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DEPARTMENT OF DEFENSE
HANDBOOK

ELECTRICAL GROUNDING
FOR AIRCRAFT SAFETY

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FOREWORD

1. This handbook is approved for use by the Department of the Navy and is available for use by all Departments and Agencies of the Department of Defense.

2. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.

3. This handbook has been prepared to provide U.S. Navy and Marine Corps personnel with the background and technical details of the different types of aircraft grounds and how they are applied. Information related to construction of facility radio frequency (RF) grounds, lightning grounds, power safety grounds, and sensitive equipment grounds are addressed in the Naval Facilities Engineering Command (NAVFAC) Unified Facilities Criteria (UFC), "Static Electricity and Lightning Protection Systems."

4. Comments, suggestions, or questions on this document should be addressed to : Naval Air Systems Command (Commander, Naval Air Warfare Center Aircraft Division, Code 4L8000B120-3, Highway 547, Lakehurst, NJ 08733-5100) or emailed to Michael.Sikora@navy.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at: https://assist.daps.dla.mil/online/start/.

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1. SCOPE

1.1 Purpose. This handbook has been prepared to provide U.S. Navy and Marine Corps aircraft maintenance and operations personnel with the background and technical details of the different types of aircraft grounds and how they are applied. In addition, this handbook provides background information for aircraft grounding, static electricity theory and how it affects aircraft, and techniques used for measurement of grounding points. This handbook is intended for use by all U.S. Navy and Marine Corps aircraft maintenance and operations personnel for the purposes of ensuring that aircraft are properly and safely grounded. This handbook is for guidance only and cannot be cited as a requirement.

1.2 Background. The philosophical position and technical information presented in this handbook are based upon results of a previous naval study documented in NAVAIR Report AIR-5181-1000, "Airframe Electrical Grounding Requirements Program Final Report." That study demonstrated that hazards exist during aircraft maintenance and established that there are valid technical reasons to ground aircraft. It also recognized that a rigorous grounding philosophy is necessary to maximize personnel and aircraft safety. Aircraft grounding methods presented in this handbook describe procedures for static grounding of aircraft during all maintenance actions including fueling/de-fueling and ordnance loading or unloading evolutions. The procedures in this handbook apply to both fixed wing and rotary wing aircraft. The grounding methods presented in this handbook make a clear distinction between static grounding and power grounding. Information related to construction of facility radio frequency (RF) grounds, lightning grounds, power safety grounds, and sensitive equipment grounds are addressed in the Naval Facilities Engineering Command (NAVFAC) UFC 3-570-01,Unified Facilities Criteria (UFC) document titled, "Static Electricity and Lightning Protection Systems."

1.3 Structure. This handbook provides guidance on grounding for safety of personnel, aircraft and aircraft equipment. It may also be used for guidance to verify facility ground points.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-83413	-	Connectors and Assemblies, Electrical, Aircraft Grounding, General Specification for
MIL-DTL-83413/4	-	Connectors and Assemblies, Electrical, Aircraft Grounding: Plugs, for Types I and II Grounding Assemblies
MIL-DTL-83413/7	-	Connectors and Assemblies, Electrical, Aircraft Grounding: Grounding Clamp for Types I and III Grounding Assemblies, Clip, Electrical

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-464	-	Electromagnetic Environmental Effects Requirements for Systems

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-235-1	-	Military Operational Electromagnetic Environment Profiles Part 1C General Guidance

(Copies of these documents are available online at https://assist.daps.dla.mil/quicksearch/ or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.2.2 Other Government documents, drawings and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

NAVAL AIR SYSTEMS COMMAND

NAVAIR 00-80T-96	-	U.S. Navy Support Equipment, Basic Handling and Safety Manual
NAVAIR 00-80T-109	-	Aircraft Refueling NATOPS Manual
NAVAIR 00-80T-122	-	Helicopter Operational Procedures for Air-Capable Ships NATOPS Manual
NAVAIR AIR-5181-1000	-	Airframe Electrical Grounding Requirements Program Final Report
NAVFAC TS-02614	-	Joints, Reinforcement, and Mooring Eyes Concrete Pavement

(Copies of these documents are available online at https://mynatec.navair.navy.mil/ or from the NAVAIR Scientific and Technical Library, Building 407, 22269 Cedar Point Road, Patuxent River, MD 20670.)

NAVAL SEA SYSTEMS COMMAND

NAVSEA OP 4	-	Ammunition and Explosives Safety Afloat
NAVSEA OP 5	-	Ammunition and Explosives Safety Ashore

(Copies of these documents are available from the Naval Ordnance Safety and Security Activity online at: https://nossa.nmci.navy.mil/nrws3/Programs/ExplosivesSafetyOperations/Library/CurrentPublications.aspx.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI C63.14-1992	-	American National Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD)

(Copies of these documents are available from http://webstore.ansi.org or American National Standards Institute, 1899 L Street NW, 11th Floor, Washington, DC 20036.)

SAE INTERNATIONAL

SAE-AS25486	-	Connector, Plug, Attachable, External Electric Power, Aircraft, 115/200 Volt, 400 Hertz
SAE-AS25487	-	Connector, Plug, Attachable External Electric Power, Aircraft, 28 Volt DC, Jet Starting
SAE-AS25488	-	Connector, Plug, Attachable External Electric Power, Aircraft, 28 Volt DC, Operating Power

(Copies of these documents are available from http://standards.sae.org or SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001.)

3. DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

3.1 Definitions. For the purpose of this handbook, the following definitions apply. In addition to the terms below, many terms used in this handbook are defined in ANSI C63.14, JCS Pub. 1-02, DoDD 3222.3, DoDI 4650.01, or the DoD 5000 series of documents.

Bond. Any fixed union between two surfaces that result in electrical conductivity between the surfaces. The union occurs either from physical contact between conductive surfaces of the surfaces or from the addition of a firm electrical connection between them. For refueling/defueling purposes the bond is the conductive contact between the refueling apparatus and the aircraft.

Breech. The rear part of the bore of a gun, especially the opening and associated mechanism that permits insertion of a projectile.

Coulomb (C). The charge transported by a steady 1 ampere current in 1 second.

Fibrillation. Fibrillation is the rapid, irregular, and unsynchronized contraction of muscle fibers. An important occurrence is with the heart.

Friction. A force on objects or substances in contact with each other that resists motion of the objects or substances relative to each other.

Induced Charge. Induced charge is one that accumulates on an object when immersed in an electric field.

Lightning Grounds. Lightning grounds are grounds that have resistances lower than 1 ohm and frequently on the order of 2.5 milliohms or less. In, addition lightning grounds must be more robust than Static/ESD grounds so that they may conduct extremely high lightning-induced currents on the order of several thousands of amperes.

Ohm's Law. Ohm's Law states that the current through a conductor between two points is directly proportional to the potential difference (voltage) across the two points, and inversely proportional to the resistance between them.

Ordnance Ground. Ordnance grounds are static grounds typically found in magazines and ordnance handling areas.

Power Grounds. Power grounds are defined as those having resistances of less than 25 ohms referenced to the power system neutral. For further information on power grounds refer to individual system technical manuals and design documents, such as NAVFAC UFC 3-570-01.

Radio Frequency (RF) Grounds. RF grounds are grounds that protect systems from voltages and currents induced from internal system generated electromagnetic fields and from external electromagnetic fields.

Static Electricity. An accumulation of electric charge on an insulated body (See Section 4.2 for more detail).

Static/ESD Grounds. Static/electrostatic discharge (ESD) grounds are defined as those having resistances of less than 10,000 ohms referenced to Earth. Static/ESD grounds are used to dissipate or "bleed" accumulated charges from triboelectric action, particle impingement, or electric field inducement. This slow bleeding avoids arcing and sparking which may occur from high potential (voltage) electrostatic charges built-up between different electrical potential points. Static/ESD currents are typically on the order of microamperes (µA) but occur between points of several thousand volts difference in electrical potential.

Temporary Grounding. In areas where no static or power grounds exist, metal rods may be driven into the ground at points adjacent to the proposed aircraft parking position.

Triboelectric Effects**.** A type of contact electrification in which certain materials become electrically charged after they come into contact with another different material and are then separated (such as through rubbing). The polarity and strength of the charges produced differ according to the materials, surface roughness, temperature, strain, and other properties.

3.2 Acronyms and abbreviations.

µA	-	microampere
A	-	ampere
A/C	-	aircraft
AC	-	alternating current
ANSI	-	American National Standards Institute
C	-	Coulomb
DBA	-	Distribution Box Assembly
DC	-	Direct Current
DoD	-	Department of Defense
DoDD	-	Department of Defense Directive
DoDI	-	Department of Defense Instruction
EED	-	Electroexplosive Device
EID	-	Electrically Initiated Device
ESD	-	Electrostatic Discharge
FARP	-	Forward Arming and Refueling Point
FOD	-	Foreign Object Damage

Hz	-	Hertz
IAW	-	In accordance with
IEEE	-	Institute of Electrical and Electronics Engineers
J	-	joule
JSC	-	Joint Spectrum Center
kA	-	kiloampere
kV	-	kilivolt
kV/m	-	kilovolt per meter
ln	-	Natural logarithm
mA	-	milliampere
mΩ	-	milliohm
mV	-	millivolt
MΩ	-	Megohm
MATCALS		Marine Air Traffic Control and Landing System
MIM	-	Maintenance Instruction Manual
MV	-	Megavolt
NATEC	-	Naval Air Technical Data and Engineering Service Command
NATO	-	North Atlantic Treaty Organization
NATOPS	-	Naval Air Training and Operating Procedures Standardization
NAVAIR	-	Naval Air Systems Command
NAVFAC	-	Naval Facilities Engineering Command
NAVSEA	-	Naval Sea Systems Command
NFPA	-	National Fire Protection Association
NRL	-	Naval Research Laboratory
NSN	-	National Stock Number
P-Static	-	Precipitation Static
P/N	-	Part number
pF	-	Picofarad
Q	-	Electric charge in Coulombs
RF	-	Radio frequency
UFC	-	Unified Facilities Criteria
V	-	Volt
VAC	-	Voltage – Alternating Current
VDC	-	Voltage – Direct Current
VOM	-	Volt-Ohm-Meter

4. GENERAL GUIDANCE

4.1 Theoretical basis for aircraft grounding. This section provides theory, background, and information necessary to understand the rationale behind the guidelines for aircraft grounding and bonding. Theory and equations associated with both electrostatic charge generation in aircraft and grounding effects are discussed. This section also includes guidance related to triboelectric effects, fuel flow, induced charge, and friction. Hazards from ground power faults, RF energy, and lightning are presented. Descriptions of aircraft electrical parameters and a discussion of hazardous thresholds and the possible dangers they present to personnel and aircraft safety are present. The section also illustrates how proper grounding will reduce these hazards.

4.2 Electrostatic theory. Electrostatic theory is the study of accumulated electrical charges. Potential differences between these charges may measure thousands of volts. However, the flow of electricity during generation and accumulation is small, on the order of thousandths or millionths of an ampere (A). A primary manifestation of static electricity is the discharge or sparking of the accumulated charges. Static electricity charges are generated by the separation of like and unlike bodies. These charges become evident when the unlike bodies, having been in contact with each other, are separated. For significant potential to be developed, the bodies holding the charges will become, and remain, insulated from each other. Insulation may occur through complete physical separation of the bodies or because at least one of the bodies is an insulator.

4.3 Scenarios. Aircraft maintenance and ordnance handling evolutions are considered in this manual. Potential hazards considered during each scenario are:

a. Static electrical shock to personnel
b. Ordnance actuation or malfunction
c. Uncommanded ordnance or stores release
d. Damage or upset to electronic subsystems

4.4 Energy sources. Evaluation of a situation's potential hazards is based on the source mechanism and the source magnitude of the electrical energy. With operations involving aircraft such as stores handling, maintenance, fueling, and aircraft parking, the following energy sources need to be considered:

a. Static
- (1) Triboelectric
- (2) Induced Static Charge
- (3) Friction

b. Power
(1) Ground Fault
(2) RF Electromagnetic Energy
(3) Lightning

4.4.1 Static energy sources. The static sources listed in 4.4 are defined and evaluated in the following paragraphs.

4.4.1.1 Triboelectric effects. These are generally associated with buildup of static charges on an aircraft in flight. High static voltages, however, can result from interaction at the contact surfaces of various materials in any type of relative motion, for example, wind-blown snow or dust particles striking a parked aircraft. A conservative estimate of electrical current in a moderate wind-blown dust situation is 30 microamperes (μA). This type of static electricity is also called Precipitation Static or P-Static. Connecting the aircraft frame to a static ground point provides a conductive path back to ground for the static charges as they are generated. A static ground point is defined as a ground point having less than 10,000 ohms resistance to Earth.

4.4.1.1.1 Triboelectric effects example. A helicopter exemplifies triboelectric effects. Static voltages in excess of 1,000 volts (V) are normally generated by a hovering helicopter. Personnel must use extreme care when approaching a hovering aircraft. Strict observance of the prescribed aircraft manual procedure will prevent the serious injury certain to occur if the aircraft is touched prior to grounding.

4.4.1.1.2 Wind-blown dust storm. A conservative estimate of electrical current for a moderate wind-blown dust situation is 30 μA. In an ungrounded aircraft, this current flows from Earth to the snow, dust, etc., via the tires and airframe. Thus, the potential between airframe and Earth is determined almost entirely by the tire resistance. A worst-case value of 40 megohms (MΩ) for tire resistance is used to compute an airframe potential of:

Equation: (1)

$$V = I \cdot R$$
$$= (30\ \mu A)\ (40\ M\Omega) = 1{,}200\ V$$

Where:
V = potential between the airframe and Earth
I = current from the airplane to Earth
R = resistance from the airframe to Earth

(For further information on precipitation static refer to the MIL-STD-464.)

4.4.1.1.2.1 Charge accumulation. Wind-blown dust storm charges will accumulate until a sufficient time to discharge them has passed or a person touches the aircraft. Twelve-hundred volts (1,200V) exceeds parameters for non-lethal shock to personnel and could cause a reflex action resulting in injury to personnel.

4.4.1.2 Induced static charge. Electrical storms involve the relatively slow movement of heavily charged clouds which set up an electrostatic field over a large area of the Earth's surface below the cloud. The presence of an electrical field between an active storm cloud system and the Earth results in large induced charges on parked aircraft. As shown on Figure 1, the negative charge in the cloud attracts a positive charge from the Earth onto the aircraft via the tires. This charging usually occurs at a relatively slow rate which results in relatively small current flows that cause no damage to the aircraft. If a person is in contact with the plane throughout the charging period, for example, as the charged cloud moves slowly overhead, he will probably feel no effect. If the storm cloud loses its negative charges either by a lightning discharge to another cloud or to some spot on the ground, or even if the storm cloud merely moves on, the electrostatic force of the negative charge holding the positive charge on the aircraft disappears. The positive charge on the aircraft will now return to ground via the tires. Should the tire resistance be high, the discharge time may be long. The positive charges are conducted from the ground up through the tires, building up charges of up to 60 kilovolts (kV) on the aircraft. These are called induced charges. Should a person now touch the aircraft and provide an alternate path to ground, the person will receive a shock which normally may do no more harm than to cause loss of balance, with perhaps a fall to the ground. However, on rare occasions the shock could be serious. If the cloud above suddenly discharges to another cloud, the charged aircraft immediately discharges back to ground via whatever path is available, this includes the person touching the aircraft. The person will now probably feel a sharp shock, the severity of which depends on the extent to which the aircraft was originally charged. It can be seen that if the aircraft were connected to a static ground point (less than 10,000 ohms), the positive charge would take this path of least resistance back to ground and thus provide protection to personnel working about the aircraft.

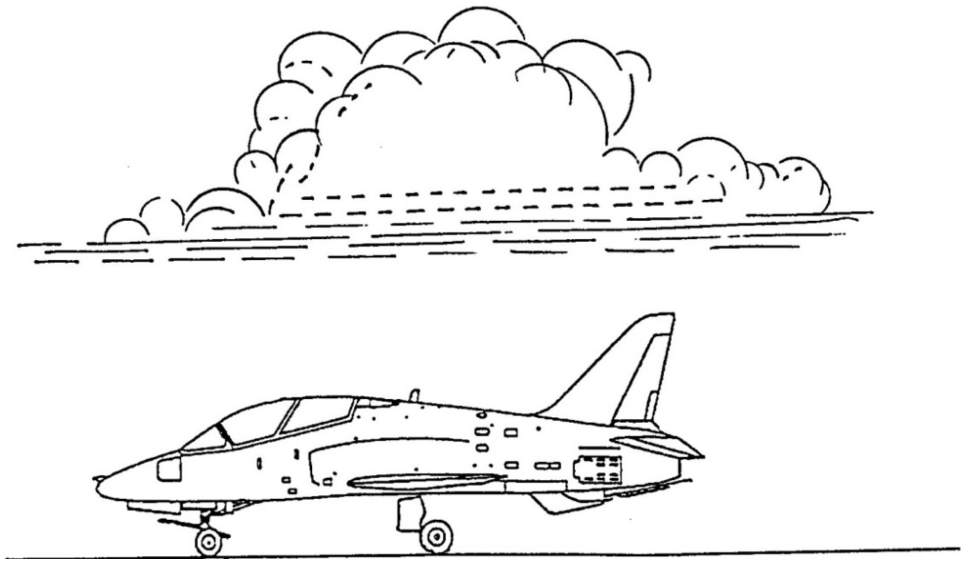


FIGURE 1. Cloud-inducing charge on aircraft.

4.4.1.2.1 Potential hazard. The situation becomes a potential hazard if a sudden change in the electric field takes place (for example, a distant lightning strike discharging the overhead cloud). The Earth's surface neutralizes more quickly than the ungrounded aircraft (due to the capacitance of the aircraft and the high resistance of the tires), resulting in potentials up to 60 kV from airframe to ground. A person in contact with the aircraft during this change in the electrical field acts as a resistor connected to ground, facilitating another path to ground for the accumulated charges (see Figure 2). This person will probably feel a sharp shock, the severity of which will depend on the extent to which the aircraft was originally charged. The current shock can result in injury to personnel in two different ways:

a. Reflex movements. The current shock can cause involuntary reflex movements that can cause fatal or serious injury due to secondary effects, such as falling.

b. Electrical effects. The current shock can cause electrical effects that result directly in injury.

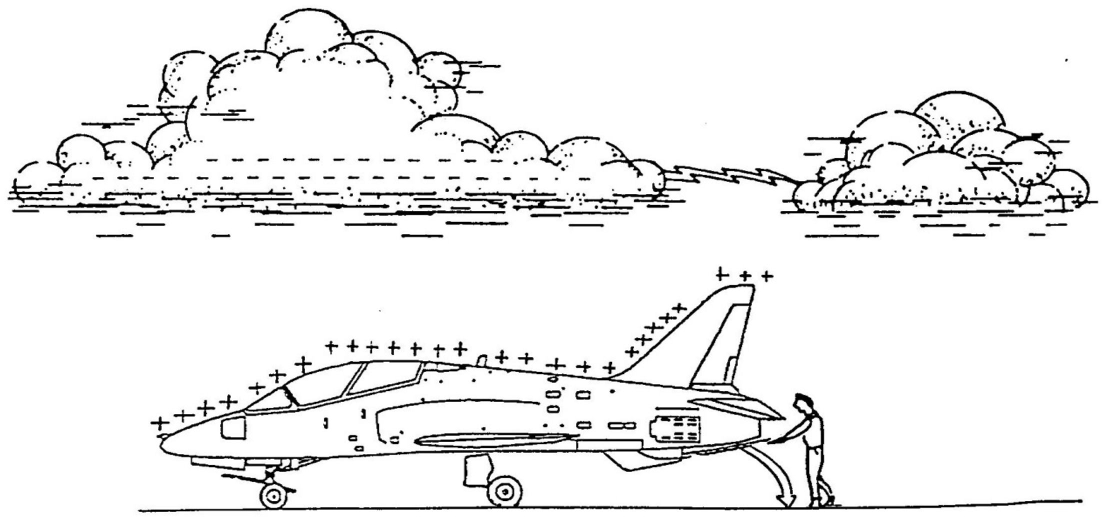


FIGURE 2. Possible return path for accumulated charge during remote discharge of clouds.

4.4.1.2.2 Personal contact. A person in contact with an aircraft charged by induction to 60 kV could discharge 9 Joules (J) of energy from the aircraft.

Equation: (2)

$$U = \tfrac{1}{2} C \cdot V^2$$
$$= \tfrac{1}{2} (0.005\mu F) \cdot (60\ kV)^2$$
$$= 9J$$

Where:

C = aircraft capacitance to ground (microfarads)
V = voltage from aircraft to ground (volts)
U = energy level (Joules)

This level well exceeds the threshold value for lethal shock and could be fatal. To further analyze potential hazards the following equations are used:

Equation: (3)

$$t = R \cdot C \cdot \ln\left(\frac{E_i}{E_s}\right)$$

Where:

t = time to reach E_s after removal of source (seconds)
R = aircraft resistance to ground (Ω)
C = aircraft capacitance to ground (F)
E_i = initial (source) voltage (V)
E_s = safe voltage level (V)
ln = natural log

Using the ungrounded aircraft resistance of 40 MΩ an aircraft capacitance to ground of 0.005 µF, a safe voltage limit of less than 30 V, and 60 kV as the initial voltage:

Equation: (4)

$$t = (40\ \text{M}\Omega) \cdot (0.005\ \mu\text{f}) \cdot \ln\left(\frac{60\ \text{kV}}{30\ \text{V}}\right)$$

$$= 1.52 \text{ seconds}$$

Heart discoordination (fibrillation) threshold levels have time durations as low as 0.2 second, a fact that makes the 1.52 second discharge time very dangerous and unacceptable.

4.4.1.3 Friction. Static electricity is generated when certain materials rub together. During such close moving contact between two materials, one of the materials is depleted of electrons, causing a surplus in the second. The magnitude of the static electrical charge thus produced depends on the materials involved and on the amount of humidity present during such friction. With synthetic materials (such as nylon) undergoing friction in a cold dry climate, the effect is greater. Voltages as high as 27 kV have been recorded in some instances. Because of hazards presented by such high charges, personnel subjected to such conditions should bring themselves to the same voltage potential as the aircraft and weapon system. Since the risk of generating static electricity is increased in a dry atmosphere, such risk is decreased in a damp, highly humid atmosphere which inhibits the accumulation of static electrical charges. Moisture in the air or on the skin provides a conductive path for the positive and negative charges to be rejoined, neutralizing the static charges. To further protect against the effects of friction, it is essential that the aircraft be grounded. Static electricity is generated when certain materials rub together.

4.4.1.3.1 Static charges on clothing. Static electrical charges are generated on clothing by friction, especially by the action of removing garments. Since clothing is frequently of synthetic materials, which amplifies the effects of friction, personnel should exercise extreme caution in areas where hazardous conditions may be present. The removal of clothing therefore, should be prohibited, especially in dry climates, during fueling and ordnance operations. The buildup of static electrical charges can be minimized by use of cotton clothing and antistatic powders.

4.4.1.3.2 Charge generated by fuel movement. The friction generated in fueling an aircraft, with passage of fuel from the supply vehicle through the filter separator and fueling hose to the aircraft, generates high electrical charges. Charge separation and consequent buildup of electrostatic charges occur between the moving fuel and fuel filters, hoses, and other surfaces. Since fuel is normally an excellent insulator, separated charges are easily removed by the flowing fuel to a distant location. If no electrically conductive return path is available, the charge accumulates on metallic surfaces and is a high potential energy source. With the continued accumulation of charge, sufficient electrical potential is generated to cause an arc across insulating barriers. These voltages build up within the aircraft fuel tank and are a serious danger. If these voltages were to arc over to points of lower potential with the right fuel-air vapor mixture present, an explosion would occur. Bonding the aircraft frame to the fuel supply vehicle provides a means of dissipating these high voltages. Bonding does not prevent generation of high voltages within hoses or tanks, but provides a return path for the accumulated charges as contact is made with the inside fuel tank surface.

4.4.1.3.3 Garments. Static electricity is generated on clothing by friction, especially by the action of removing garments. There is also a continuous generation of charges in the garments of a moving clothed person. The total amounts of charge at any time will depend on the rate of charge production and the rate of charge decay. If a person rubs against external objects, charges can be produced on the outside of the garments, otherwise, the charges will be produced within the clothing system as shown on Figure 3.

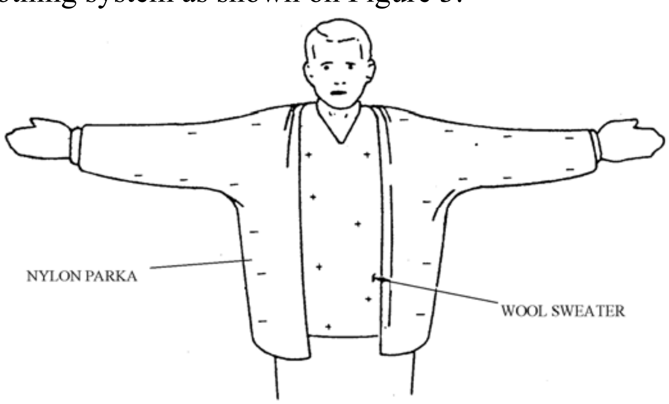


FIGURE 3. Charge accumulation on clothing.

4.4.1.3.3.1 Charge accumulation. It is generally considered that all parts of the skin are sufficiently moist to allow only negligible amounts of charge to be formed between the skin and the garment next to the skin. Provided the person does not remove any garments, the only effect of the charged clothing can be to cause an attraction between the layers (since opposite charges attract) or for the clothing to cling to the body.

4.4.1.3.3.2 Removal of outer garments. If a person removes their nylon parka, a charge of up to 27 kV can reside on the outside surface of the newly exposed wool sweater. The positive charge on the wool sweater and the negative charge on the parka are developed due to static effects. The opposite charges on the sweater and parka may produce a spark from one to the other.

4.4.1.3.3.3 Worst-case friction static electricity. The 27 kV value is used herein as representative of the worst-case friction static electricity hazard levels produced by servicing personnel. Using Equation 2, $U = \frac{1}{2} C \cdot V^2$, with C= 500 pF for body capacitance, the amount of available energy is 0.18 J or 180 mJ. This is above the threshold levels for fuel vapor ignition, component damage, electroexplosive device (EED) ignition, and reflex action shock as discussed further in 4.7 and shown in Table IV.

4.4.1.4 Static Summary. Various sources of static electricity, such as triboelectric, induced charge and friction have been discussed. In general, direct effects of static electricity are not serious, although such shocks can cause involuntary reflex movements resulting in injury to the affected person or others nearby. On the other hand, sparks generated in the vicinity of a fueling operation can have disastrous results. Catastrophic results can occur from discharge of static electricity into a squib, cartridge, or EED. Care in ensuring that the aircraft, weapon system, fueling system, and personnel are kept at ground potential will minimize the dangerous effects of static electricity. A ground of up to 10,000 ohms is considered an adequate safety measure.

4.4.2 Power. Various types of electrical power such as 115 volts alternating current (VAC) and 28 volts direct current (VDC), ground faults, lightning, and RF electromagnetic energy are discussed in the following paragraphs. The term power used in this context assumes electric current flow measurable in amperes, in contrast to static electricity whose current flow, typically, is in the range of thousandths (0.001) of an ampere. The current generated by ground faults, lightning, or RF energy sources can be substantial.

4.4.2.1 Operational power. During aircraft flight, all electric power required by onboard equipment is supplied by generators driven by the aircraft engines. Two basic types of electrical voltage are used: 28 VDC and 115 VAC, at 400 Hertz (Hz). The 28 VDC system is a two-wire system, positive and negative, with the negative side of the system connected to the aircraft structure. The 115 VAC is a four-wire system consisting of phases A, B, C, and neutral (N), with the neutral wire connected to the aircraft structure. Equipment using AC power may use either single phase power consisting of neutral and phase A, B, or C, or 3-phase power which requires phases A, B, C, and N.

4.4.2.1.1 Mobile electric power plants. When the aircraft is on the ground, it is not practical to run the engines for electrical power, so the required AC and DC power is supplied by generators external to the aircraft. These sources may be mobile or fixed. The mobile sources are called Mobile Electric Power Plants (MEPPs). Following are a few examples:

Use	Model	Type	Outputs
Ship	NC-2A	Engine-driven, self-propelled	115/200 VAC, 400 Hz, 30 kVA, 28 VDC, 500A
Ship	A/S37A-3	Mobile Electric Power Plant, self-propelled	115 VAC, 3-phase, 400 Hz, 28 VDC
Flight Line	NC-8A	Engine-driven, self-propelled	115/200 VAC, 400 Hz, 60 kVA, 28 VDC, 500A
Flight Line	NC-10A/B/C	Engine-driven, self-propelled	115/200 VAC, 400 Hz, 90 kVA, 28VDC, 750 A
Hangar	MMG-1A	Electric motor-driven	115/200 VAC, 400 Hz, trailer-mounted, 60 kVA, 28VDC, 500 A
Hangar	MMG-2	Electric motor-driven	115/200 VAC, 400 Hz, trailer-mounted, 30 kVA, 28VDC, 500 A
Land-based	PU-820/T	Diesel Generator Set	35 kW, 120/208 VAC, 60 Hz, 3-phase

A complete listing of MEPPs, together with a description of each model can be found at the Naval Air Technical Data and Engineering Service Command (NATEC).

4.4.2.1.2 Alternative external electric power. The AC and DC generators are diesel engine-driven and are mounted on a self-propelled chassis on rubber tires. The AC neutral (N) and DC negative wires are both connected to the chassis. In this configuration, the supply cables provided with the MEPP are about 30 feet (ft) long. The AC and DC connector plugs are non-government standard fittings which mate with most aircraft. Alternative equipment used to provide external electric power is:

a. MMG-1. This is an electric motor-driven MEPP, normally used inside hangars. The electric motor input is 220/440 VAC, 3-phase, 60 Hz. The input power includes a safety ground line which is connected to the MEPP chassis. The generator output neutral is also connected to the MEPP chassis. Both engine-driven and motor-driven MEPPS are bonded to the aircraft, independent of the power cable neutral or negative. Neither MEPP is independently grounded.

b. Flight line electrical distribution system (FLEDS). This system is installed on shore station aprons. AC power is provided to the system by a MEPP located at a central location. The AC neutral line is connected to ground at the point of entry to the FLED and at the remote ends. Distribution boxes assemblies (DBA) are provided at intervals throughout the system, each containing circuit breakers, overload relays, and service cables to supply two aircraft. The distribution cables are protected from taxiing aircraft by a metal ramp.

c. Deck edge power. This is a similar system to the FLEDS except for being installed aboard an aircraft carrier. The 115 VAC, 400 Hz generator is driven by an electric motor fed from the 220/440 VAC, 3-phase, 60 Hz, three-wire delta system. Aboard ship, the 3-phase, 60 Hz system is not grounded.

4.4.2.1.3 Deck Edge Power Connector. The 115 VAC, 3-phase, 400-Hz power is fed to the aircraft via a standard connector. This connector (SAE-AS25486) has six connections, A, B, C, and N for the 3-phase AC, and E and F for control purposes only. The manner in which E and F are connected varies from aircraft to aircraft. The 28 VDC supply is fed to the aircraft by a separate 3-pin connector. The connector is designed in accordance with SAE-AS25487 or SAE-AS25488. In each case, two pins are for 28 VDC positive and negative, with the third pin for aircraft control purposes.

4.4.2.2 Ground fault. Prior to mating the power connectors to the aircraft, be sure that the aircraft is connected to a power ground. The purpose of this is to provide protection against a ground power fault for all personnel working on or about the aircraft. Occasionally, a fault may occur in the electrical supply system, probably at the supply connector, that results in the neutral line becoming disconnected from the aircraft and a phase line contacting the aircraft structure. In this condition, the aircraft skin is said to become "hot," with about 115V AC potential with respect to ground. If the aircraft is not connected to ground, a person standing on the ground who touches the aircraft could receive a lethal shock. It is accepted that electrical voltage in excess of 45 VDC or 30 VAC can give lethal shocks to humans. This is based on a body resistance of 1,500 ohms and lethal current levels of 30 mA DC or 20 mA AC.

4.4.2.2.1 Predominant fault mode. Since the predominant fault mode concerns the external power supply connector, one cannot rely on the neutral connection to the aircraft to provide a fault return circuit to activate the overload trip. For that reason, it is necessary to bond the aircraft to the external electrical power source, for example, the MEPP or FLEDS DBAs. In the case of deck edge power, this has already been done when the aircraft is grounded to the ship's deck. Usually, the power required to activate the overload circuit is very high, well in excess of 100 amperes. It is possible that the total resistance in the bond circuit will be high enough to restrict the current flow and thus prevent activation of the overload circuit. In this case, the bond strap between aircraft and the MEPP might become hot and cause the wire to overheat. A "smoking" ground or bond wire is often the first indication of an electrical circuit problem and requires that external electrical power be shut off immediately. In the case of the engine-driven MEPP, the aircraft is grounded to a static ground. This ground also serves to ground the MEPP via the external bond wire and, under normal circumstances, the AC neutral wire. It is then not necessary to independently ground the engine-driven MEPP.

4.4.2.2.2 Engine-driven MEPP problem. The engine-driven MEPP provides a different problem. The MEPP engine is connected to the 220/440 VAC, 60 Hz main system. A 60 Hz supply cable includes a safety ground wire connected directly to the MEPP chassis. When an aircraft is connected to an engine-driven MEPP, it is not uncommon for 115 VAC, 60 Hz powered equipment to be used on or about the aircraft. It then becomes essential that should a fault occur in any of the 60 Hz powered equipment, including the MEPP engine, that the aircraft be grounded to a low resistance point of less than 25 ohms which is connected to the 60 Hz power source ground system.

4.4.2.2.3 Aircraft serviced in hangar. For aircraft being serviced inside a hangar this presents no problem, as all aircraft are routinely connected to low resistance points connected to the 60 Hz power ground. For aircraft parked on an apron and fed by an engine-driven generator, it may be difficult to locate a power ground of less than 25 ohms, but every effort should be made to meet this requirement. It should be noted that 25 ohms is not a low enough resistance to provide adequate short circuit protection at all times against power ground faults, when the airframe may be at a 115 VAC potential. The 25-ohm value was chosen as a practical, obtainable value to provide reasonable safety and an adequate airframe system ground.
A 25-ohm ground resistance will not provide enough fault current to trip a 50-amp circuit breaker, nor will it cause a grounding cable to burn; in fact, there may be no indication of a power system fault. The wire may get too warm to touch if a ground fault exists.

4.4.2.2.4 Defective cables. Since many electrical problems are caused by defective cable plugs, it is imperative that cable plugs be carefully and frequently examined for bare or broken wires, or other damage prior to connection to the aircraft. It is also extremely important that the cable and connector be thoroughly checked and tested after repair and before being returned to service. The U.S. Navy Support Equipment, Basic Handling and Safety Manual, NAVAIR 00-80T-96, paragraph 3-3200, addresses the hazards of electric shock associated with defective electrical cables and connectors.

4.4.2.2.5 Deck edge power. Deck edge power supplied by the ship's electrical system is not grounded to the ship's structure. The neutral of the 3-phase power is not tied to the ship's structure and therefore the system represents a floating neutral power source.

4.4.2.3 RF electromagnetic energy. Today's environment has many unintended side effects caused by radio frequency transmitting devices used in conjunction with naval flight operations. Of concern are those high power communication and radar transmitters that may be located near parked aircraft. The best example of this situation is the aircraft carrier flight deck, which probably contains the highest concentration of transmitted RF energy to be found on any base from which aircraft operate. Although high power communication and radar transmitters may be found at greater distances from parked aircraft at a shore station, an aircraft may be affected by any adjacent aircraft whose onboard communication system or radar transmitters are being tested. Aircraft aboard ship could be similarly affected.

4.4.2.3.1 Amount of RF energy. The principal problem is the amount of RF energy induced into the aircraft frame and circulating on the aircraft skin. This quantity or level of RF energy is greatly affected by the position of the aircraft relative to a particular RF transmitter, the power output of the transmitter and the actual frequency of the RF energy being transmitted. It is further affected by the actual location of any connections between aircraft and ground (deck). Where position of one ground may have a significant effect on induced current, other ground connections from different locations on the aircraft to other locations on the deck may not have the same effect. Any existing aircraft grounding scheme should not be altered in an effort to provide the aircraft with additional protection against RF energy. If the ground connection is broken while the RF transmission is in progress, an electric arc may be drawn. This is an important fact to note. If an arc is produced while disconnecting a ground, the source may be RF energy, caused by a local transmitter and the current flow can be high. (A power line short circuit to ground may also produce an arc when the ground is disconnected.) If, on the other hand, an arc is drawn while a ground is being attached to the aircraft, the source is static electricity and the current flow will be light.

4.4.2.3.2 RF energy protection. Since there is limited protection from transmitted RF energy, it is necessary that personnel ensure that no operations are conducted without observation of all recommended procedures. For instance, a fuel hose nozzle should always be bonded to the aircraft before the filling cap is removed and the hose nozzle inserted into the fuel tank. Conversely, the filling cap should be replaced before the bond is disconnected from the aircraft. These procedures will ensure that no RF arcs are inadvertently produced in a hazardous atmosphere while the fuel tank cap is removed.

4.4.2.3.3 Induced RF energy. Naval aircraft encounter high powered communication and radar transmitters in their operating environments. Of most concern are those which may be located near parked aircraft, for example, on the carrier flight deck, which probably contains the highest concentration of transmitted RF energy to be found on any aircraft operating base. Transmitters onboard adjacent aircraft may have interfering effects also. The principal problem is the amount of RF energy that is induced into the aircraft frame and circulating on the aircraft skin. This quantity or level of RF energy is greatly affected by the position of the aircraft relative to a particular RF transmitter, the power output of that transmitter, and the actual frequency of the RF energy being transmitted. It is further affected by the actual location of any connections between the aircraft and ground (deck). Where the position of one ground may have a significant effect on the induced currents, other ground connections from different locations on the aircraft to other locations on the deck may not have the same effect. Any existing aircraft grounding scheme should not be altered in an effort to provide the aircraft with additional protection against RF energy. If the ground connection is broken while the RF transmission is in progress, an electric arc may be drawn. This is an important fact to note. If an arc is produced while disconnecting a ground, the source may be RF energy, caused by a local transmitter and the current flow can be high. A power line short circuit to ground may also produce an arc when the ground is disconnected. Additional guidance on electromagnetic energy effects can be found in MIL-HDBK-235-1 and MIL-STD-464.

4.4.2.3.4 RF arcing. RF arcing is not limited to aircraft. In high RF fields, arcs generally occur at the discontinuities in conductors (conductor meaning any metal surface). A discontinuity is any place where the nature of the conductor changes. Examples include gaps between metal surfaces and places where the type of metal changes or the thickness of the metal changes. Another factor that has an influence on the occurrence of RF arcing is the actual physical dimensions of the metal surface. Not all conductors within an RF field are susceptible to arcing at their discontinuities. Objects that are large with respect to a wavelength (several wavelengths in each direction perpendicular to the line of transmission) tend to reflect RF energy and are less apt to produce arcing. Objects that are long in one dimension but not in the other tend to be a more favorable site for arcing.

4.4.2.3.4.1 RF arcing categories. RF arcing can be separated into two categories: RF glow discharges and RF arc discharges. In RF glow discharges, a high minimum voltage is necessary to maintain the discharge. The voltage rises to an ignition voltage of 350 V to 500 V, and then decreases slightly after the current flow begins. The current flow ceases when the field can no longer sustain the high voltage. Even at very small separations between elements, a minimum voltage of 275 V is necessary to sustain the glow. Conversely, RF arc discharges are sustained at relatively low voltages. The events leading to the formation of the arc discharge are similar to those of glow discharge. However, once the arc forms, the voltage can usually drop to as low as 30 V without the arc extinguishing.

4.4.2.4 Lightning. Lightning is a discharge of atmospheric electricity from one cloud to another, within a cloud, or from a cloud to Earth. Table I provides a listing of lightning characteristics. The cloud to Earth or ground strike is the type of discharge that produces the direct lightning strike. Due to its large amount of energy and potential for destruction, the direct lightning strike is one source of energy that can be very dangerous to personnel and aircraft. A direct lightning strike can damage an aircraft and its equipment. Voltages as high as 100 MV and currents to 650 kiloamperes (kA) have been known to occur. When a charge of sufficient magnitude builds up in a cloud, preliminary breakdown occurs and a stepped leader is initiated. As the stepped leader nears the Earth, upward-moving discharges may be produced from local high points that are at or near ground potential. For this reason, the tail of an exposed aircraft often provides the primary attachment point for a stepped leader. As the leader completes its path to Earth, a return stroke is generated. The currents in return strokes typically reach levels of 20 kA, with peaks of up to 650 kA recorded. During the life of an aircraft, it may be struck many times by lightning, but only on rare occasions is significant damage sustained. Little can be done to prevent a lightning strike to an aircraft parked on a concrete/asphalt apron outside a hangar. A low resistance ground will reduce the amount of time needed to bleed-off the induced charge due to nearby lightning, and reduce the chance of side-flashes. Of course, no ground will totally protect personnel working on the exterior of an aircraft near an electrical storm. If weather conditions are such that lightning strikes are imminent, all operations involving refueling, ordnance handling, or maintenance should be suspended. These high levels could puncture the aircraft if the skin is not sufficiently thick or could possibly cause structural damage or localized melting. Damage to the aircraft's electronic equipment or ignition of the fuel tank could also occur, depending on the location of the strike. A person in contact with the ungrounded aircraft during a direct lightning strike risks severe injury or death. For personnel who wear communication headsets the probability of occurrence and the severity of injury increases.

TABLE I. Lightning characteristics.

Characteristic	Specification
Types	Intra/Inter Cloud Cloud-to-Ground
Potential	Positive or Negative 30 – 100 MV
Current	Up to 650 kA (peak)
Power	10^{12} W nominal (peak)
Energy	5 X 10^{8} J nominal (200 lb TNT equivalent per strike
Extent	3-30 km per strike (path is predominantly horizontal)
Spectrum	Peak energy near 10 kHz, some above 10 MHz
Duration	Strike – 100 µs Flash 0.2 second (1- 20 strikes)

4.4.2.4.1 Typical discharge. A typical discharge between cloud and ground starts in the cloud and eventually neutralizes tens of coulombs (C) of negative cloud charges. The total discharge is called a flash and lasts less than ½ second. A flash is made up of various discharge components, among which an average of three or four high-current pulses occur, called strokes, and a possible continuing current stage. In the idealized models, electrical storms cause the clouds to acquire a negative charge. The Earth, or in this case the aircraft, has an opposite charge and lightning occurs when the electric field in the vicinity of the charge center of the cloud builds up to the point where the air starts to ionize.

4.4.2.4.2 Cloud breakdown. The breakdown within the cloud produces what is called a stepped leader. The leader starts from the cloud and heads toward the ground. The leader advances in a series of rapid discontinuous steps each about 50 meters (m) long and separated by pauses of about 50 µs. The luminous diameter of the stepped leader is between 1 and 10 meters (m), although it is thought that the leader current of about 100 amperes flows in a small diameter core at its center. The average propagation velocity is about 1 meter per second. It looks like a column of light with branches emanating from the sides. The electric potential of the leader channel with respect to the ground is about -l x 10^{8} V. As the leader tip nears ground or aircraft, the electric field beneath it becomes very large and causes one or more upward-moving discharges, which start the attachment process. When one of the upward-moving discharges from the ground contacts the downward-moving leader, the leader tip is connected to ground or aircraft potential. The leader channel is then discharged into the aircraft. The height of the aircraft affects the probability of this happening. The taller the aircraft the more likely it is to happen. Thus, by locally compressing the field, there are more likely to be points where the discharge takes place.

4.4.2.4.3 Cloud discharge. Intracloud and intercloud lightning discharges occur between positive and negative cloud charges and have total durations about equal to those of ground discharges (½ second). A typical cloud discharge neutralizes 10 to 30 coulombs of charge over a total path length of 5 to 10 km. Intracloud and intercloud discharges have not been studied as extensively as cloud discharges to ground, and hence much less is known about their detailed physical characteristics. The charge motion for intracloud and intercloud discharges produces electric fields whose frequency spectra have roughly the same amplitude distribution as electric fields produced by cloud-to-ground discharges for frequencies below about 1 kHz and above 100 kHz. Between 1 and 100 kHz, the ground discharge is a more efficient radiator. Energy levels of near strikes can be sufficiently high to damage electronic equipment, again, depending on the location of the strike. Distant lightning strikes and lightning from one cloud to another will also charge an aircraft. Grounding will not keep these induced charges from accumulating on an aircraft, but will reduce the amount of time needed to bleed off the charge.

4.4.2.4.4 Current waveform parameters. The most important parameters of the current waveform are peak current, rate of rise, total duration, charge transferred, and action integral (see 4.4.2.3.6). The units of action integral are ampere-seconds, which may alternatively be expressed in units of joules per ohm since the action integral is proportional to the energy dissipated in a given resistance (see Figures 4 and 5).

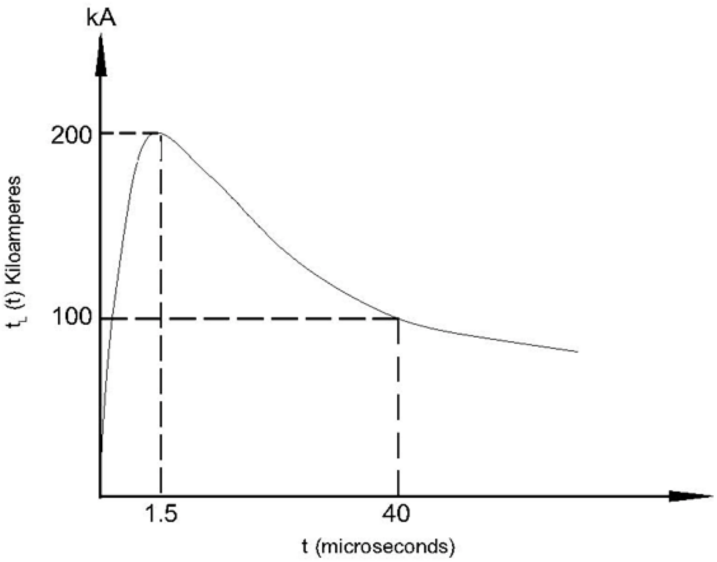


FIGURE 4. Lightning current pulse, time domain.

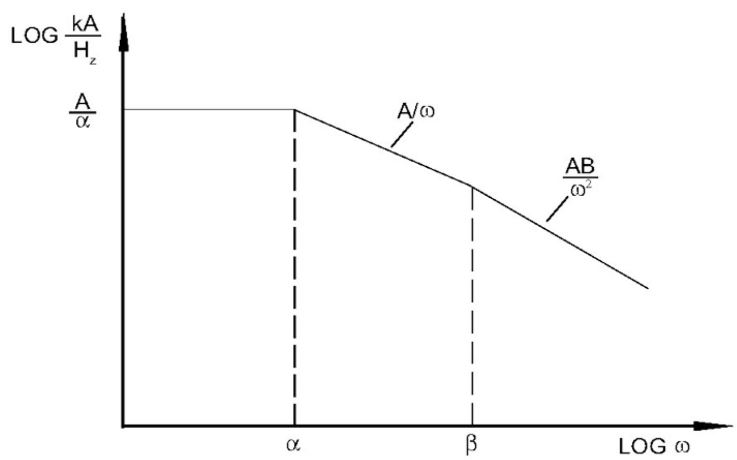


FIGURE 5. Lightning current pulse, frequency domain.

4.4.2.4.5 Charge transfer. The charge transfer, Q, is defined as the integral of the time-varying current over its entire duration, or:

Equation: (5)

$$Q = \int_{o}^{t} i\,dt \text{ (Ampere - seconds)}$$

Where:

Q = charge in coulombs
t = time in seconds
i = current in amperes

4.4.2.4.6 Action integral. The action integral of a current waveform is a measure of the ability of the current to deliver energy and is defined as the integral of the square of the time-varying current over its entire duration.

$$\int_{o}^{t} i^2\,dt \text{ (ampere}^2\text{-seconds)}$$

Where:

t = time in seconds
i = current in amperes

4.4.2.4.7 Aircraft grounding. Grounding an aircraft offers some protection against the effects of lightning, even a direct strike. A major direct lightning strike usually is preceded by less powerful leaders that determine the direction of the main strike. Grounds can control the direction of the leaders away from the tires and consequently control the direction of the main strike. In addition, if a direct strike occurs, the ground wire may vaporize contributing to the conductivity of the ionized path, and thereby minimize leakage currents through nearby personnel.

4.4.2.4.8 Lightning discharge through aircraft. Lightning discharge through an aircraft to Earth is an extremely variable phenomenon. Lightning voltages as high as 100 MV and currents up to 650 kA are cited in literature. At such high levels, grounding will not afford the degree of protection or confidence factor attained for static electric protection. Nevertheless, a safety ground will aid in protecting personnel and equipment to some extent, especially for the lower energy strikes.

4.4.3 Summary. In summary, the levels of electrostatic and power electrical energy sources considered are given in Table II.

TABLE II. Summary of electrical energy sources.

Source	Levels	
	Voltage	Current
Triboelectric	-	30 μA
Induced charge	60 kV	-
Friction	27 kV	-
RF induced	No established value	No established value
Lightning	100 MV	650 kA

4.5 Airframe/personnel electrical parameters**.** When energy sources are considered in terms of voltage or current, the electrical characteristics, for example, tire resistance to ground and airframe capacitance to ground are used to establish time duration and other parametric relationships. Airframe electrical parameters interact with charge generation mechanisms and thereby establish the actual hazard levels and time duration for these hazards. Airframe capacitance to Earth and airframe resistance to Earth are most relevant. Capacitance establishes the total charge stored due to a particular potential and the time factor needed to dissipate the charge from a surface through a particular resistance. Resistance establishes the voltage associated with known current flows and the time factor for charge reduction when the capacitance is known. Resistance was found to be the more variable parameter.

4.5.1 Electrostatic charge storage. The ability of a body to store electrostatic charge is determined by the capacitance of that body. The amount of charge that can be stored in a capacitor is expressed by the equation:

Equation: (6)

$$Q = C \cdot V$$

Where:

Q = amount of charge (in Coulombs)
C = capacitance of the body (in Farads)
V = voltage (in Volts) developed between the plates of the capacitor

The electrical resistance, R (in ohms), determines the rate at which the capacitor charges or discharges.

4.5.2 Electrical properties of aircraft. Aircraft in their normal environment have electrical properties similar to resistors and capacitors. Tires, mooring chains, or static ground straps usually determine the resistance.

4.5.3 Aircraft resistance. Aircraft resistance is affected by both the resistances of its tires and the runway surface, and by the contact between the tires and the surface. Tire resistance is a highly variable parameter. As a tire wears, its resistance increases due to the breaking of the carbon black chains.

4.5.4 Aircraft tire resistance. The load on the aircraft and the pressure of the tire affect the resistance of the aircraft by affecting the tires' contact with ground. Increasing tire pressure increases resistance, and increasing load decreases resistance. Laboratory measurements have indicated tire resistances as high as 3,400 MΩ.

4.5.5 Runway material. Finally, the material of the runway is a factor in the resistance of the aircraft to the ground. Dry asphalt has an exceedingly high resistance, while snow and water on surfaces decrease the resistance. Field measurements have measured total aircraft resistance to ground as high as 40 MΩ.

4.5.6 Aircraft capacitance. The capacitance of aircraft was found to be a consistent parameter. Values of 0.002 to 0.005 μF were measured over a wide range of aircraft types and ground plane materials.

4.5.7 Human body electric parameters. In addition to the characteristics of the aircraft, the values of human body electrical parameters are needed. Values of 500 pF capacitance and 50 to 1,500 ohms resistance are representative values for descriptive/discussion purposes. The pertinent electrical characteristics are summarized in Table III.

TABLE III. Electrical parameters.

Characteristic	Range of values
Aircraft capacitance	0.001 to 0.005 μF
Aircraft resistance	1.0 kΩ to 40 MΩ
Body capacitance	500 pF
Body resistance	50 to 1,500 Ω

4.5.8 Aircraft or capacitor discharge. The rate at which a capacitor or an aircraft discharges is determined by its time constant and is given by the equation:

Equation: (7)

$$t = R \cdot C$$

Where:

t = time in seconds
R = resistance of airframe to ground in ohms
C = capacitance of aircraft in Farads

A capacitor can be assumed to be completely discharged after five time constants or 5t. Aircraft capacitance is a fixed quantity under a particular parked configuration. Therefore, in order to reduce the discharge time, the resistance should be reduced. Aircraft tires measured in the field have resistances as high as 40 MΩ. Aircraft capacitance values have been measured as high as 0.005 µF. Using equation (7):

$$t = R \cdot C$$
$$t = (40 \times 10^{6}) \cdot (0.005 \times 10^{-6})$$
$$t = 0.2 \text{ second}$$
$$5t = 1 \text{ second}$$

4.5.9 Discoordination threshold levels. Discoordination threshold levels of the human heart action have time durations as low as 0.2 second. Thus, 1 second for the aircraft to discharge is unacceptably long. If, for example, a maximum resistance of 10,000 ohms is considered, the same calculation yields a capacitance discharge time of 0.25 ms. This is well below the 0.2 second critical value. Therefore, it is necessary to reduce aircraft-to-ground resistance by grounding the aircraft, thus bypassing the aircraft tires and mooring chains.

4.6 Damage threshold levels. The third variable needed for analysis is the threshold for injury or damage due to electrical effects.

4.6.1 Ordnance. A current level greater than 15 percent of the maximum no-fire value is the potential danger level during ordnance handling. The ignition of EEDs in various actuating mechanisms is the most common danger area.

4.6.2 Sources of injury from shock. There are two possible sources of injury to personnel from shock:

a. Involuntary reflex movements. Involuntary reflex movements may occur, which can result in injury due to secondary effects, such as falling.

b. Direct injuries. Electrical effects may result directly in injury.

4.6.3 Range for reflex actions. Reflex action appears in the area of 10 to 30 mJ (1 to 3 mA across 10,000 ohms); a representative voltage is approximately 50 V (30 mJ and 1,500 ohms). The threshold level for potentially lethal shock was established at 30 VAC and 45 VDC at energy levels of 600 mJ AC and 1.35 J DC, assuming a body resistance of 1,500 ohms.

4.6.4 Equipment damage level. The threshold level for equipment damage is a function of dielectric breakdown (high-voltage effect), high temperature damage (high-power effect), or a combination of both. One mJ can cause upset when directly injected into sensitive circuits. However, since direct injection is unlikely, a coupling factor of approximately 1/10 is assumed to establish a minimum threshold of 10 mJ for the practical lower limit of sensitive equipment upset. Damage levels are taken as 35 mJ, comparable with ordnance thresholds.

4.6.5 Summary of damage threshold levels. In summary, the levels of electrostatic and electrical energies considered are tabulated in Table IV.

4.7 Analysis. The basic purpose of the material in 4.5 through 4.6.5 has been to establish the data which verify or disprove the hypothesis that an electrical hazard exists and grounding will eliminate or reduce this hazard. The first hypothesis (hazard exists) is assessed by a comparison of energy source levels with hazard threshold levels and scenario particulars. The second hypothesis (grounding reduces hazard) is assessed by considering the extent to which application of an electrical ground alters the available energy, location of discharge, or duration of hazard. The results of the analysis are summarized in 4.7.3 following the detailed analysis in 4.7.1 through 4.7.2.2.

TABLE IV. Summary of hazard threshold levels.

Action	Electrical energy
Reflex action shock	10 mJ, 50 V
Shock to personnel power	600 mJ AC or 32 VAC or 3 mA 1.35 J DC or 45 VDC or 3 mA
Ordnance	
EED ignition	35 mJ
Component damage	35 mJ
Component upset	10 mJ

4.7.1 Source magnitude and hazard threshold level. The magnitude of potential energy sources is compared with hazard threshold levels to identify those combinations that could result in a hazard.

4.7.1.1 Worst-case scenario for current level. An upper boundary of 30 µA has been described as a worst-case scenario of a static triboelectric energy source. Since in an ungrounded aircraft this current flows from Earth, through the aircraft tire resistances to the airframe, and thence to the snow, dust, etc., causing the effect, the potential between airframe and Earth is determined almost entirely by the tire resistance. While laboratory measurements of tire resistance well over 100 MΩ have been made, the worst-case measured value of 40 MΩ obtained in the field, is used here to compute airframe potential utilizing equation (1):

$$V = I \cdot R = (30\ \mu A) \cdot (40\ M\Omega) = 1{,}200V$$

Where:

V = potential in Volts from the airframe to ground
I = triboelectric current in amperes
R = resistance in ohms from the airframe to ground

Using equation (2) and a value of C = 0.005 µF, the energy level (U), could reach 3.6 mJ.

$$U = \tfrac{1}{2}\, C \cdot V^2$$
$$= \tfrac{1}{2}\, (0.005\ \mu F) \cdot (1{,}200V)^2 = 3.6\ mJ$$

The values of U and V exceed the hazard threshold levels for fuel vapor ignition and non-lethal shock to personnel.

4.7.1.2 Worst case static voltage level. The value for the worst-case static voltage level for personnel is 27 kV. Energy levels produced by this voltage may range as high as 0.18 J or 180 mJ. Comparing this value with the hazard threshold values in Table IV shows that the thresholds for reflex action shock to personnel and ordnance EED ignition levels are exceeded. (For further information on P-Static refer to MIL-STD-464.)

4.7.1.3 Charge induced by storm activity. The source level has been established as due to charge induced by storm activity. Energy levels may then reach:

$$U = \tfrac{1}{2}\, C \cdot V^2$$
$$= \tfrac{1}{2}\, (0.005\ \mu F) \cdot (60\ kV)^2 = 9\ J$$

These levels exceed threshold values for all hazards.

4.7.2 Time duration consideration. Some of the phenomena cited above are transient in nature. Knowledge of their duration is necessary to assess them as realistic hazards. Induced voltages, friction voltages, and voltage buildups following fueling are considered transients.

4.7.2.1 Time calculation. Using the ungrounded aircraft resistance of 40 MΩ, an aircraft capacitance to ground of 0.005 µF, and a safe voltage limit of less than 30 V, the following time durations were computed using equation (3):

$$t = R \cdot C \cdot \ln \left(\frac{E_i}{E_s} \right)$$

Where:

- t = time to reach E_s after removal of source (seconds)
- R = aircraft resistance to ground (Ω)
- C = aircraft capacitance to ground (F)
- E_i = initial (source) voltage (V)
- E_s = safe voltage level (V)
- ln = natural log

Using the ungrounded aircraft resistance of 40MΩ, an aircraft capacitance to ground of 0.005 microfarad (µf), a safe voltage limit of less than 30V, and 60kV as the initial voltage,

$$t = (40\ \text{M}\Omega)(0.005\ \mu\text{f})\ \ln\left(\frac{60kV}{30\ V}\right)$$

$$t = 1.52\ \text{sec}$$

Heart discoordination (fibrillation) threshold levels have time durations as low as 0.2 second (s), a fact that makes the 1.52 second discharge time very dangerous and unacceptable.

4.7.2.2 Safety of transients. Any transient is objectionable from a safety standpoint. As stated earlier, heart action discoordination (fibrillation) threshold levels have time durations as low as 0.2 second. Thus, the duration of even the shortest of the three transients considered is unacceptably long.

4.7.3 Hazards. Ungrounded aircraft should be considered to be in jeopardy from the indicated energy source, since at least one (and generally more than one) hazard threshold level is exceeded during each scenario. These results are summarized in Table V. The possibility of these hazardous events occurring is ensured by the physical data available. However, each is dependent on a number of factors that may occur simultaneously. In any single one-time event, such as an aircraft ordnance evolutions, consideration could be given to the fact that hazardous combinations appear so seldom that they may be neglected. However, when consideration is given to the number of naval aircraft involved, the rapid tempo of operations, the fact that these are military operations (not always conducted under ideal conditions), the high cost of equipment, and the threat to personnel safety, electrical grounding becomes essential. Electrical airframe grounding, like safety belts in automobiles, is statistically indicated by, among other things, the vast numbers involved.

4.7.4 Effects of grounding. In each of the scenarios considered, the use of a proper ground connection ensures that the airframe is maintained at the same potential as the ground point for those sources considered, except in the case of external power systems. In addition, since the airframe resistance to ground is greatly reduced, the duration of such effects as induced voltages is reduced to fractions of a millisecond. As an additional advantage, the use of a proper grounding procedure ensures that any arcing or electrical discharge associated with the act of connecting grounds takes place at the ground point rather than near the airframe.

TABLE V. Potential hazard relationship to energy sources and scenarios.

Scenario	Energy Source				
	Triboelectric	Friction	Atmosphere induced fields	External power source	Lightning
Ordnance Handling	A	A,B,C	A,B,C	-	B,C
Parked	A	A,B,C	A,B,C	-	B,C

TABLE NOTES:
1. A = Static shock to personnel,
2. B = Ordnance EED/stores actuation/uncommanded release,
3. C = Electronic equipment damage.

5. DETAILED GUIDANCE

5.1 Testing and identification of ground points (ashore). This section provides guidance that should be used to measure resistance of the grounding system. It includes theoretical background, measurement equipment, measurement methods and procedures.

5.2 Theoretical background. The following figures illustrate the Three-Terminal Fall of Potential Method. Using Ohm’s Law, the Earth’s resistance can be determined using known values of voltage and current. With a 30 V source and a measurement current of 6 amperes, the resistance of the resistor is 5 ohms (see Figures 6 and 7). The Three-Terminal Fall of Potential Method should be used when measuring ground points on the apron. This includes certified power grounds, certified static grounds, mooring eyes, and FLEDS lightning protection grounds. (see Figures 8 and 9).

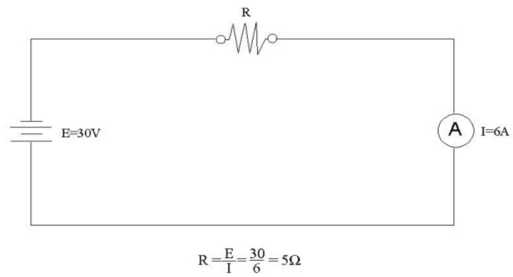


FIGURE 6. Simple electrical circuit utilizing Ohm's Law.

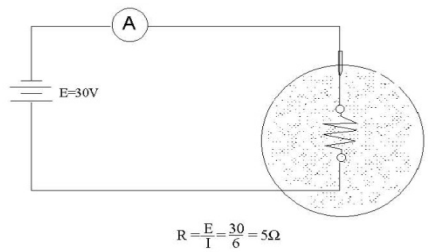


FIGURE 7. Illustration of Earth's resistance.

5.2.1 Earth's shell. Visualize a ground rod being surrounded by shells of Earth; all of equal thickness (see Figure 8). The Earth's shell closest to the rod has the greatest resistance due to the fact that it has the smallest surface area. Each successive shell has a larger area than the previous one and thus less resistance. Farther out, a point is reached where the inclusion of additional Earth shells have no significant effect on the resistance of the Earth surrounding the rod. Therefore, a measurement can be made (within a reasonable distance) between the ground rod and a test rod.

5.2.2 Measuring ground points. In measuring ground points, the measurement is taken of the resistance between the driven ground rod and the main body of the Earth. If a test connection could be made on the centerline of the Earth (see Figure 9), Ohm's law could again be applied to the circuit. Since such a connection is impractical, an alternate method should be used.

5.2.3 Resistance of the ground rod. In reality, the rod has a resistance (R_c) associated with it. To exclude this resistance from the measurement, a three-terminal test technique called the Three-Terminal Fall of Potential Method is used, as shown on Figure 9. The use of a potential probe enables a voltage measurement to be made across R. Using the meter reading for the current through R, we can compute the value of R using Ohm's law. The resistance of R_p is very high, a characteristic of all voltmeter probes.

5.3 Measurement equipment. The following measuring equipment has proven useful in measuring ground resistance in the past: Three-terminal Ground Resistance Tester, Transcat Order No. 8175E, Analog Display, 0.5-500 Ω Range and the Earth Testing Kit, Two or Three-Terminal, Transcat Catalog No. DET3TD, Digital Display, 0.01-199.9 Ω/0.001-19.9 Ω Range. Similar testers by other manufacturers that have equivalent characteristics may also be used. Volt-Ohm Meters (VOMs) have not proven suitable for this task, in past experience.

5.3.1 Null balance Earth tester. The null balance Earth tester includes batteries for its voltage source and an ohmmeter to measure the resistance directly. The tester generates an AC test current that is passed between the ground rod and the current rod. AC is used to eliminate errors due to existing direct currents and voltages that may be present in the Earth. The voltage drop at the potential rod is applied to a bridge circuit and nulled with a three-decade variable resistance. When at balance (no current flowing through the potential rod), the ground resistance is obtained from the readout of the digital decade switches. Although other equivalent meters may have different types of power supplies (such as hand-cranked generators) and different readout devices, the principles of operation are still the same.

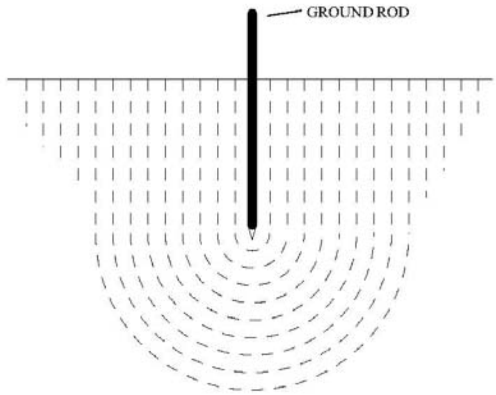


FIGURE 8. Illustration of Earth's shells.

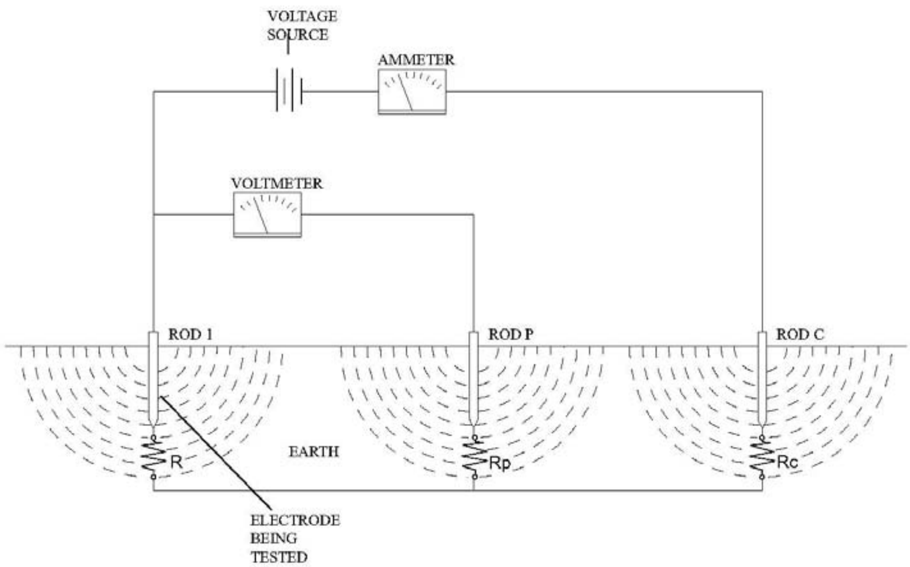


FIGURE 9. Three-terminal test technique.

5.4 Ground point measurement procedures. The three-terminal fall of potential method should be used when measuring ground points on the apron. This includes certified power grounds, certified static grounds, mooring eyes, and FLEDS lightning protection grounds. The two-terminal method should be used when measuring hangar ground points, the facility's AC neutral line, and in situations where the three-terminal method is impractical. A resistance value of less than 25 ohms is recommended for certified power grounds, FLEDS lightning protection grounds, hangar ground points, and the facility's AC neutral line. Certified static grounds and mooring eyes are recommended to be less than 10,000 ohms.

5.4.1 Three-terminal fall of potential method. The recommended test setup for performing the three-terminal fall of potential method is shown on Figure 10. This test is performed as follows:

a. Connect test lead I from the tester to the ground point being evaluated.

b. Drive a metal reference rod (rod C) into the ground at a distance of 100 feet (30.5m) from the ground point being evaluated. Connect test lead C from the tester to this rod.

c. Drive a metal rod (rod P) into the ground approximately 62 feet (18.9m) from the ground point being evaluated and in line with the reference rod (rod C) installed in step b above. Connect test lead P from the tester to this rod (rod P).

d. Adjust the resistance dials on the tester until the indicator dial is centered (zeroed) on the scale. When the dial is centered, the resistance value (in ohms) of the ground point being evaluated can be read directly on the tester's digital readout.

5.4.2 Two-terminal method (direct method). The test setup for performing the two-terminal method is shown on Figure 11. This test should be performed as follows:

a. Connect a jumper across the P and C terminals of the tester.

b. Connect test lead I from the tester to the ground point being evaluated.

c. Locate a large, unpainted, metal water pipe at least 100 feet (30.5m) from the ground point being evaluated and connect test lead C from the tester to this water pipe.

d. Adjust the resistance dials on the tester until the indicator dial is centered (zeroed) on the scale. When the dial is centered, the resistance value (in ohms) of the ground point being evaluated can be read on the tester's digital readout.

5.5 Schedule for resistance testing of ground points. Static, power, ordnance and lightning grounds should be checked every 24 months. Guidelines on this topic can be found in NAVSEA OP 5, Chapter 5.

5.6 Identification of ground points. It is recommended that ground points be identified in the manner indicated on Figure 12.

5.7 Use of mooring eyes as static ground points. Mooring eyes (also referred to as padeyes) may be used as static ground points provided that they have been identified and measured properly. Surveys (for example, NAVAIR Report AIR-5181-1000, "Airframe Electrical Grounding Requirements Program Final Report") have indicated that samplings of the resistance values of mooring eyes showed them to be under 10,000 ohms and therefore acceptable as static ground points. Mooring eyes selected for use as static grounds should have their resistance measured.

5.7.1 Mooring eye installation details. Figure 13 shows typical mooring eye installation details. Additional information is available in NAVFAC Technical Specification TS-02614. At some facilities a stainless steel bead has been welded to the upper exposed area of the mooring eye. This prevents corrosion buildup on the mooring eye and reduces its likelihood of providing a poor ground.

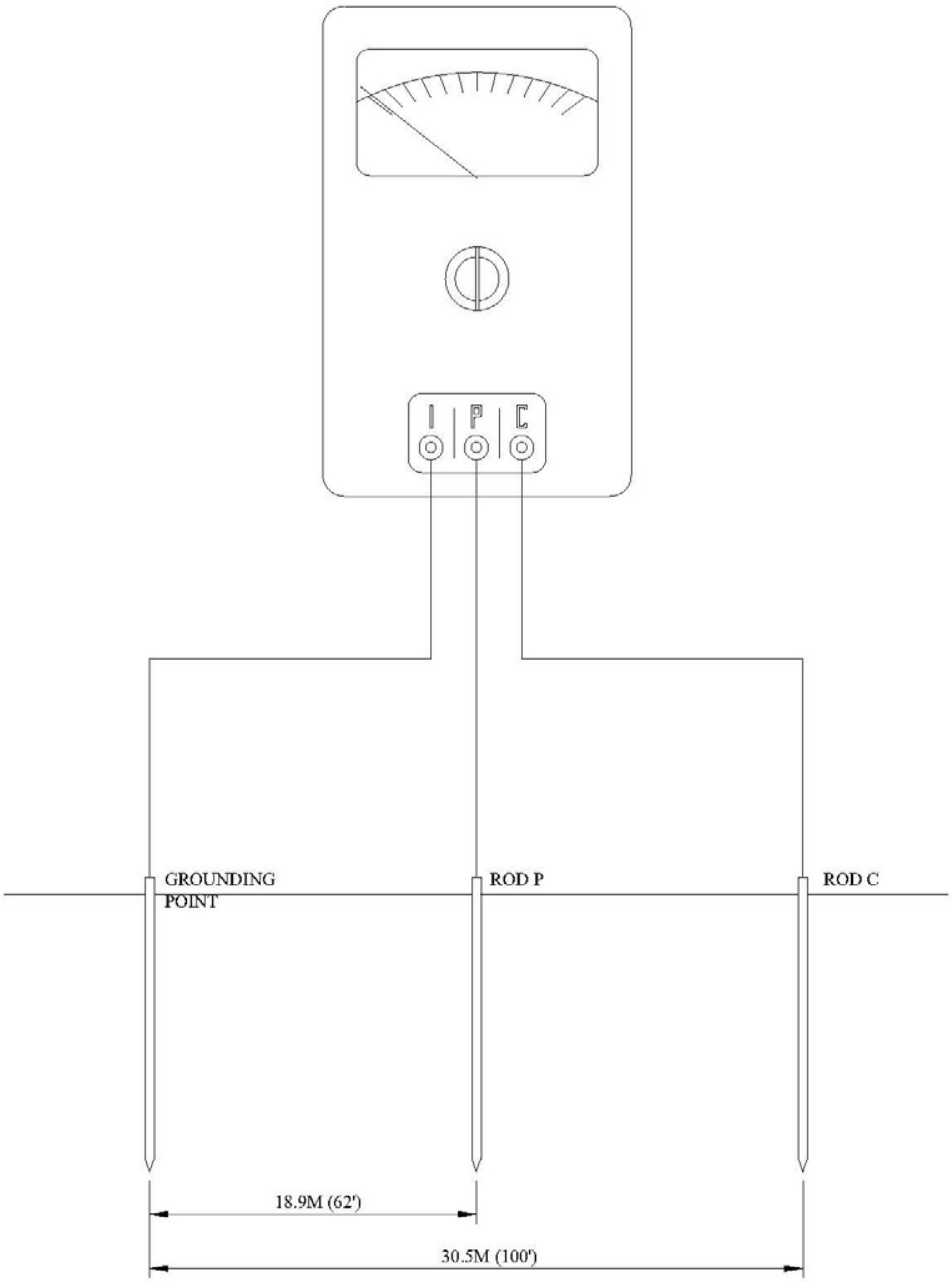


FIGURE 10. Three-terminal fall of potential method test setup.

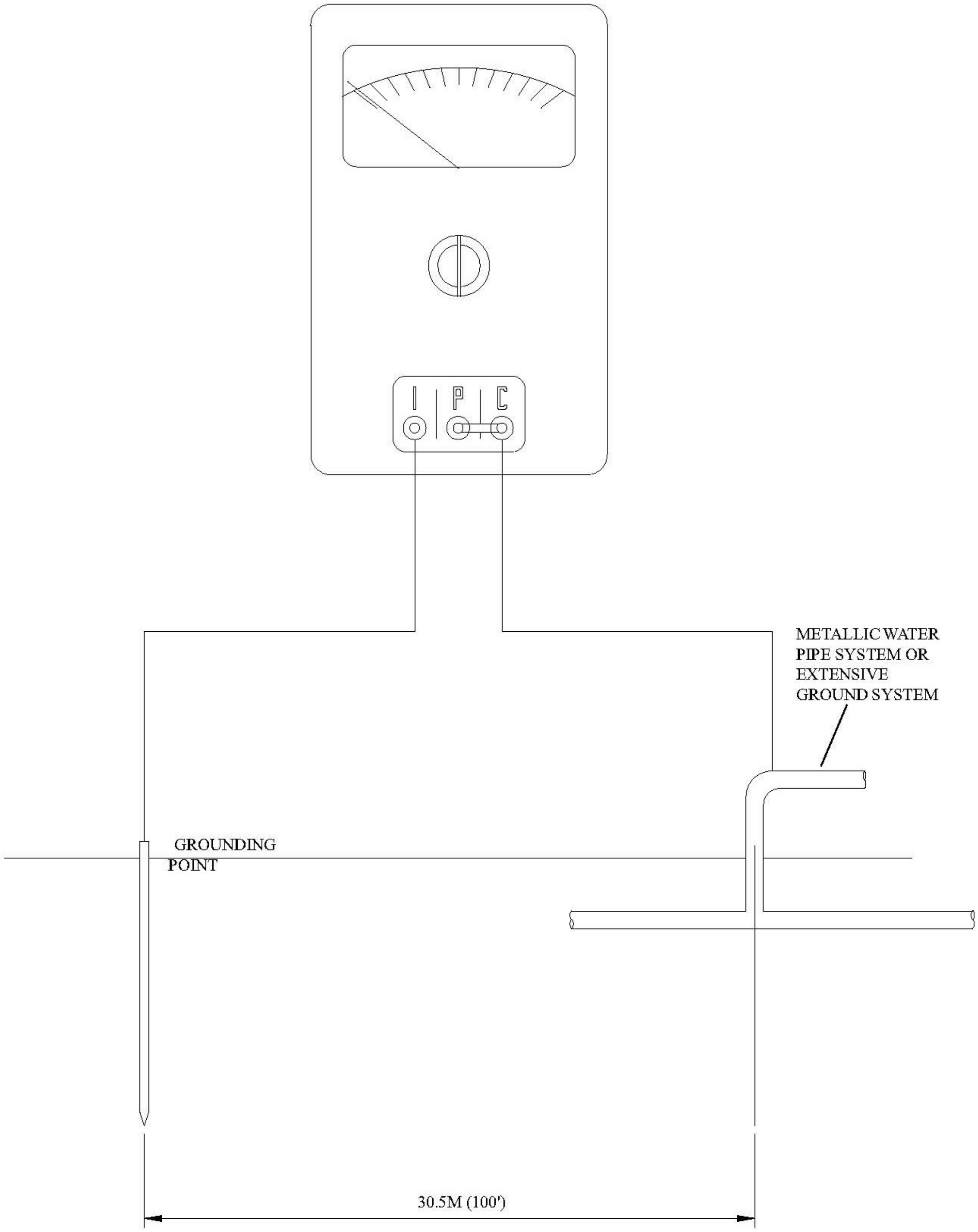


FIGURE 11. Two-terminal method test setup.

NOTES:
1. ALL LETTERS SHALL BE 25.4mm (1") HIGH.
2. TESTING INFORMATION SHALL BE CENTERED AS SHOWN WITH 19mm (3/4") SPACING BETWEEN LINES.

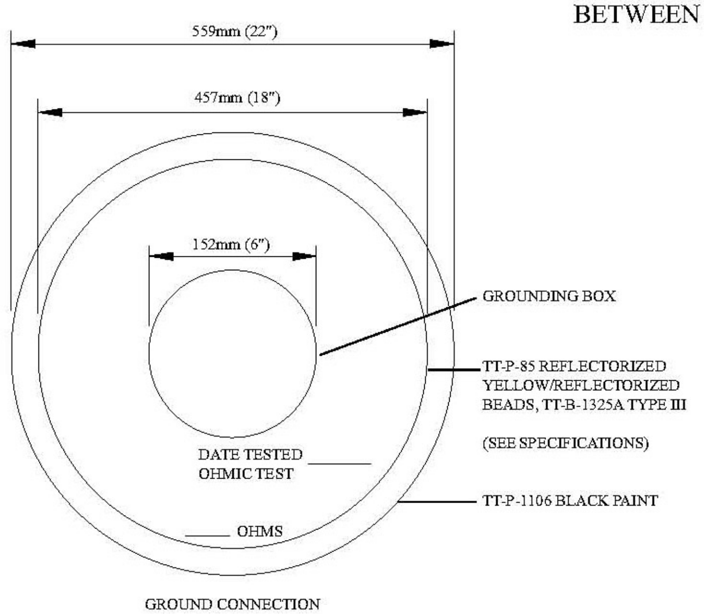
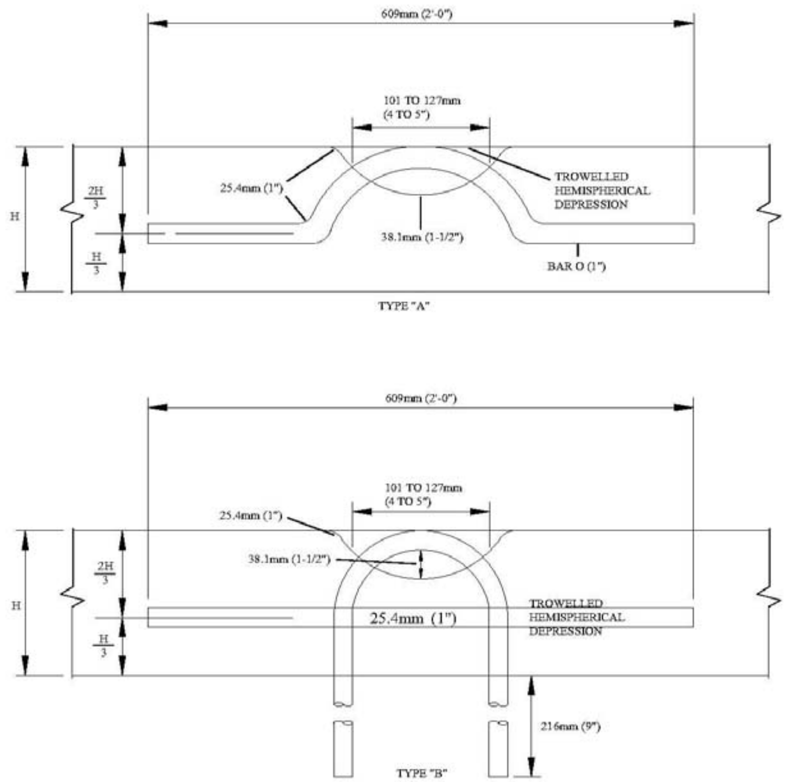


FIGURE 12. Measured ground point identification.



BAR SIZE FOR TYPES "A" AND "B"	
< 254 mm (10")	19 mm (3/4")
254 mm (10") to 305 mm (12")	25.4 mm (1")
330 mm (13") to 406 mm (16")	31.7 mm (1-1/4")

NOTES:
1. PLACE MOORING EYES IN THE CENTER OF EACH 3.81 mm (12.5") BY 4.57 mm (15") SLAB OVER ENTIRE SURFACE OF WARM-UP OR PARKING AREA PAVEMENTS UNLESS OTHERWISE INDICATED.
2. PLACE MOORING EYES IN HANGAR FLOORS AS DETERMINED BY PROJECT REQUIREMENTS

FIGURE 13. Mooring eye details.

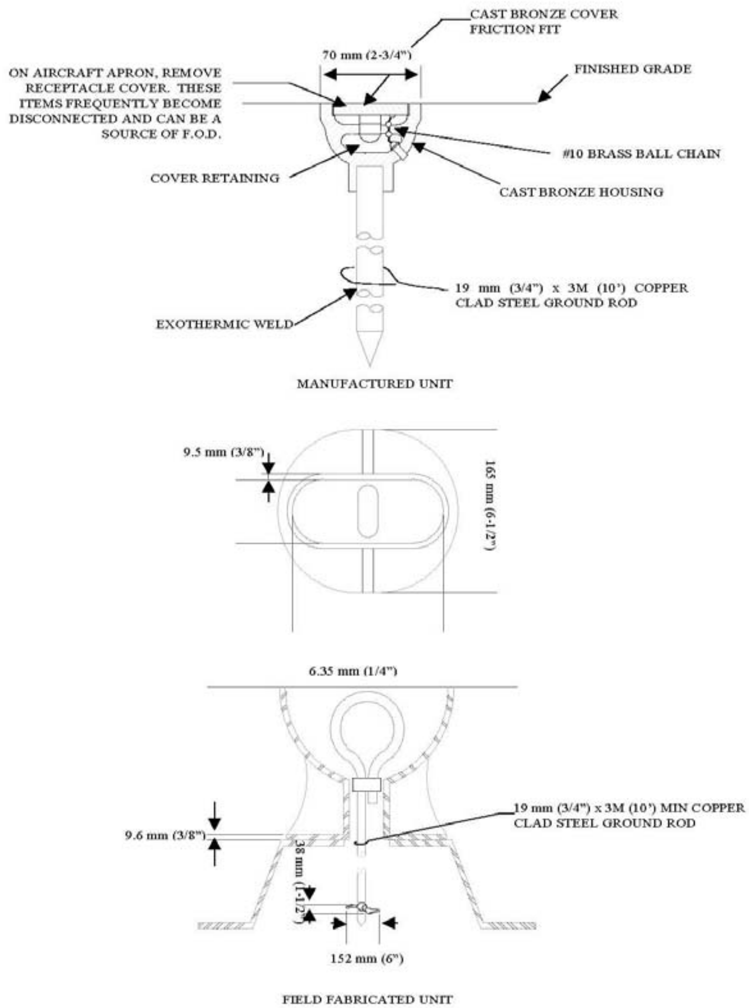


FIGURE 14. Combination tie-down/grounding receptacle.

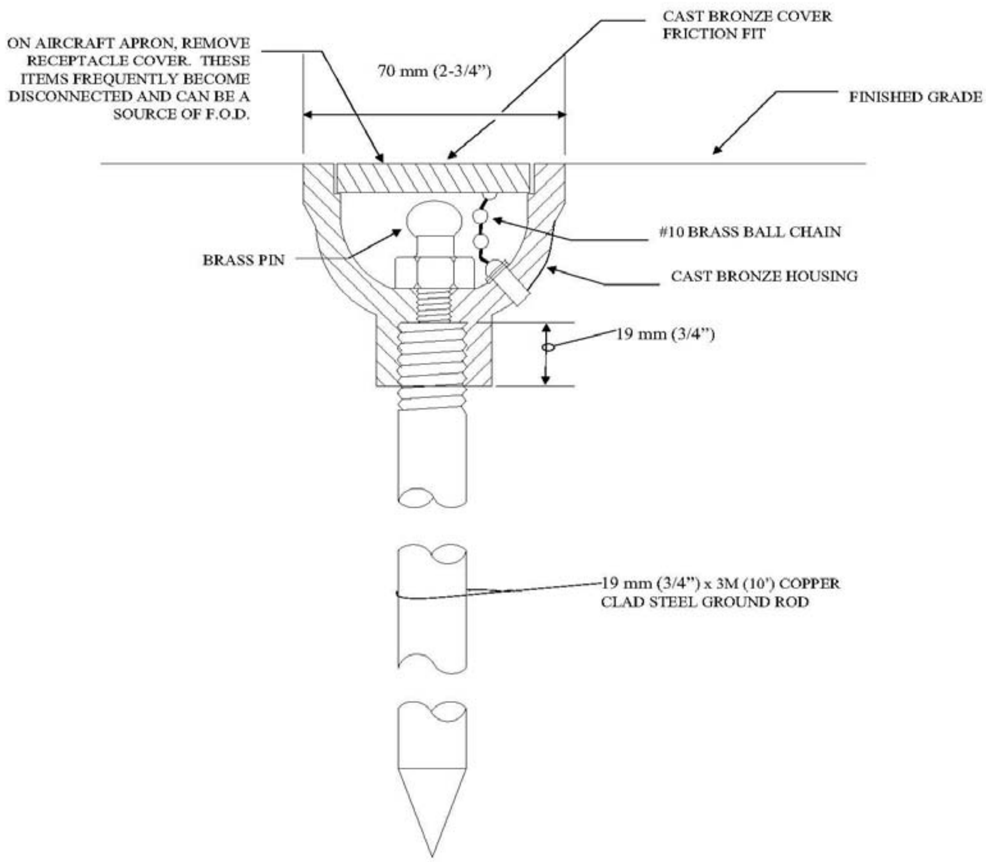


FIGURE 15. Static ground receptacle.

5.7.2 Additional tie-down/grounding points. Figure 14 shows additional tie-down/grounding points that may be encountered. The manufactured unit shown on Figure 14 would normally be found in aircraft hangars while the field fabricated unit would be found on aircraft aprons. The static ground receptacle shown on Figure 15 may be found at either location. The grounding conductor may or may not be part of the installation. Units with cast bronze covers held in place by chains should not be used on aircraft aprons as the covers may come loose and could contribute to Foreign Object Damage (FOD).

5.8 Resistance measurements for alternate grounding points. If conditions prevent the use of known aircraft grounding points, resistance checks using a two-point measurement technique should be performed to verify that the alternate location is an acceptable grounding point. Prior to performing resistance measurements, the meter should be calibrated. Routine checks of the reliability of the meter's readings are obtained by using test standard resistors. A test standard resistor of 0.0025 ohm is typically supplied with the meter. The calibration reading should be accurate within 5 percent of full scale. If the reading is not accurate, resistor values within the meter should be changed. For a detailed procedure of changing internal resistors, refer to the operating or maintenance manual for the meter.

5.8.1 Test method for resistance measurements of alternate grounding points. The test setup for performing resistance measurements is shown on Figure 16. Perform this test as follows:

a. Connect the clamp type probe to the known aircraft grounding point.

b. Connect the second probe to the proposed alternate grounding location. Make certain that the probe's two tips are making good contact with this location.

c. Place "OHMS FULL SCALE" selector switch on highest range and change the range setting in descending order until largest deflection is obtained when the "TEST" switch is depressed. Prior to depressing "TEST" switch, make sure meter is properly adjusted to the red line or full-scale position as determined by the range selector.

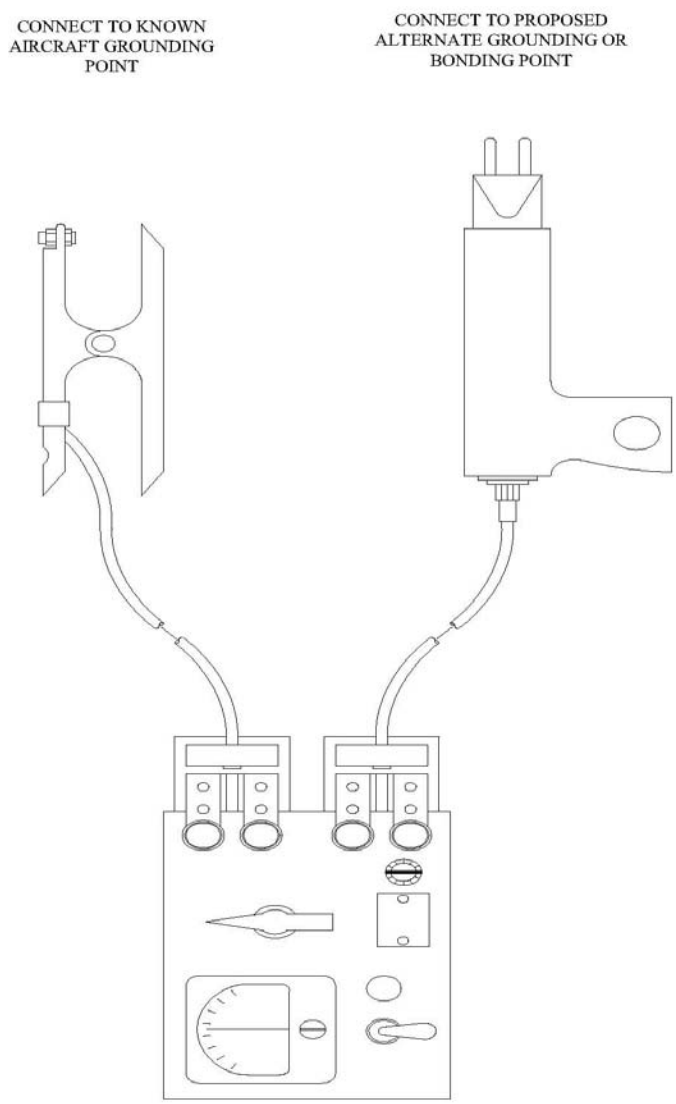


FIGURE 16. Resistance measurement for alternate grounding points.

5.9 Operational grounding overview. This section provides information to understand the need for grounding. This section discusses the grounding problems and hazards encountered in everyday ground handling of aircraft during maintenance and ordnance handling operations. Descriptions are given of static electricity, energy sources, and grounding effects. Various aircraft scenarios are presented that involve safety related servicing situations, together with the approved methods of handling such problems.

5.9.1 Operational procedures during ordnance handling. The following paragraphs summarize grounding procedures performed during ordnance handling evolutions.

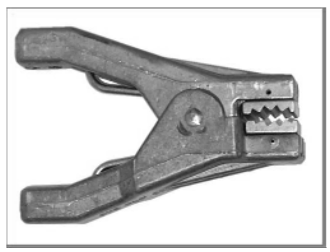


FIGURE 17. MIL-DTL-83413/7-1 clamp.

Note: Ensure that any area that the M83413/7-1 electrical ground connector (clamp type) is clamped to provides a good electrical connection. This can be obtained by grinding the clamp teeth into the grounding point to ensure the connection is free of paint, corrosion and dirt. This action enables metal to metal contact. Connections to composite materials do not provide an acceptable ground.

5.9.1.1 Ordnance handling grounding procedures. The following paragraphs provide grounding considerations and procedures during ordnance handling operations.

5.9.1.1.1 Loading of ordnance. During the loading/downloading of ordnance, the aircraft should be properly grounded. Loading/downloading of ordnance cannot be conducted while external power is applied to the aircraft in accordance with the aircraft's applicable NAVAIR weapons/store loading checklist.

5.9.1.1.2 Tie-down chains. Tie-down chains do not provide an acceptable ground. A new tie-down chain can have a resistance less than 0.5 ohm, and used chains have been measured at 5,000,000 ohms. This is due to excessive corrosion, and this condition is not improved when the installed chain is being subjected to continuous movement when the ship is rolling and the weight of the aircraft is continuously transferring from one chain to another.

5.9.1.1.3 Ground path terminations. In accordance with NAVSEA OP4 Ninth Revision, "Ground paths should never be terminated at:

a. Electrical conduits or wiring coverings;
b. Gas, air or steam pipes or tubing;
c. Sprinkling systems, including dry sprinkling systems;
d. Electrical source neutral points;
e. Hydraulic, fuel or lubricating lines;
f. Electronic transmitter cables, waveguides or ground leads; or
g. Internal communication signal system conduits."

5.9.1.1.4 Ordnance handling. Due to the inherent hazards in handling ordnance, all personnel should be aware of the unique characteristics of individual weapons by reviewing the technical manual and the Conventional Weapons Checklist for that weapon. Familiarization with the contents of NAVSEA OP 4, Ninth Revision, Chapter 7 is advised.

5.9.2 Temporary grounding. In areas where no static or power grounds exist, metal rods may be driven into the ground at points adjacent to the proposed aircraft parking position. For temporary grounds that may be used for some period of time, these rods should be approximately 2.43 meters (8 feet) long and 22.2 mm (0.875 inches) in diameter. Care should be taken that the rod is not driven into a place where it will damage underground services.

5.9.2.1 Temporary field grounding. For aircraft operating in the field, a temporary ground may be obtained by driving a metal rod a minimum of one meter (3.28 feet) in length and 12.7 mm (0.5 inch) in diameter into the ground adjacent to the parked aircraft. This usually provides an acceptable static ground. The quality of the ground depends on the type of soil and the amount of moisture available. The ground resistance can be improved by saturating the area with water. Note that at below freezing temperatures, soil resistivity increases significantly, and this effect can be minimized by burying the ground electrode below the frost line.

5.9.2.2 Temporary ground rod. A temporary ground rod that is in use for some time should have its ground resistance measured on a frequent basis. The resistance should be less than 10,000 ohms. If it is not, consideration should be given to driving additional or longer rods in order to reduce ground resistance.

5.9.2.3 Grounds in deep ice areas. In geographical areas covered by deep ice, such as Antarctica, a temporary ground can be established as follows:

a. Drive a metal rod approximately one meter (3.28 feet) long and 12.7 mm (0.5 inch) in diameter into the ice.

b. During fueling operations, follow the triangulation grounding procedures outlined in the handbook using temporary grounding rods (see 5.9.2.2).

5.10 Grounding hardware/receptacle considerations. In all of the previously mentioned grounding procedures and considerations, the receptacle is the preferred method of connection. Care should be taken to ensure that the receptacle is in good condition. Any evidence that the mating connection is loose indicates that the receptacle is defective and it should be replaced. Periodically, all receptacles should be inspected and their resistance to the aircraft structure should be measured and found to be less than 0.1 ohm. An M83413/4-1 plug, as shown on Figure 18, should be inserted in the receptacle and found to be firmly seated. The pulling force necessary to withdraw the plug should be between 3.628 and 6.342 kilograms (8 and 14 pounds). A pull of less than 3.628 kilograms (8 pounds) indicates a weak or damaged receptacle; a pull exceeding 6.342 kilograms (14 pounds) may indicate a corroded receptacle. In either case, the receptacle should be replaced. Additionally, the complete cable should be maintained in good electrical condition.

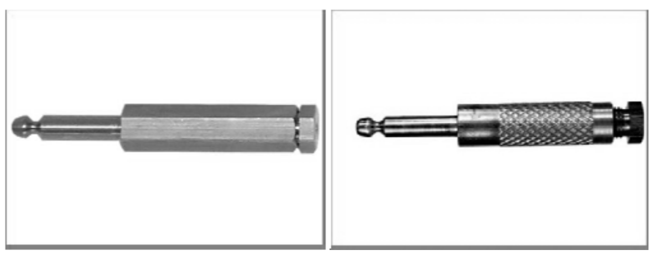


FIGURE 18. M83413/4-1 plug and M83413/4-1 knurled plug.

5.10.1 Use of alligator clips or braided panel strap. The use of alligator clips or braided panel strap to ground or bond aircraft and support equipment is not a safe practice and should be avoided.

5.10.2 Grounding cable. If a grounding receptacle is not available, an approved grounding cable constructed in accordance with MIL-DTL-83413 should be used.

5.11 Aircraft grounding methods. This section provides an overview of the methods for grounding aircraft during aircraft maintenance evolutions including fueling or defueling and loading or downloading of ordnance.

5.11.1 Grounding for shore-based and shipboard operations. The grounding recommendations for both shore-based and shipboard operations are shown in Tables VI and VII. Painted, corroded, dirty, greasy areas or areas of composite materials should not be used for aircraft grounding points. In addition, if the intended grounding point is loosely connected to the aircraft structure through bearings or springs, an unacceptable intermittent ground could result.

5.11.2 Ordnance loading/downloading. Personnel injury or death may result from the inadvertent discharge of explosive devices. No electrical power transient should be applied to the aircraft during ordnance loading/downloading evolutions per NAVSEA OP 4 and NAVSEA OP 5.

5.11.3 Aircraft ground connections. The grounding matrices in Tables VI and VII are intended as a quick reference guide for general aircraft grounding. Refer to the U.S. Navy and Marine Corps Aircraft Naval Air Training and Operating Procedures Standardization (NATOPS) Flight Manual and Maintenance Instruction Manual (MIM) for detailed procedures and specific aircraft ground point locations. Aircraft NATOPS Flight Manual, MIM or operations manual direction will take precedence over this document in the event of a conflict.

5.11.3.1 Failure to ground. Failure to ground to a designated certified power ground, when necessary, may result in generating a charge potential, if discharged, and could result in personnel injury or death.

5.11.3.2 Aircraft tie-down chains. Aircraft tie-down chains do NOT provide an appropriate static ground. For ordnance loading/downloading and aircraft fueling/de-fueling evolutions, a separate grounding cable should be used to connect the aircraft to an approved grounding point. If an approved grounding point is not available, then the deck padeye is an acceptable static ground if metal-to-metal contact is ensured by grinding the teeth of the ground clamp into the padeye to ensure paint is not impeding the ground to padeye connection.

5.12 Shore-based grounding guidelines. Table VI outlines standard grounding guidelines for aircraft during shore-based operations. An “X “indicates the appropriate aircraft grounding methods; flight line, hangar or Forward Arming and Refueling Point (FARP) designated grounding point for the corresponding aircraft operation.

TABLE VI. Grounding matrix for shore-based operations.

*Aircraft Grounding Matrix for Shore-based Operations			
Aircraft Operation	Flight Line (Designated grounding point)	Hangar (Designated grounding point)	FARP (Designated grounding point)
	Certified Static Ground or Mooring Padeye (Note 1, 2)	Certified Power Ground identified IAW 5.2 and 5.5, and indicating less than 25 ohms resistance (Note 3)	Certified Static Ground, mooring padeye or grounding rod installed IAW 5.9.2, Temporary Grounding (Note 1, 2, 7)
Parked without External Power	X	X	X
Maintenance performed without External Power	X	X	X
MEPP external power applied; Diesel Driven Generator (for example. NC-8, NC-10) (Note 4)	X	X	X
MEPP external power applied; Electric Driven Generator (for example,. MMG) (Note 4)	N/A	X	N/A
Hangar Power Applied	N/A	X	N/A
FLEDS (Flight Line Electric Distribution System) (Note 5)	X	N/A	N/A
Fueling/Defueling (Note 6 & 7)	X	N/A	X
Ordnance Load/Download	X	N/A	X
Vertical Replenishment (Note 1, 7)	X	N/A	X

*Refer to NATOPS Flight Manual or MIM for detailed grounding instructions of specific aircraft.

NOTES:

1. When grounding to a padeye, good metal to metal contact is recommended. This can be obtained by grinding the clamp teeth into the padeye to ensure the connection is free of paint, corrosion and dirt.
2. A Certified Static Ground will have less than 10,000 ohms resistance referenced to

Earth ground.

3. A Certified Power Ground will have a current certification (dated within a 24-month period) and be labeled with resistance values of less than 25 ohms referenced to the power system neutral (Ref NAVSEA OP 5, Chapter 5).
4. When a MEPP is utilized, a grounding cable must be attached from the MEPP to the aircraft airframe (Ref NATOPS Flight Manual/ MIM).
5. FLEDS operations also recommend grounding of the aircraft airframe to the FLEDS earth neutral.
6. Grounding triangulation (fuel delivery system bonded to aircraft and aircraft grounded to static ground) is recommended during fueling/defueling operations (Ref NATOPS Flight Manual/ MIM)
7. Refer to Aircraft NATOPS Flight Manual and Aircraft Refueling NATOPS Manual (Ref. NAVAIR 00-80T-109, Chapter 16)

5.13 Shipboard grounding recommendations. Table VII outlines standard grounding recommendations for aircraft during shipboard operations. An "X" indicates the aircraft should be grounded to the appropriate deck or hangar designated grounding point for the corresponding aircraft operation.

TABLE VII. Grounding matrix for shipboard operations.

*Aircraft Grounding Matrix for Shipboard Operations		
Aircraft Operation	Deck (Designated grounding point)	Hangar (Designated grounding point)
	Mooring Padeye (Note 1)	Certified Power Ground identified IAW 5.2 and 5.5, and indicating less than 25 ohms resistance (Note 2)
Parked without External Power	X	X
Maintenance performed without External Power	X	X
MEPP external power applied; Diesel Engine Powered Generator (for example,. NC-8, NC-10) (Note 3)	X	X
MEPP external power applied; Electric Driven Generator (for example, MMG) (Note 3)	N/A	X
Hangar Power Applied	N/A	X
Deck Edge Power	X	N/A
Fueling/Defueling (Note 4)	X	N/A
Ordnance Load/Download	X	N/A
Vertical Replenishment (Note 5, 6)	X	N/A
HIFR (Note 5, 6)	X	N/A

*Refer to NATOPS Flight Manual or MIM for detailed grounding instructions of specific aircraft.

NOTES:

1. When grounding to a padeye, good metal to metal contact is recommended between clamp and padeye. Ensure connection contact point is free of paint or corrosion.
2. A Certified Power Ground will have a current certification (dated within a 24-month period) and be labeled with resistance values of less than 25 ohms referenced to the power system neutral. (Ref NAVSEA OP5, Chapter 5)
3. When a MEPP is utilized, a grounding cable is recommended to be attached from the MEPP to the aircraft airframe (Refer to specific aircraft NATOPS Flight Manual or MIM)
4. Grounding triangulation is recommended during fueling/defueling operations. (Refer to specific aircraft NATOPS Flight Manual or MIM)
5. Refer to aircraft NATOPS and Helicopter Operating Procedures for Air-Capable Ships (Ref. NAVAIR 00-80T-122)
6. Refer to aircraft NATOPS Flight Manual and Aircraft Refueling NATOPS Manual (Ref. NAVAIR 00-80T-109, Chapter 16)

5.13.1 Aircraft tie-down chains. Aircraft tie-down chains do not provide an appropriate static ground. For ordnance loading and downloading and aircraft fueling/de-fueling evolutions a separate grounding cable should be used to connect the aircraft to an approved grounding point. If an approved grounding point is not available then the deck padeye is an acceptable static ground if metal-to-metal contact is ensured by grinding the teeth of the ground clamp into the padeye to ensure paint is not impeding the ground to padeye connection.

5.14 Grounding cable details. When using grounding cables, the specific type of connector used on the ends will be determined by the aircraft type. Some Navy or Marine Corp aircraft may not have grounding receptacles available in other than the fueling area, and they are therefore not readily available for use as the static grounding point on the aircraft. In these instances a cable having MIL-DTL-83413 clamps on each end, Figure 19, or a clamp and a plug, Figure 20, may be used, one end attached to an approved static ground point, the other to a clean metal area of the aircraft. It is important to remember to attach the grounding cable to the approved ground point prior to attaching it to the aircraft. The National Stock Numbers (NSNs) and part numbers (P/Ns) may be used to order cables and MIL-DTL-83413 connectors and plugs.

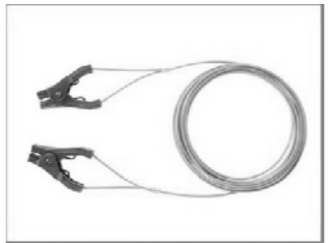


FIGURE 19. Grounding cable with clamps.

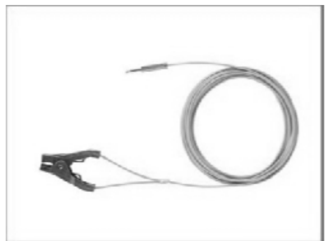


FIGURE 20. Grounding cable with clamp and plug.

5.14.1 Ground cable construction. Ground cable construction: cables should be of "7 x 7" construction, 2.38mm (0.094 inch) nominal diameter wire rope with MIL-DTL-83413 clamps at each end. In accordance with OP 5, all grounding cables should have clamp-to-clamp or clamp-to-structure resistance less than or equal to the design specification or less than 1 ohm if no design specification is given. Flight line reel type cables (see Figure 21) are required to have 25 ohms or less resistance. Cable length should be determined by user operational requirements but cable DC resistance should not exceed 25 ohms. The cables should be marked as an "ordnance grounding cable" and serialized. IAW OP 4 and OP 5 Volume I, Paragraph 5-9.7.3: "All grounding cables shall have a visual inspection and electrical test after procurement or fabrication, prior to being placed in service. Thereafter, a visual inspection and electrical test shall be performed on every repaired cable before the cable is placed back in service. Proof of the last electrical test must be provided for each grounding cable in use."

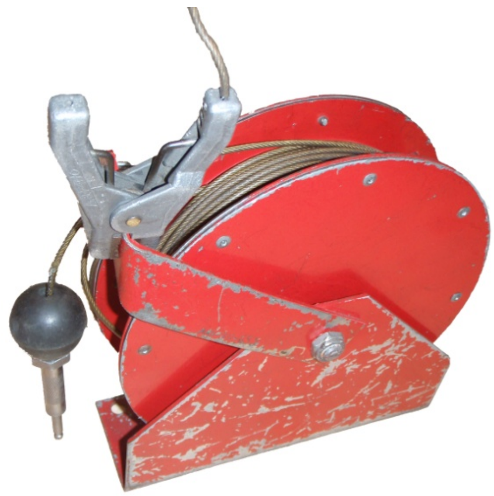


FIGURE 21. Grounding cable reel with clamp and plug.

5.14.2 Recommended cable parts. The following parts are recommended for use in making a cable:

a. Plug: NSN - 5935-00-572-5174, P/N: M83413/4-1.
b.Clamp: NSN - 5999-00-134-5844, P/N: M83413/7-1.
c. Cable: NSN - 4010-00-286-2681, P/N: 84610.
d. Reel Assembly (reel, cable clamp and plug): NSN - 4930-01-150-3807.

6. NOTES

6.1 Intended use. This handbook provides recommended procedures for establishing safe and effective aircraft grounding.

6.2 Actual grounding problem. Paragraph 6.2.1 is a paraphrased excerpt from the Naval Safety Center files. This paraphrased excerpt is included to demonstrate an actual problem that occurred during an ordnance handling evolution.

6.2.1 Details of grounding issue. After shutdown from flight, aviation ordnance personnel began the procedure for loading Mk 82 practice bombs on outboard racks. After successful completion of jettison release checks, the jettison release cartridge was being installed on the port outboard station. As the jettison cartridge was being inserted into the breech, the cartridge actuated. Personnel injuries were superficial and there was no damage to the aircraft. Immediately after the incident, ordnance personnel checked both cockpit switches to determine switch positions and stated both were in the OFF/SAFE position. It was noted that the aircraft was not grounded. While inconclusive, a potential cause of this incident could be the failure of ordnance personnel to properly ground the aircraft prior to executing loading procedures.

6.3 Responsible technical activity. The NAVAIR E3 Division provided the technical information contained in this handbook. Contact the preparing activity currently listed in ASSIST for this document for contact information on the E3 Division.

6.4 Changes from previous issue. Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extent of the changes.

6.5 Subject term (key word) listing.

Cable
Clamp
Ordnance
Power
Plug
Reel
Shipboard
Shore-based
Static
Tie-down chains

Custodian:
Navy – AS

Preparing activity:
Navy – AS

Project EMCS-2011-004

NOTE: The activities listing above were interested in this document as of the date of the document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST online database at https://assist.daps.dla.mil.