERAL STRUCTURAL INSTALLATIONS. USE ONLY WHERE A HIGH CURRENT OR RF BOND OF HIGH QUALITY IS NECESSARY.

FIGURE 11 - Method of Bonding Between Structural Parts of an Assembly Requiring Sealant

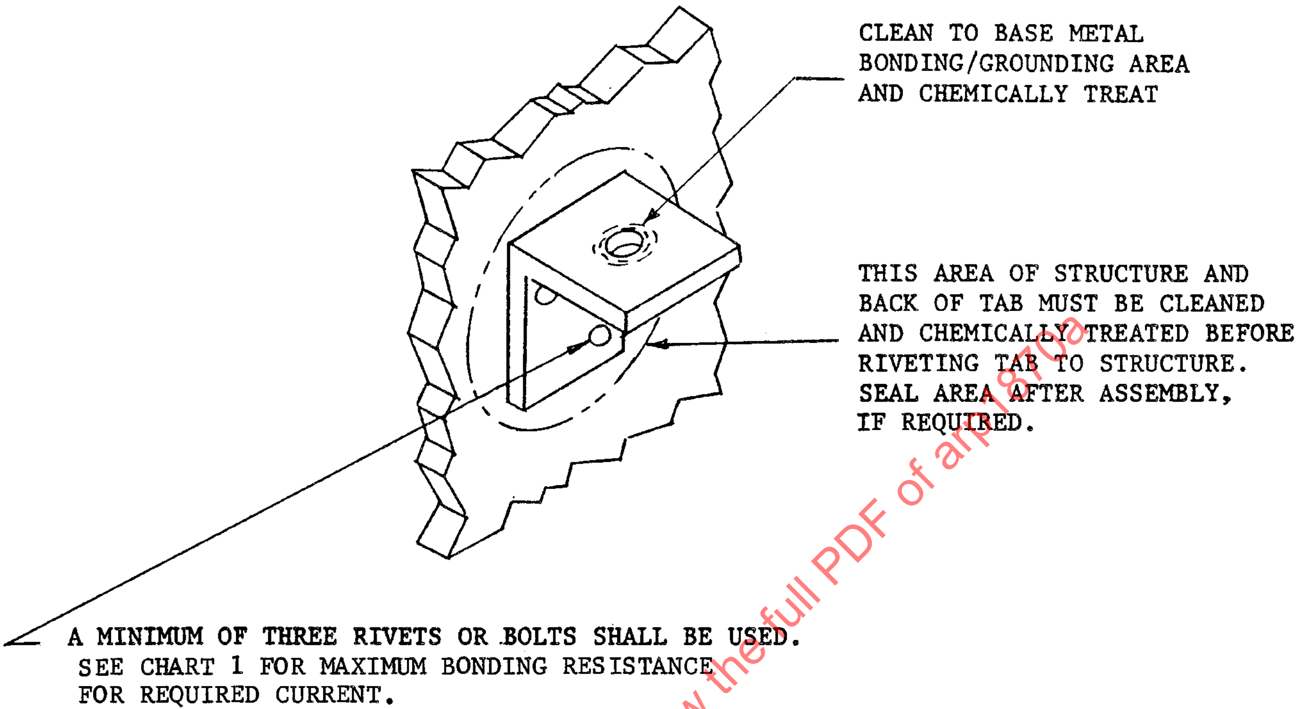
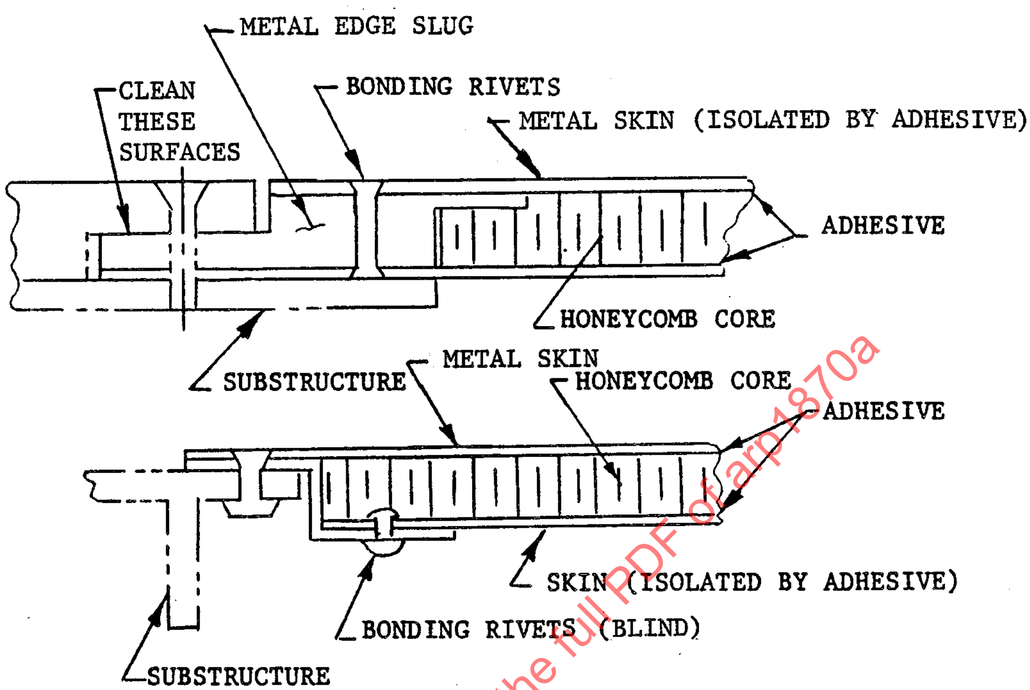
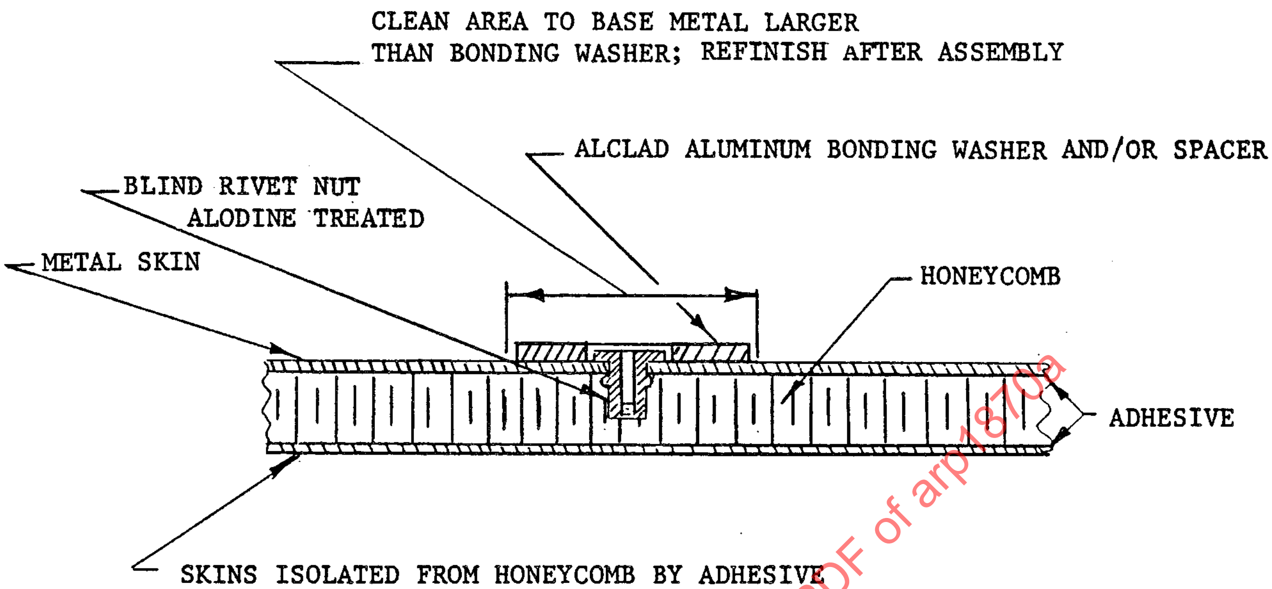


FIGURE 12 - Typical Bonding Tab to Structure



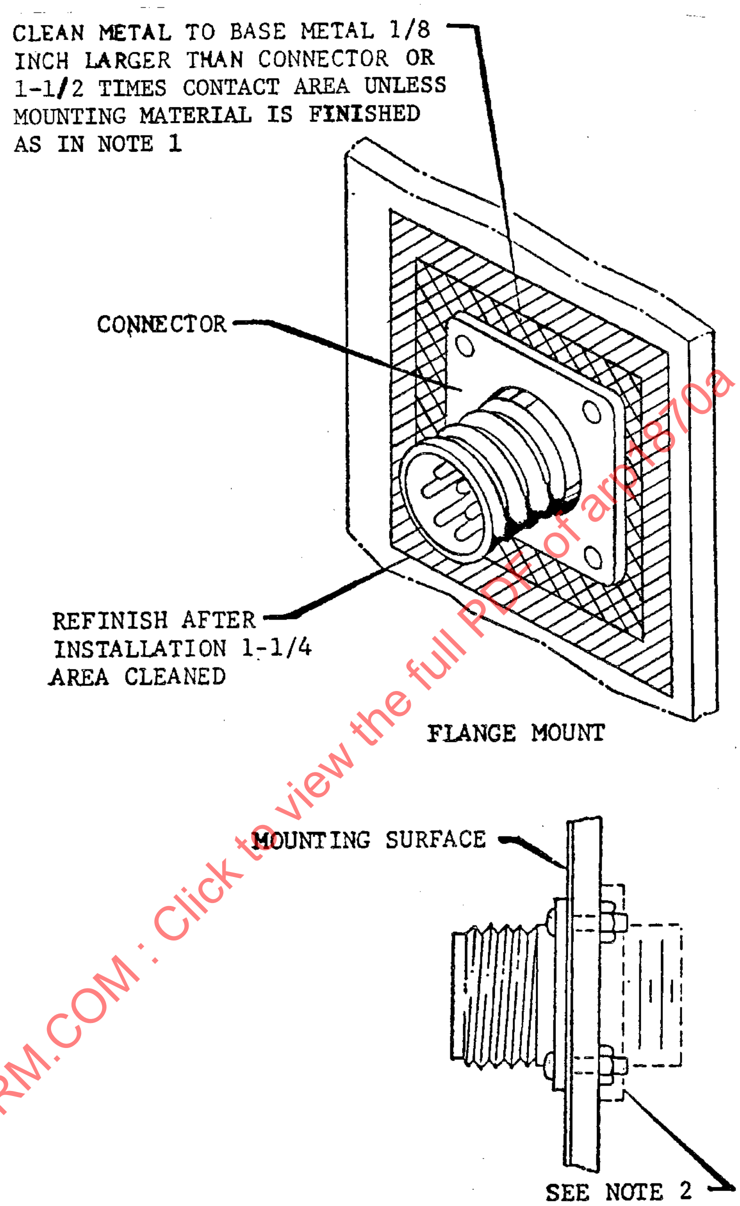
NOTES:
1. Bond assemblies isolated by nonconducting faying strips to the substructure with rivets or steel bolts.
2. Metal details which are completely shielded by other metal parts will not require electrical bonding.
3. All rivet holes shall be drilled and rivets installed after metal bonding adhesives are cured.
4. Use a minimum of three rivets for any one connection.

FIGURE 13 - Typical Electrical Bonding of Details Which are Electrically Isolated by Adhesives



NOTE: The bonding washer shall be used with all RIV-NUT installations when electrical bonding is required.

FIGURE 14 - Typical Bonding When Blind Rivet Unit is Used for Special Applications



NOTES:

1. ALUMINUM SURFACE MATING WITH CONNECTOR SHALL BE CLEANED AND REFINISHED IN ACCORDANCE WITH ORIGINAL FINISH SPECIFICATION
2. THIS METHOD OF BONDING IS APPLICABLE FOR FLANGE OR JAM-NUT MOUNTED CONNECTORS
3. APPLICABLE WHEN CONNECTOR SHELL HAS CONDUCTIVE FINISH

FIGURE 15 - Methods of Bonding Connectors to Attaching Part

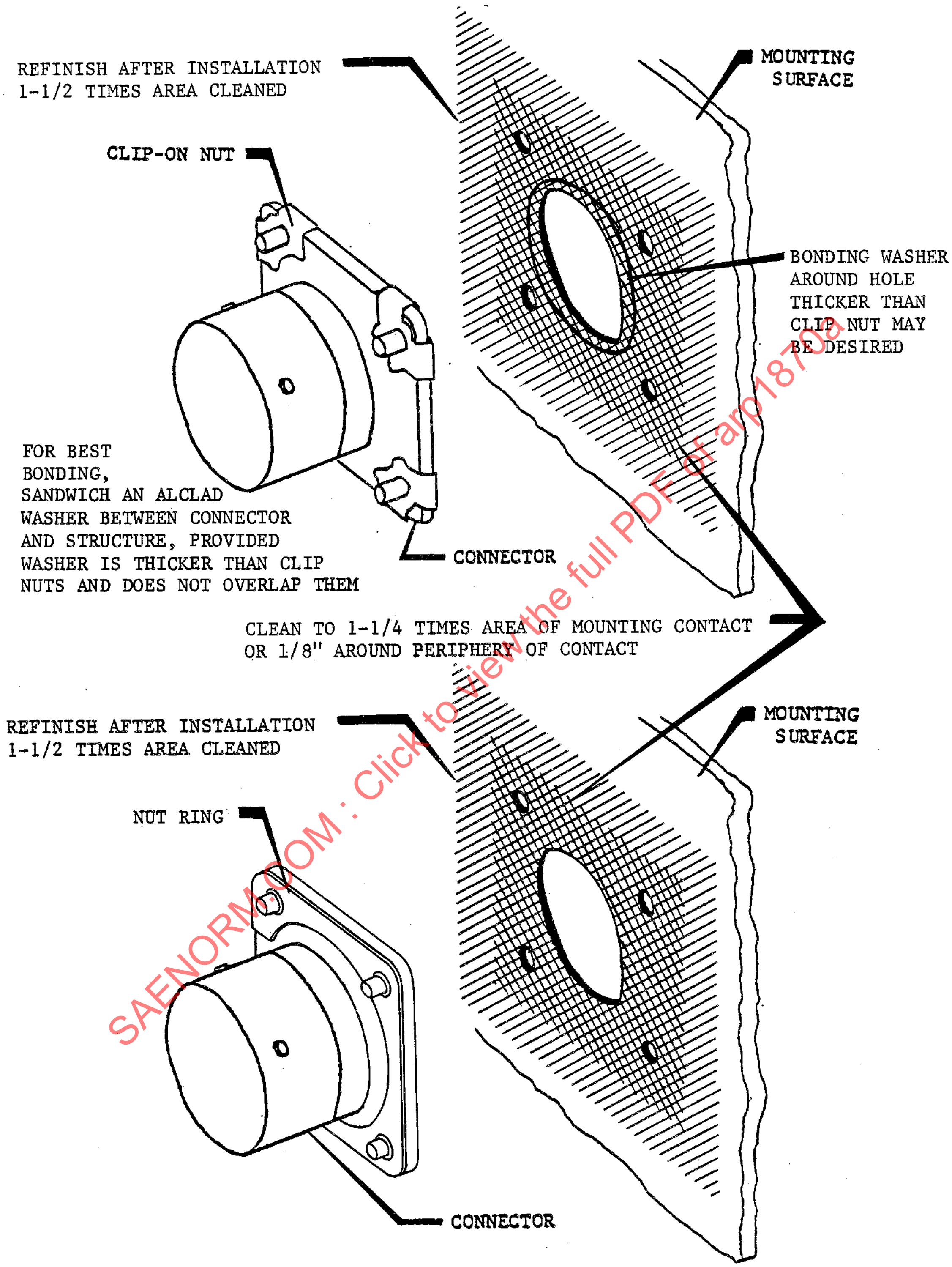


FIGURE 16 - Methods of Bonding Connectors to Attaching Part

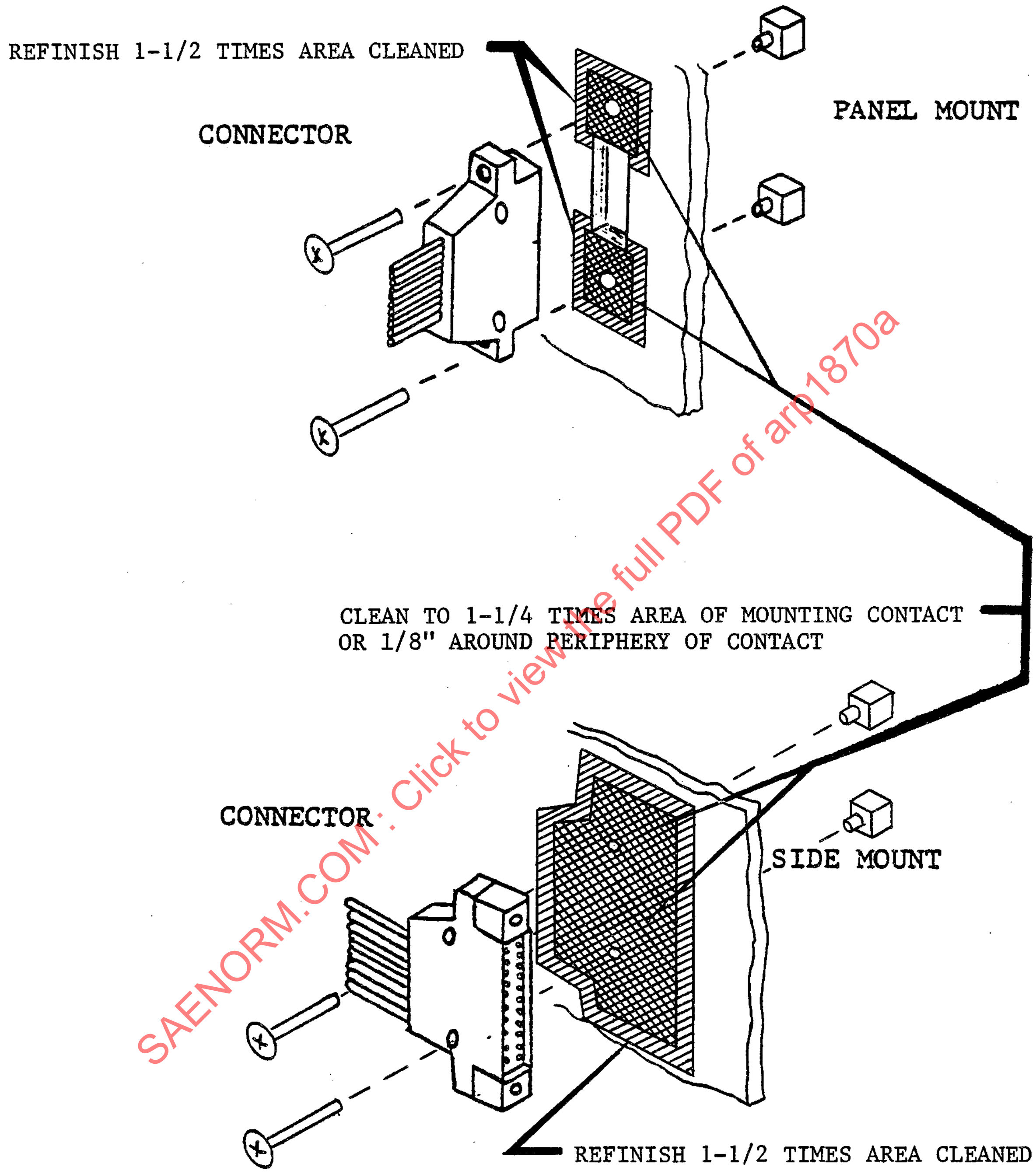
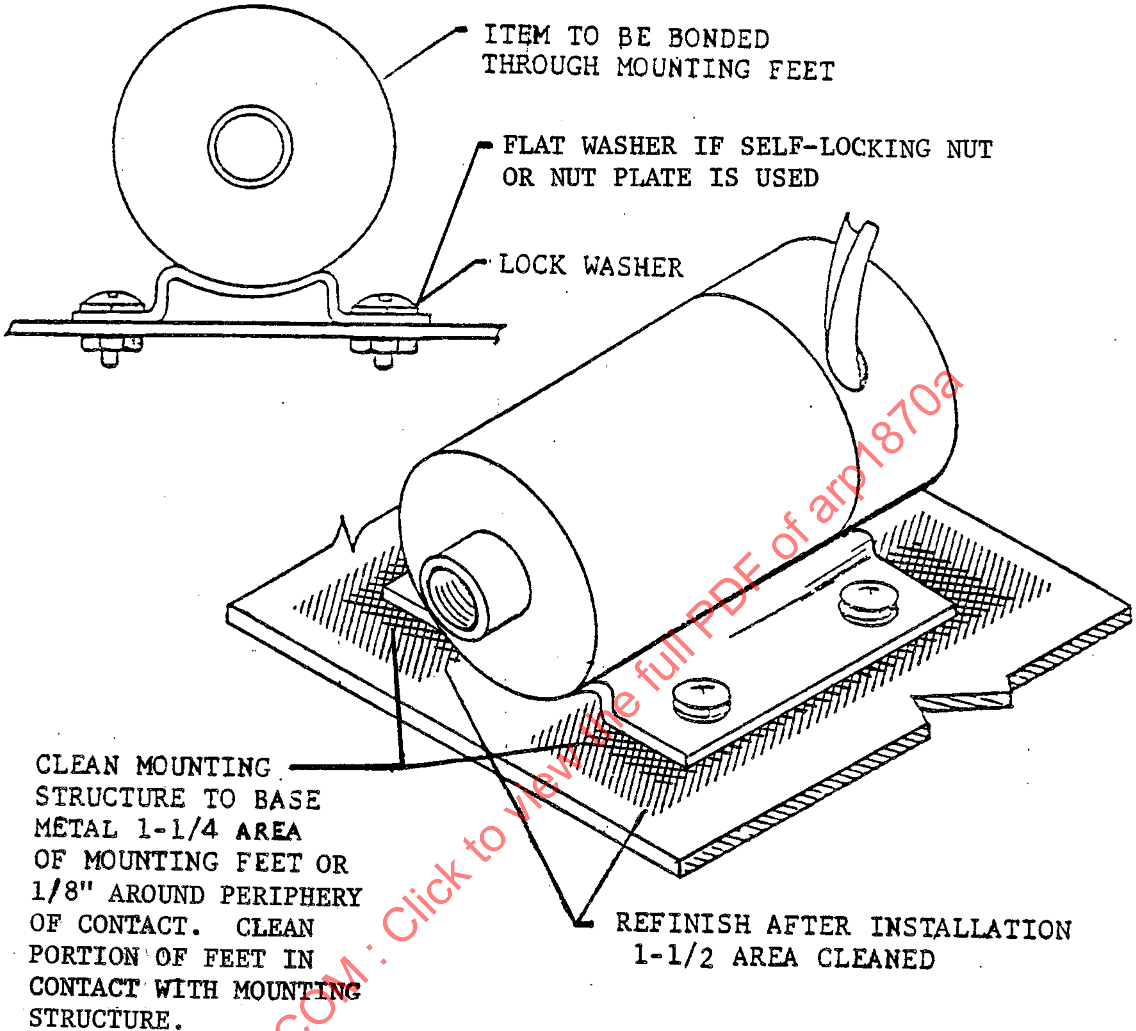
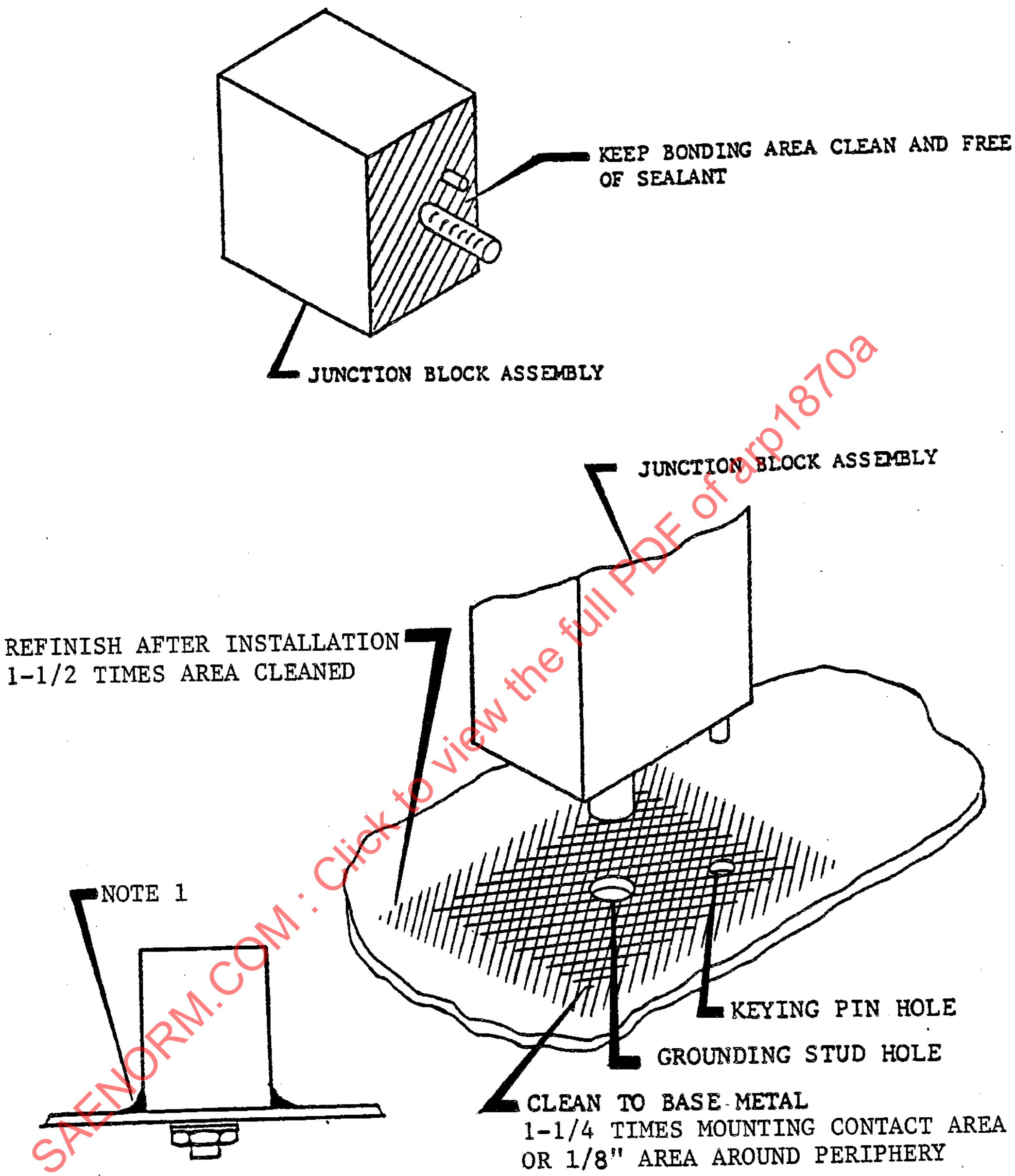


FIGURE 17 - Methods of Bonding Metal Connectors to Attaching Part



NOTE: ON ITEMS THAT HAVE THE BOLTS SPACED MORE THAN 6 INCHES APART, IT IS ONLY NECESSARY TO CLEAN THE AREA 2 INCHES ON EACH SIDE OF THE ATTACH BOLTS OR SCREWS.

FIGURE 18 - Method of Bonding Equipment Installed on Vehicle Structure With Mounting Feet



NOTE: SEALANT REQUIRED IN EXTERIOR COMPARTMENTS

FIGURE 19 - Electrical Bonding of Junction Block Assemblies to Attaching Part

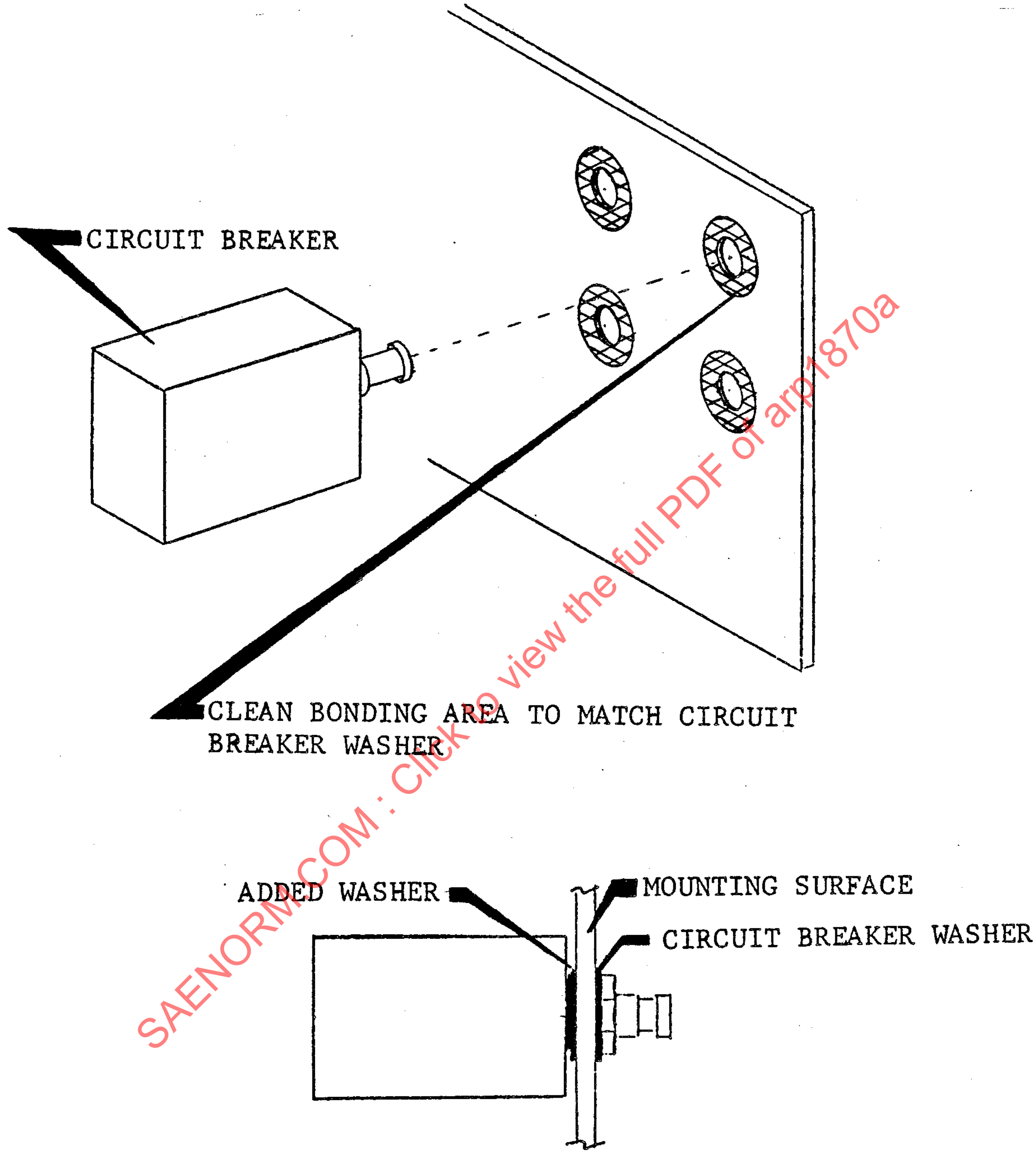
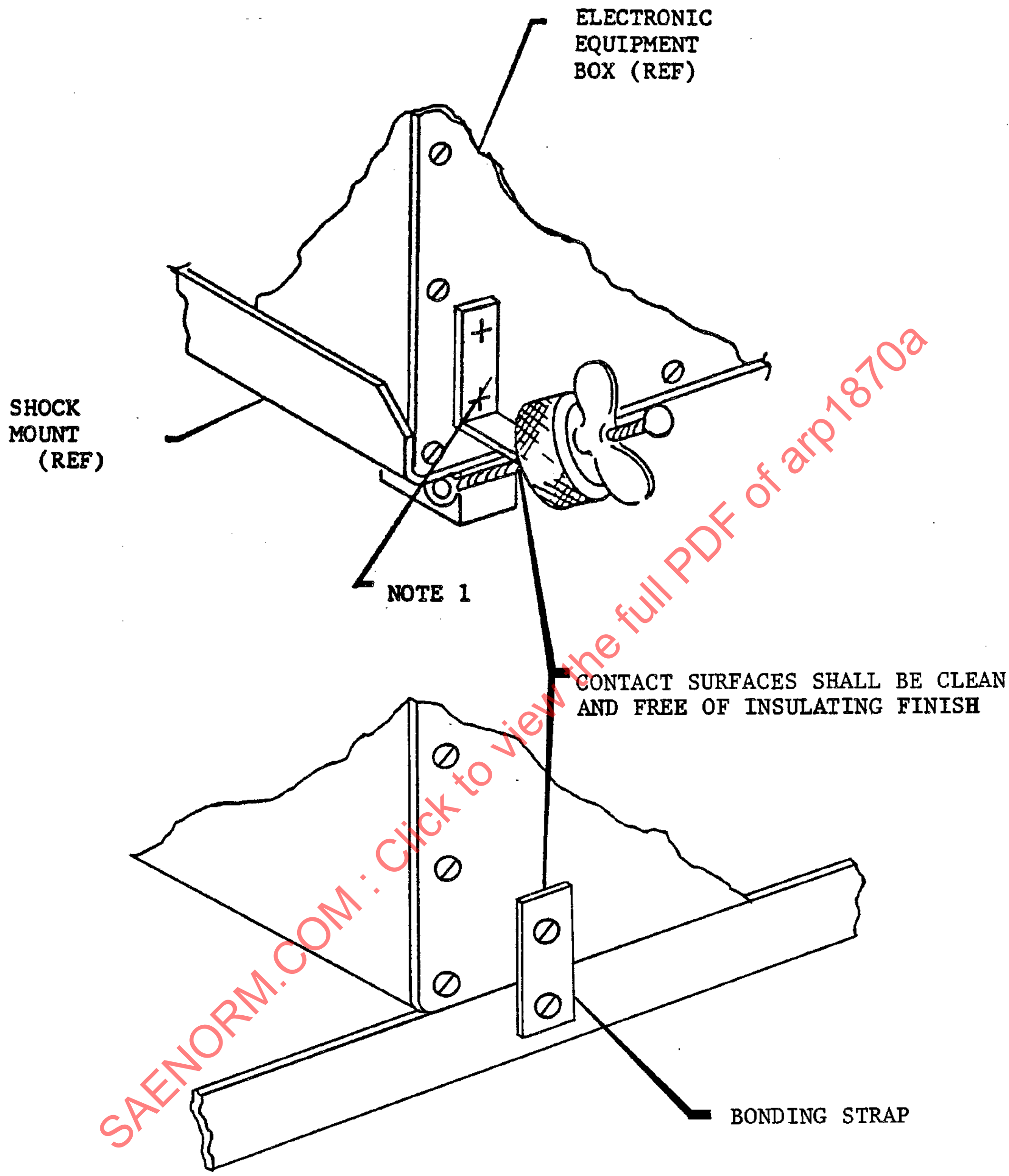


FIGURE 20 - Method of Bonding Circuit Breakers to Circuit Breaker Panel



NOTE: THIS METHOD OF BONDING IS APPLICABLE WHERE THE EQUIPMENT CASE IS NOT DESIGNED TO BOND THROUGH METAL-TO-METAL CONTACT WITH THE MOUNTING BASE.

FIGURE 21 - Methods of Bonding Electronic Equipment to Mount Through Front Attachments When No Other Method is Possible